Light signal simulation and light maps for 6x6x6m^3 detector

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Laboratoire d'Annecy-le-Vieux
de Physique des Particules

Introduction

Light simulation can be divided in two parts:

- Scintillation (production of the photons)
- Light propagation in the detector.

→ This talk focuses on the light propagation simulation

Main part : production of pre-calculated light maps

- Since last General Meeting (March 2016), we have worked on the LightSim software:
  - The method and functions related to the map generation have been implemented
  - Studies about design impact on light collection have been performed
  - The current design of 6x6x6 has been implemented

Light maps for $6x6x6m^3$ have been produced

- QScan has been updated to use these new maps (WA105Soft rev438)

Light production in Argon
- S1 and S2 signals -

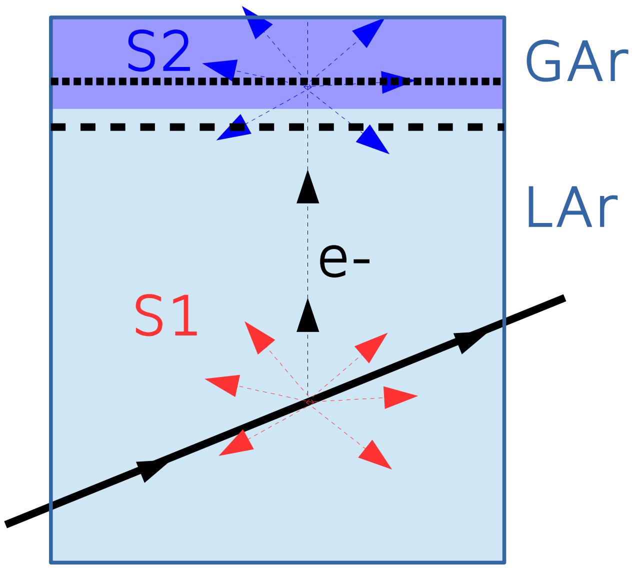
Charge particle crossing LAr

Direct excitation → scintillation photon → S1 Signal

Ionisation
e- / ion pair creation → electron drifted toward CRP → electroluminescence in GAr → S2 Signal

e- / ion pair creation → recombination → scintillation photon

For both signals: $\lambda = 128\text{nm}$



In **LightSim**:

- #S1 photons is calculated using the deposited energy and the recombination rate.
- #S2 photons is estimated via an **electrominescence gain** G

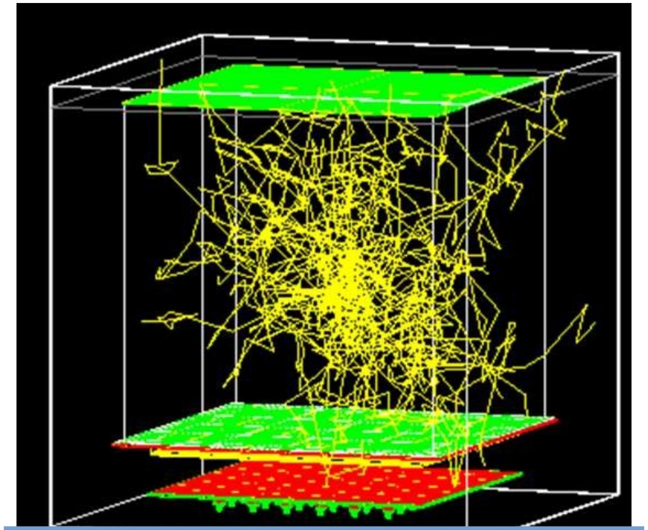
$$N_{S2} = N \times G$$

N: number of electrons reaching the extraction grid

Light Propagation in WA105

Propagation of scintillation photons (**128nm**):

- Absorption in LAr
- Rayleigh scattering on LAr molecules
- Absorption on different detector components (field cage, cathode supporting structure, tank...)



Rayleigh scattering effect

Problematic:

- Tracking each scintillation photon takes a lot of time
- Less than 1% of photons reach the PMTs

Solution: simulate the tracks only once, and store the useful information in Light Maps

Important points about light map **generation**:

- These maps describe the photon propagation
  → Independent from the scintillation parameters
- LAr absorption process is **not** taken into account for the map generation to allow studies with different absorption length
  → Will be simulated when using the maps in QScan

Light Propagation in WA105

Solution: simulate the tracks only once, and store the useful information in Light Maps

For each photon **production point** in the detector, and each **PMT**, the map gives:

- Probability to reach the PMT
- Travel time distribution

Light Propagation in WA105

Solution: simulate the tracks only once, and store the useful information in Light Maps

For each photon **production point** in the detector, and each **PMT**, the map gives:

- Probability to reach the PMT
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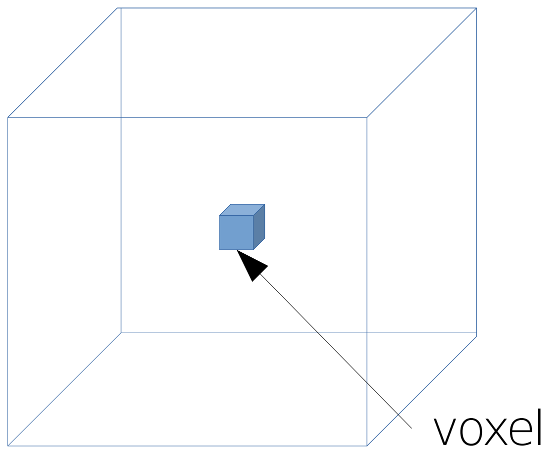
LAr and GAr volumes are **split** in **voxels**



Production point

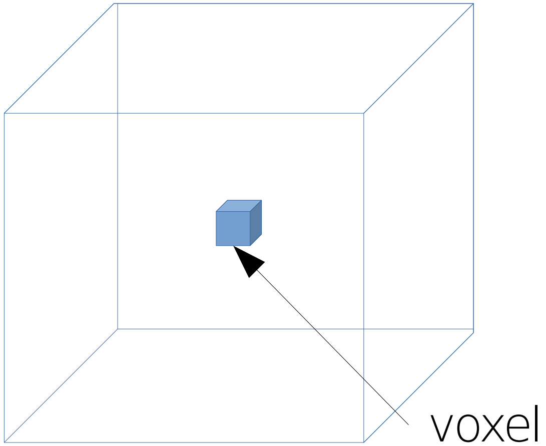
Light Propagation in WA105

Solution: simulate the tracks **only once**, and store the **useful** information in **Light Maps**

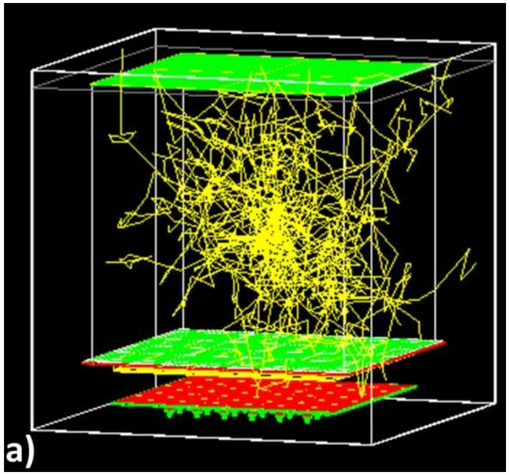
For each photon **production point** in the detector, and each **PMT**, the map gives:

- Probability to reach the PMT
- Travel time distribution

LAr and GAr volumes are **split** in **voxels** → Generation of **N photons** in each voxel → Photons are **tracked** across the detector



Production point



Tracking

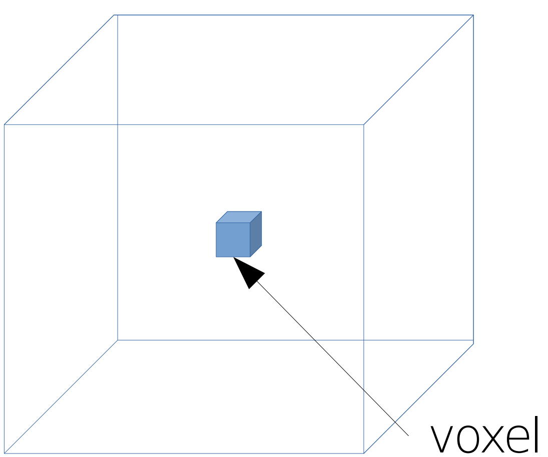
Light Propagation in WA105

Solution: simulate the tracks only once, and store the useful information in Light Maps

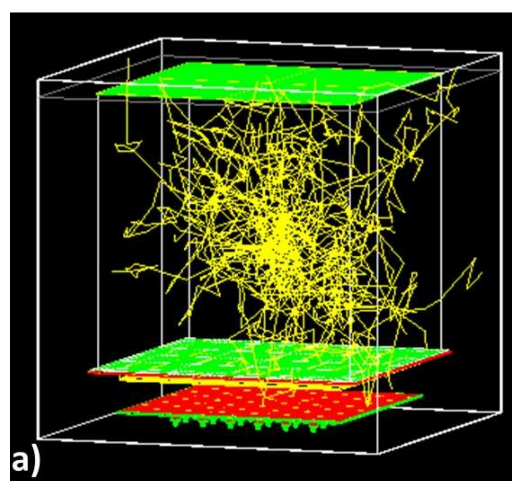
For each photon **production point** in the detector, and each **PMT**, the map gives:

- Probability to reach the PMT
- Travel time distribution

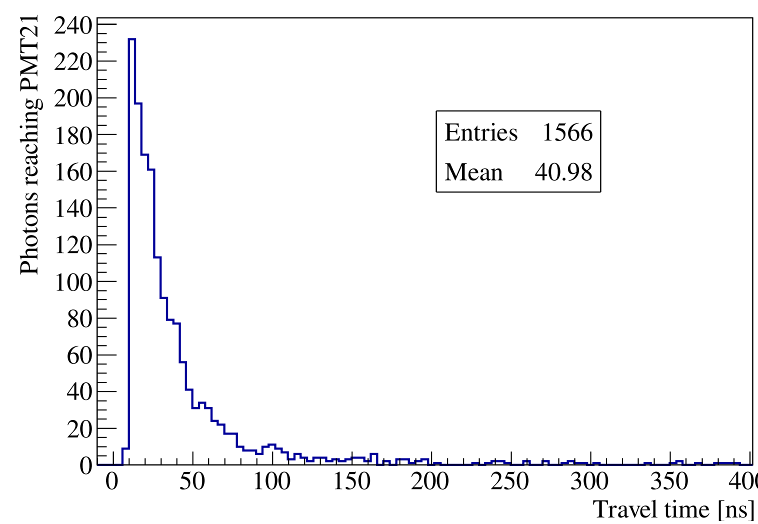
LAr and GAr volumes are **split** in **voxels** → Generation of **N photons** in each voxel → Photons are **tracked** across the detector → **Travel time distribution** obtained for each PMT



Production point



Tracking



Travel time distribution

Light Propagation in WA105

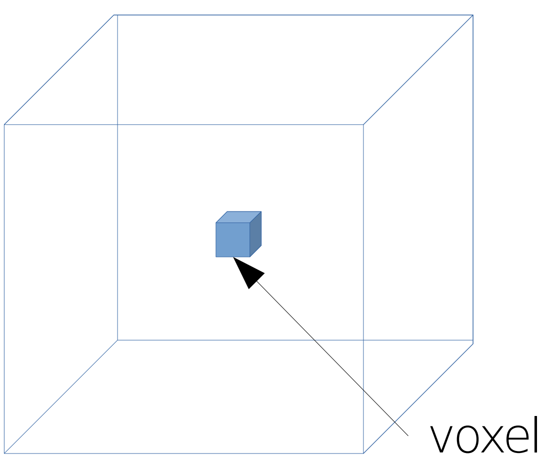
Solution: simulate the tracks **only once**, and store the **useful** information in **Light Maps**

For each photon **production point** in the detector, and each **PMT**, the map gives:

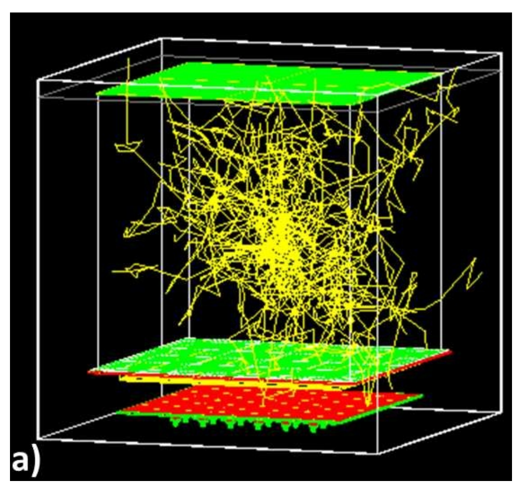
- Probability to reach the PMT
- Travel time distribution

LAr and GAr volumes are **split** in **voxels** → Generation of **N photons** in each voxel → Photons are **tracked** across the detector →

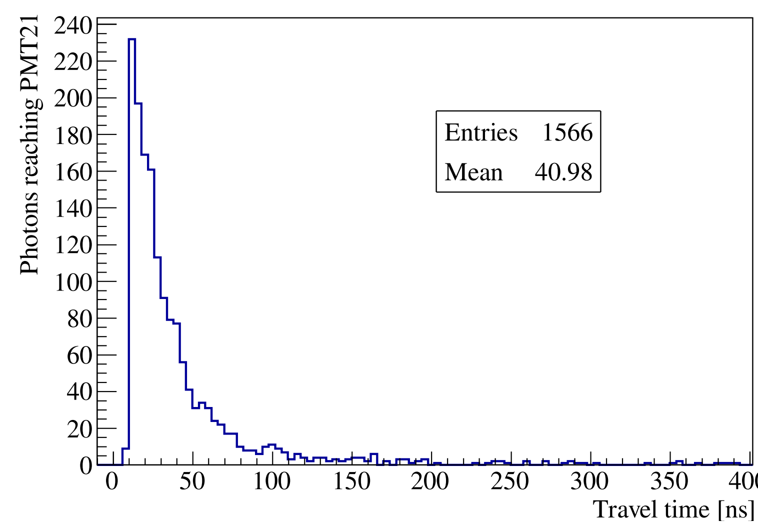
→ **Travel time distribution** obtained for each PMT → Extraction of time distribution **parameters** → Light Maps



Production point



Tracking

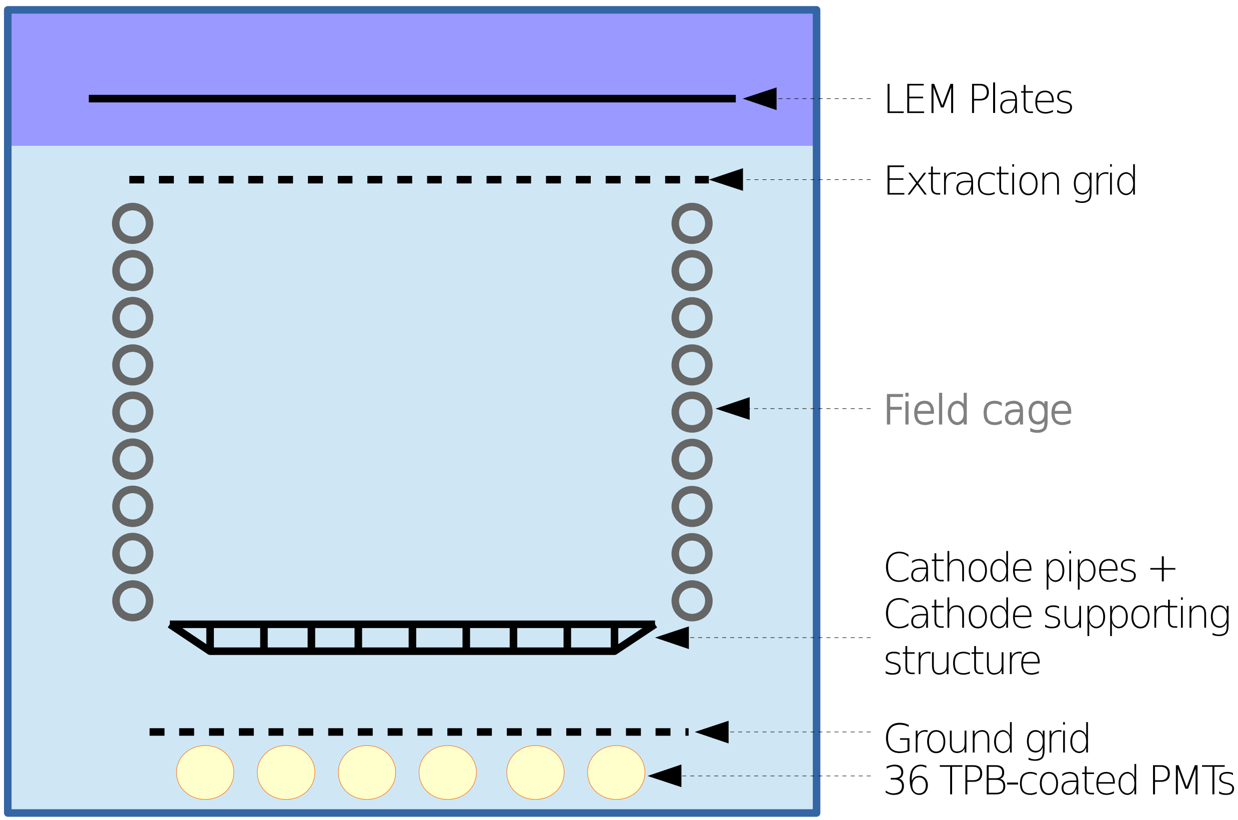


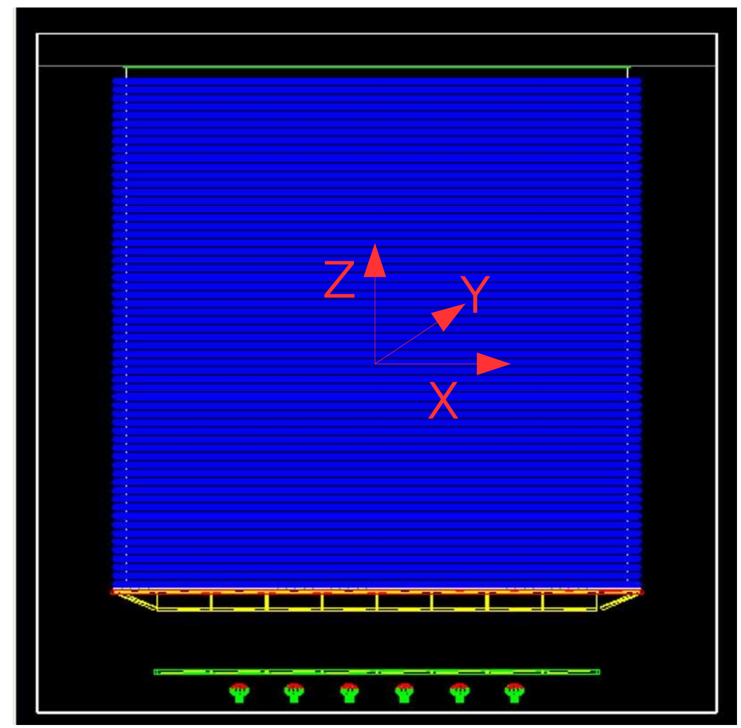
Travel time distribution

Implemented geometry

The detector geometry has evolved in parallel to the TB design studies during the last months

Detector components implemented for the map generation:





The positioning of the PMTs is not yet defined. 2 options: uniformly spaced (65cm) or non-uniformly spaced

→ Production of 2 different maps

Dependence on the detector geometry

Study of the geometry modification impact on **light signal** collection

Studies concerning stainless-steel components:

- Cathode pipes
- Cathode supporting structure
- Ground grid

Method:

Generation of photons at different points of detector, and comparison of the **number of collected photons** before and after the detector component implementation

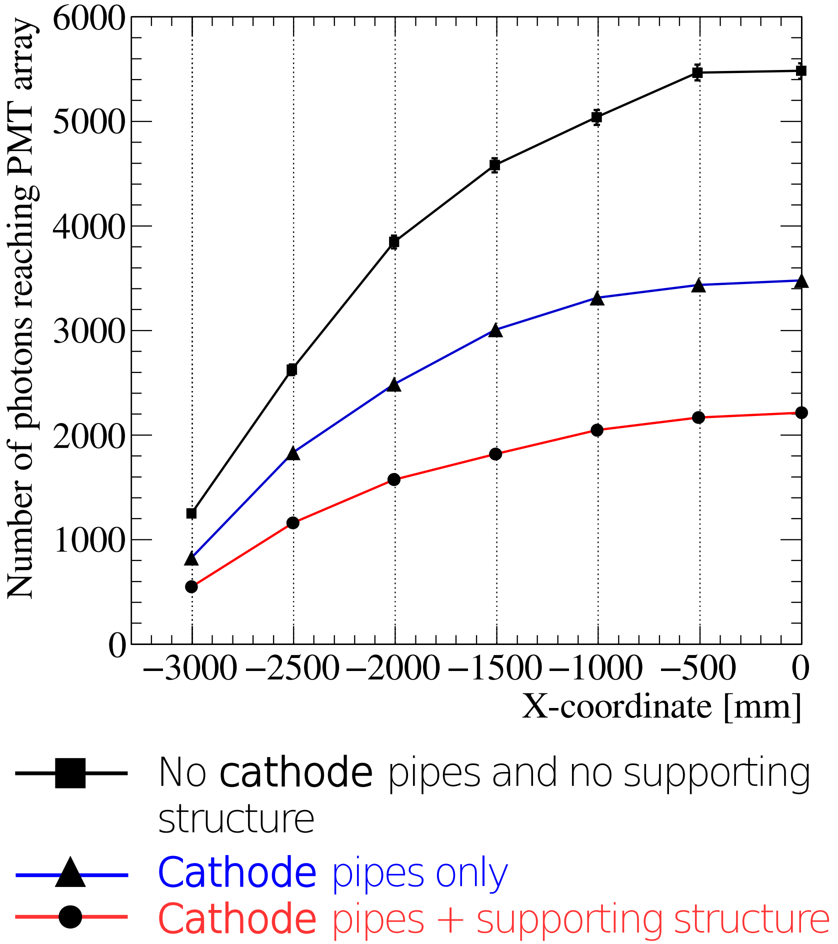
Results:

- Cathode pipes and cathode supporting structure: average loss of **60%**
- Ground grid: average loss about **25%**

→ The light loss is mainly due to the absorption on stainless steel (**100%**)

Note: the previous maps (/sps/hep/lbno/dataset/LightMap_old) didn't took these stainless steel structures in account

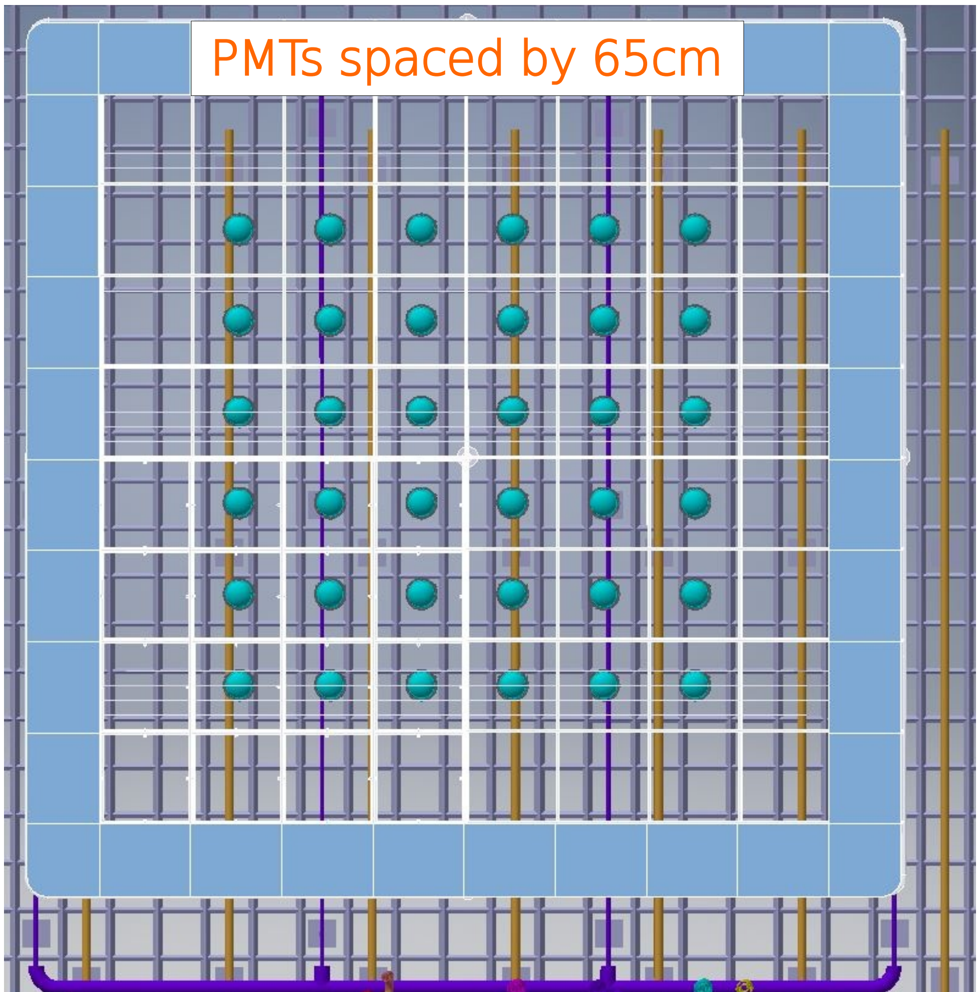
Impact of the cathode design
For 10^6 photons generated
~1m above the cathode pipes
(PMT uniformly spaced)

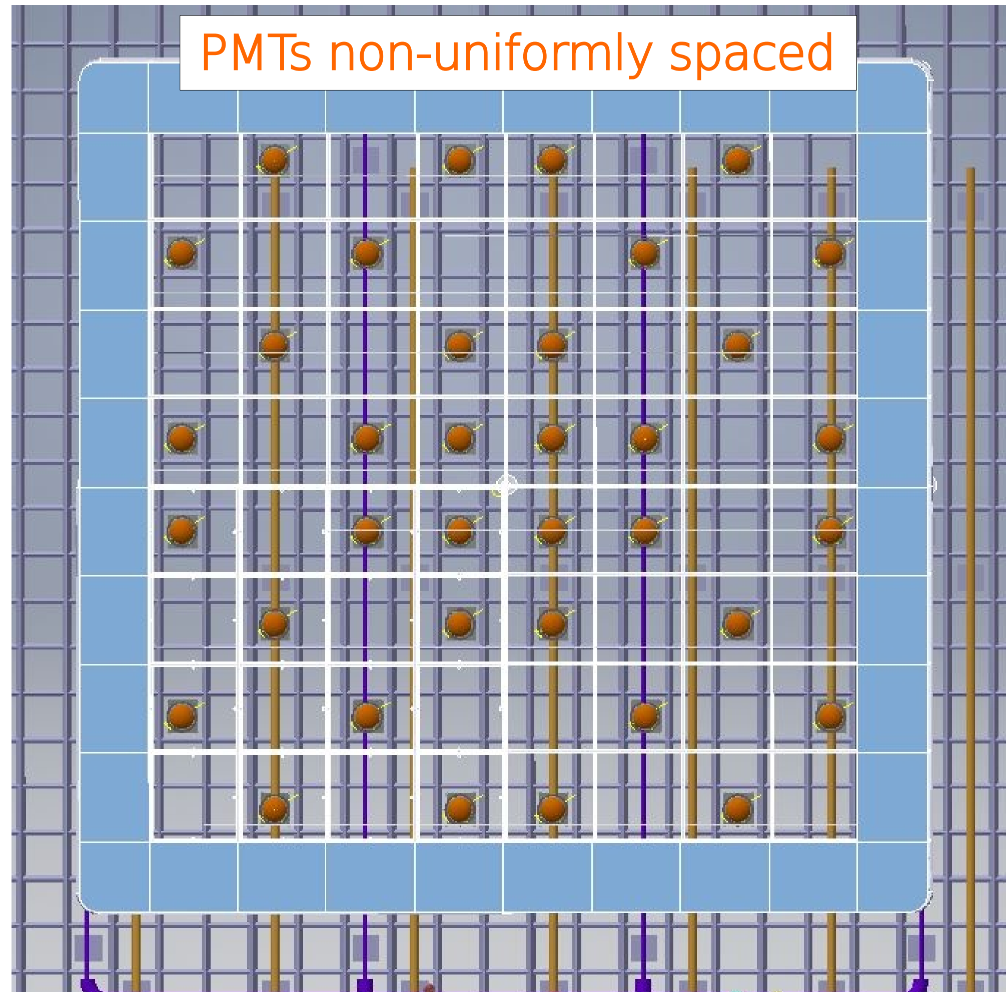


PMT positioning impact on light signal collection

The PMT positioning is not yet fixed:

Comparison between PMT spaced by 65cm and PMT non-uniformly spaced





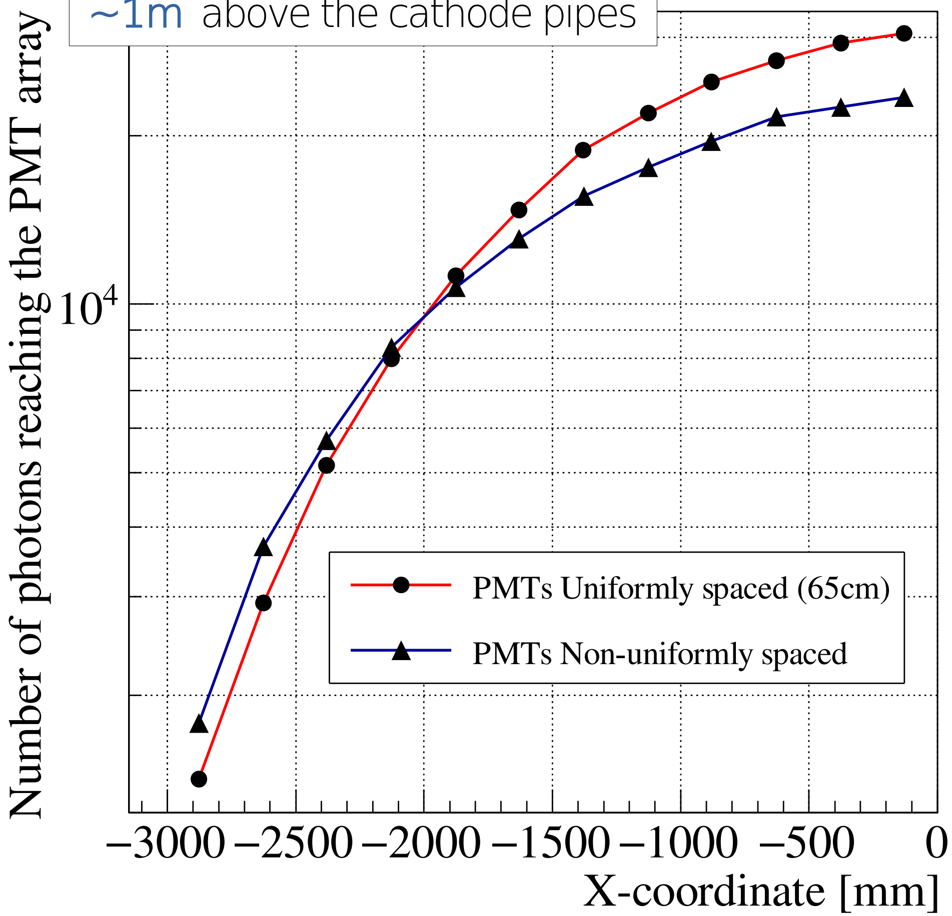
Default drawing in the SPSC report

WA105

PMT positioning impact on light signal collection

Reminder: the absorption in LAr is not taken into account

For 10^7 photons generated
~1m above the cathode pipes



- PMTs uniformly spaced:

  → **increases** the number of collected photons at the detector center

- PMTs non-uniformly spaced:

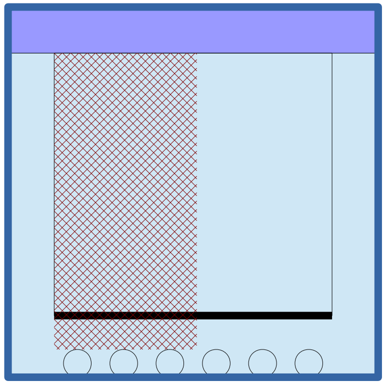
  → **increases** the number of collected photons at detector edges (for low Z)

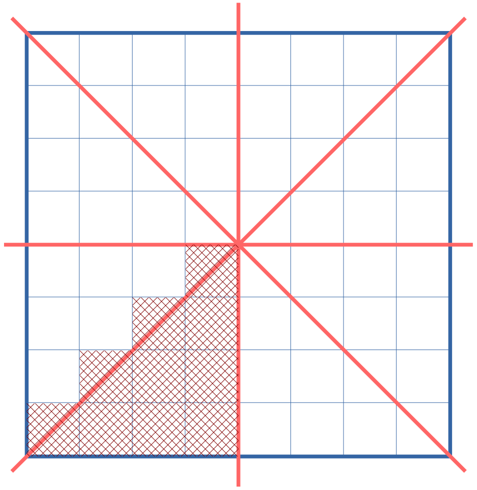
If we compute the ratio $N_{Non\ Uniform}/N_{65cm}$ for each photon generation point, the mean ratio is about ~0.95.

→ Impact on the background induced by cosmic muons ?
(will be discussed at the end of the talk)

Light map characteristics
Voxel definition and propagation parameters

- **LAr maps:**
  - Large voxels definition: 250mmx250mmx250mm
  - Number of voxels: 24x24x29 = 16704 voxels
  - Cover a volume of about 6mx6mx7m
  - Number of generated photons per voxel: 10^7 over 4π





- **GAr maps:**
  - Voxel definition: 250mmx250mmx5mm (576 voxels)
  - Only 1 voxel in Z (photons generated between LEM plates and LAr surface)
  - Number of generated photons per voxel: 5.10^8 over 4π

✔ To save time, photons are generated in ~1/8 of the detector, then we use the X-Y symmetry of the detector to reconstruct the whole map.

→ Simulation of 2262 voxels instead of 16704 for LAr map

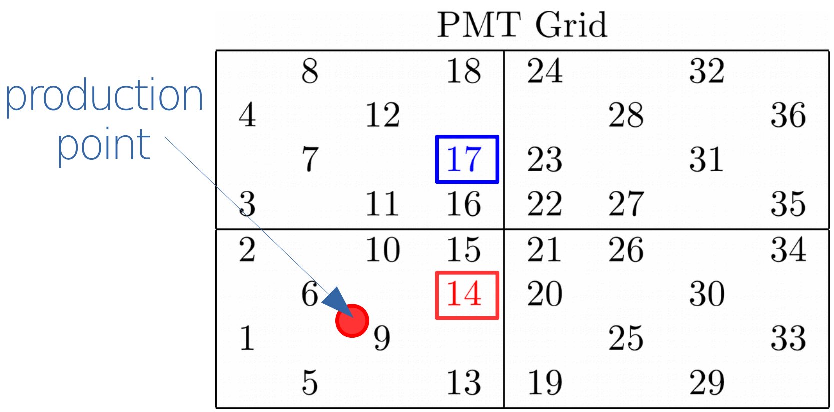
- **Propagation parameters in LAr**

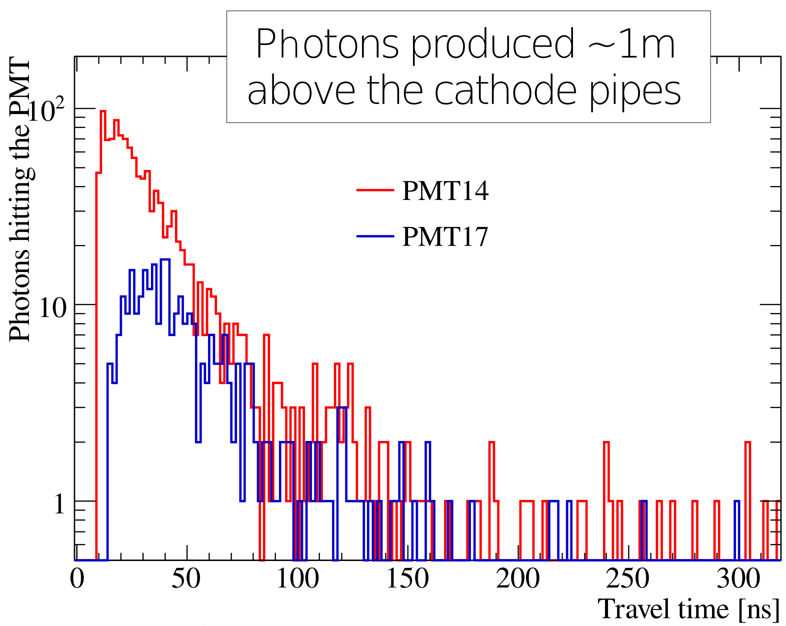
  (Reminder: the absorption in LAr is not include in the map generation, but is taken into account in QScan)

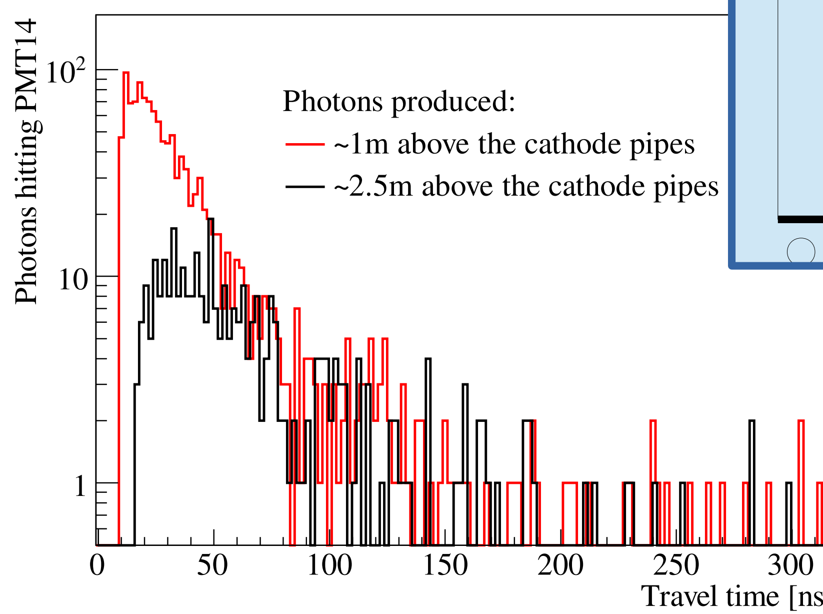
Rayleigh scattering length	55cm 350cm	(128nm) (435nm)
Absorption on stainless-steel and copper	100% 50%	(128nm) (435nm)
LAr refractive index	1.38 1.25	($\lambda < 130$nm) ($\lambda > 130$nm)

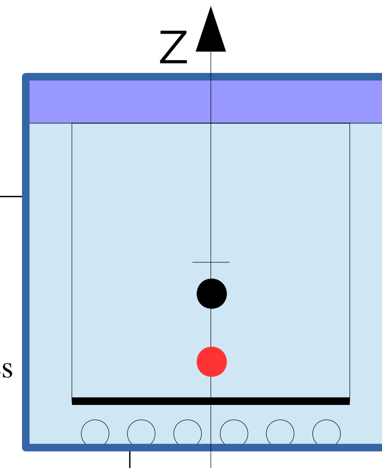
Time distribution characteristics

- **Probability** to reach the PMT: $\text{weight} = \dfrac{\text{Number of photons reaching the PMT}}{\text{Number of generated photons}}$
- **Travel time** distribution **shape**: strongly depends on the **distance to the PMT**









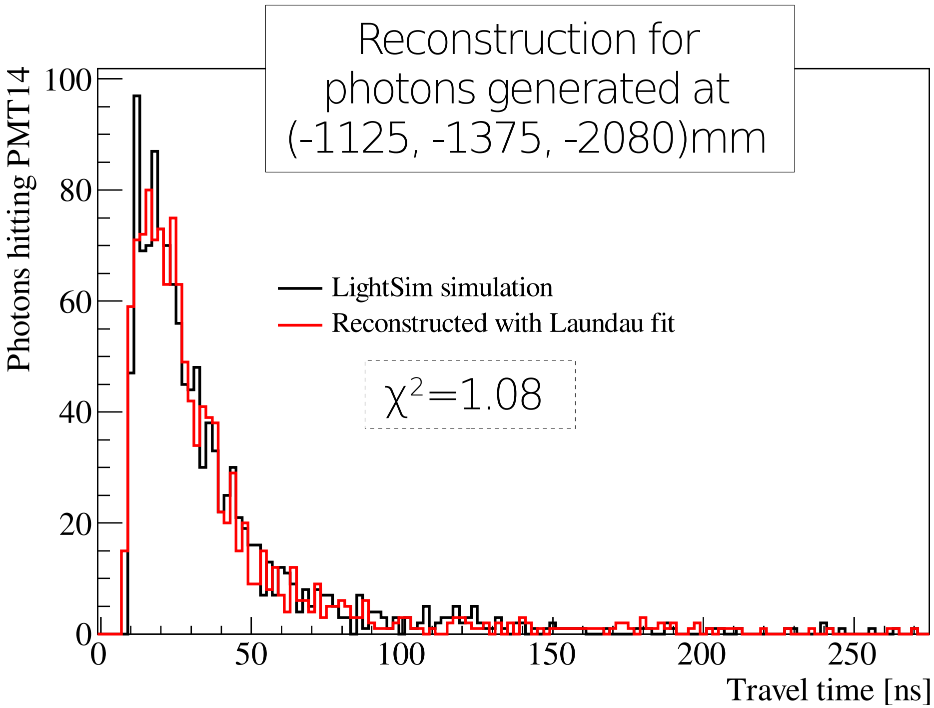
→ Find a **parametrisation** working for **as much distributions** as possible, with the **minimum** number of **parameters**

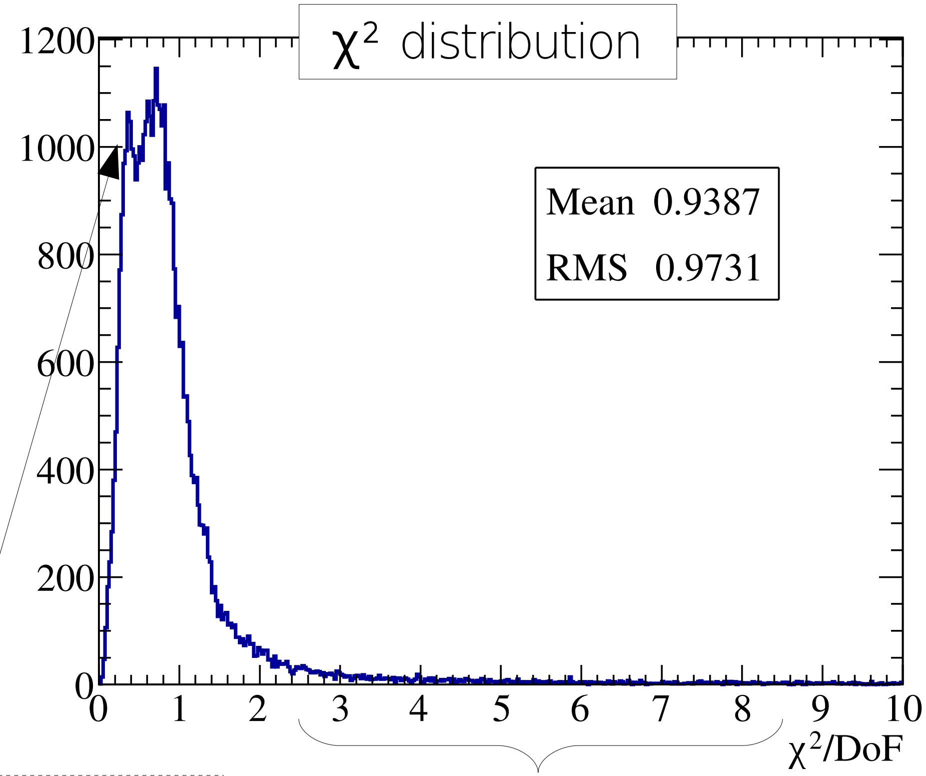
Time distribution characteristics

The **time distribution** is reconstructed using a **landau fit** and **3 parameters**:

- t0 (the first bin $N_{entries} > 0$)
- The MPV and σ of the **landau fit**
- Voxels with $N_{entries}$<50 are not taken into account

+ **weight** → 4 parameters stored





Peak at χ^2 < 0.4: voxels with a **small number** of collected photons

6.2% of voxels with χ^2 > 2.5: voxels close to the PMT

→ **Satisfactory** in most cases

→ Has to be **optimized** for voxels with too **few collected photons** and voxels **close to the PMT** (narrow distributions)

Maps utilization in QScan

Updated maps are available at /sps/hep/lbno/dataset/LightMap

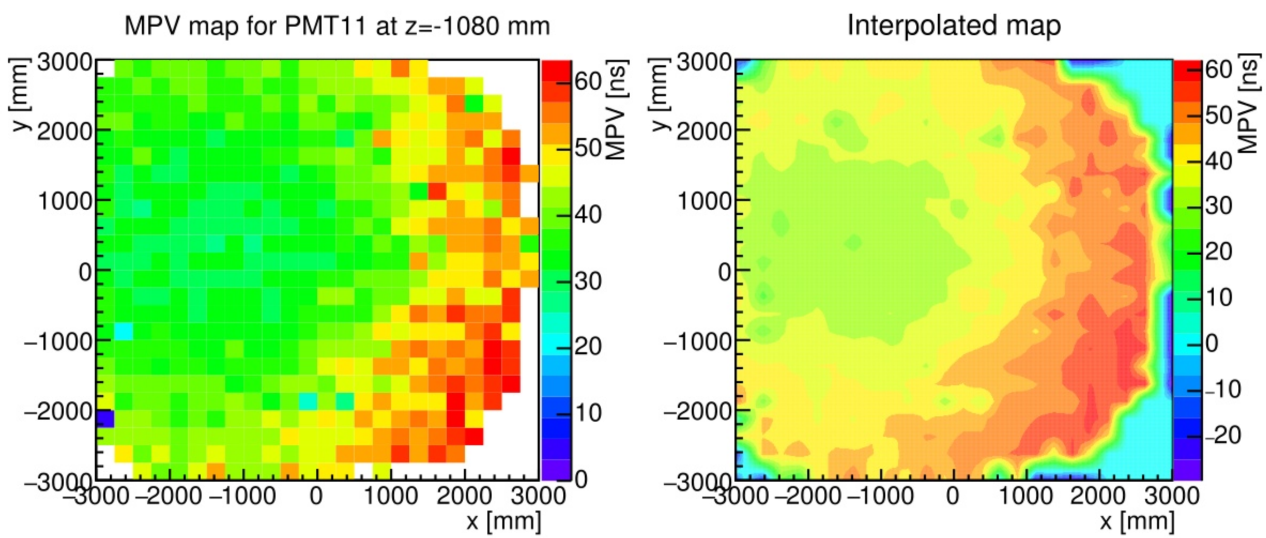
LightMap_6x6x6_PMTNonUni_LAr
LightMap_6x6x6_PMTNonUni_GAr
LightMap_6x6x6_PMT6x6_LAr
LightMap_6x6x6_PMT6x6_GAr
+ README_MAPS

The changes in **QScan** and **datacards** corresponding to these **new** light maps have been released on **svn** (WA105Soft rev438)

Light maps in QScan:

- For **each step** and **each PMT**:
  - Interpolation of the map values to the **step coordinates**

    → Interpolation between the 8 nearest voxel centers (weighted average method)



- Computation of: # detected S1 photons (with the number of **produced photons** and the **weight**)
  # detected S2 photons (using the number of **drifted electrons**, **G**, and the **weight**)

- For **each detected photon**: computation of the photon **travel time** (using **landau parameters** and **t0**)

LAr absorption implementation in QScan

LAr absorption in QScan (first order approach)

1. For each photon reaching the PMT array, computation of the probability to not being absorbed by LAr

$$p = \exp\left(-\mathrm{travel\_time} \cdot \frac{c}{\lambda_{Abs} \cdot n_{LAr}}\right)$$

(called **w_absorption** in QScan)

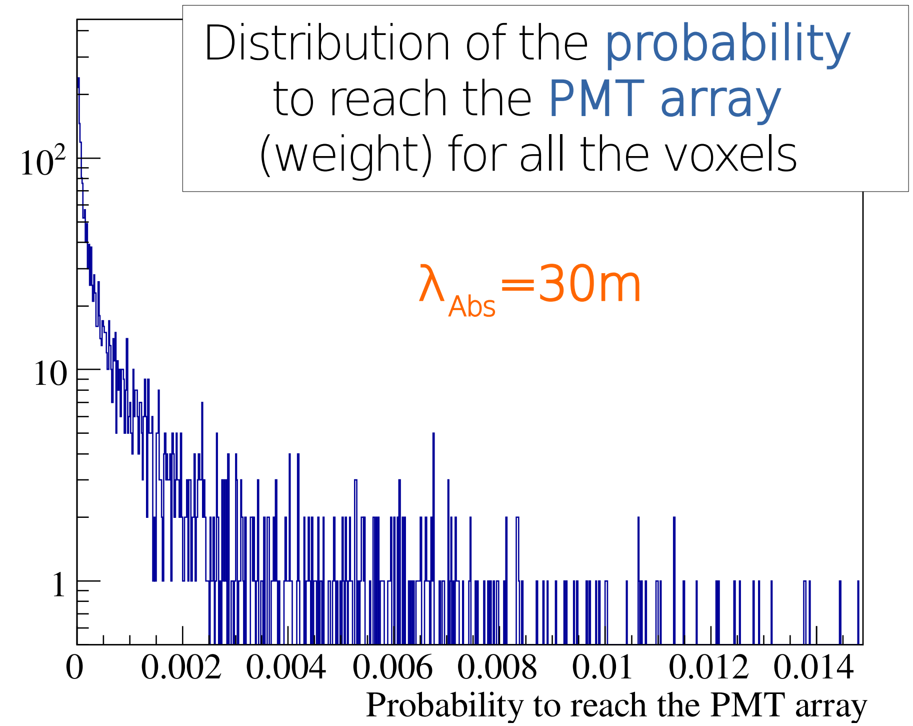
2. Generation of a random number between 0 and 1 (uniformly distributed).

3. rdm $<$ p: the photon is **not absorbed**
   rdm $>$ p: the photon is absorbed

→ The absorption reduces the probability to reach the PMT array for all the photons

λ_{Abs}	∞	30m	4m
Mean probability to reach the PMT array	0.00138	0.00113	0.00061

Stored in the maps: Rayleigh scattering and stainless steel absorption effects



Results on cosmic background

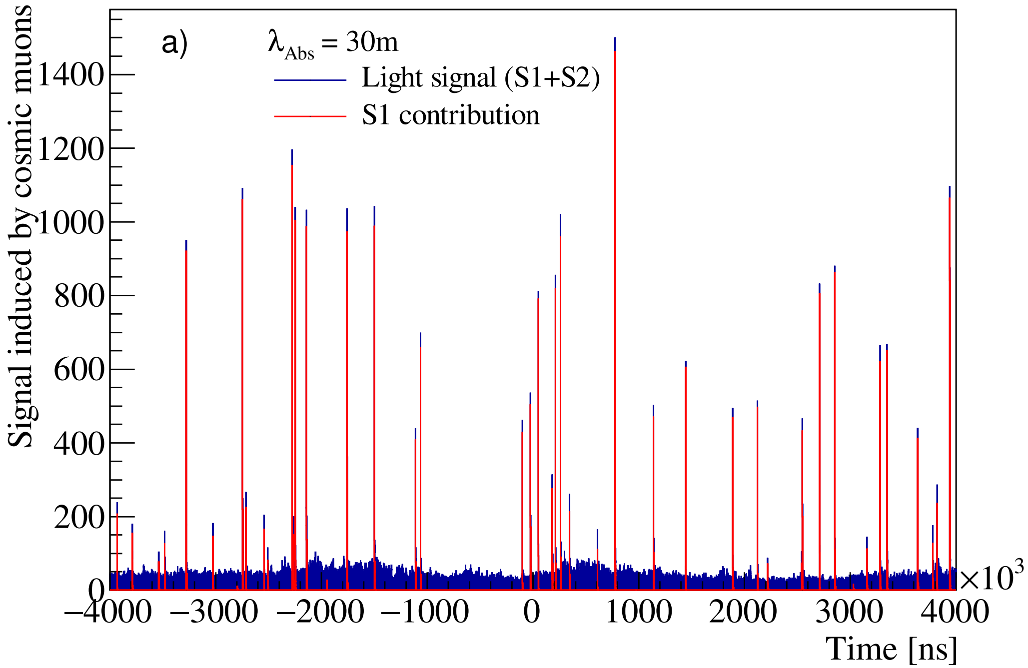
Cosmic muons are generated within a (-8ms, +4ms) time window

→ We look at the signal within a (-4ms , +4ms) time window

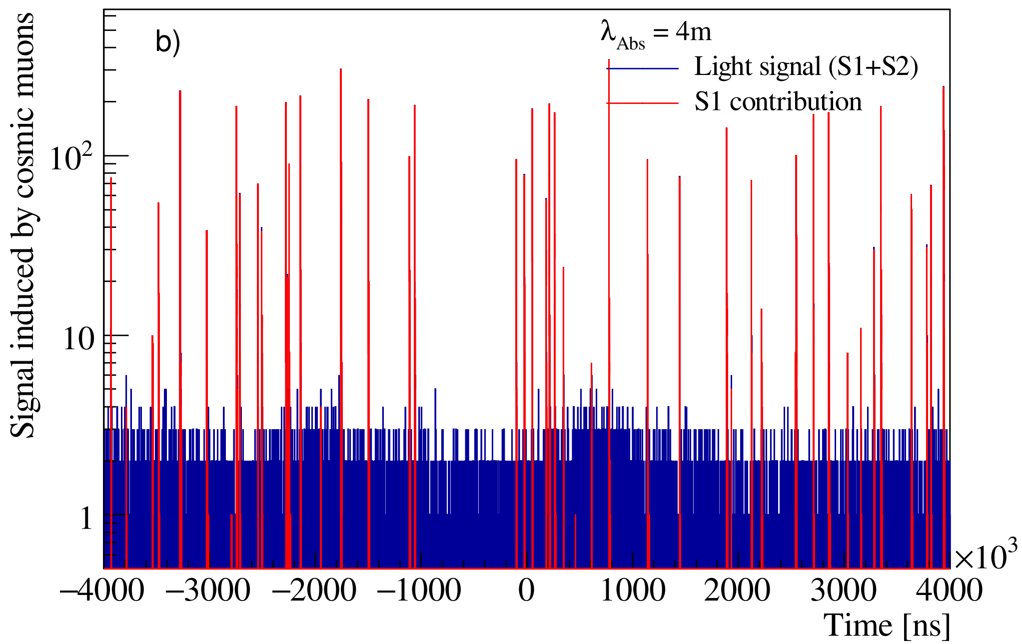
- PMT quantum efficiency: 0.20
- Electroluminescence gain G=300
- PMT and electronics response not taken into account

- 400ns sampling
- PMTs non-uniformly distributed

λ_{Abs}=30m



λ_{Abs}=4m



→ Changing the LAr absorption length from 30m to 4m reduces by a factor 10 the number of collected photons

Electroluminescence gain impact

- The **number of S2** photons is computed using an electroluminescence gain G

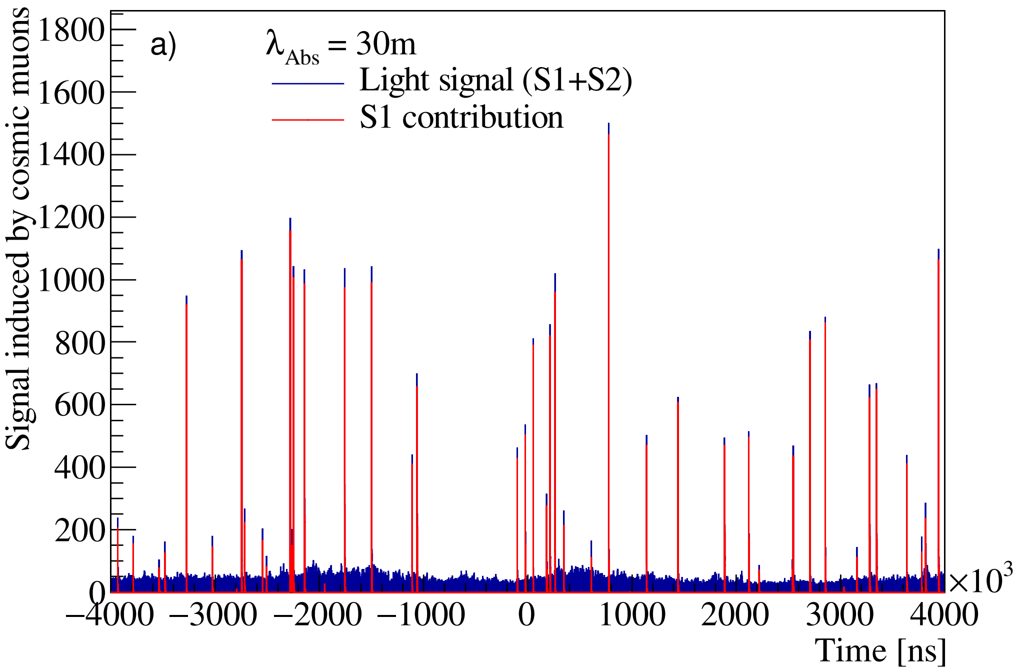
G = number of S2 photons per electron reaching the extraction grid

- This gain is fixed at 300 ph/e (generated over **4π**)in QScan, but the true value is unknown

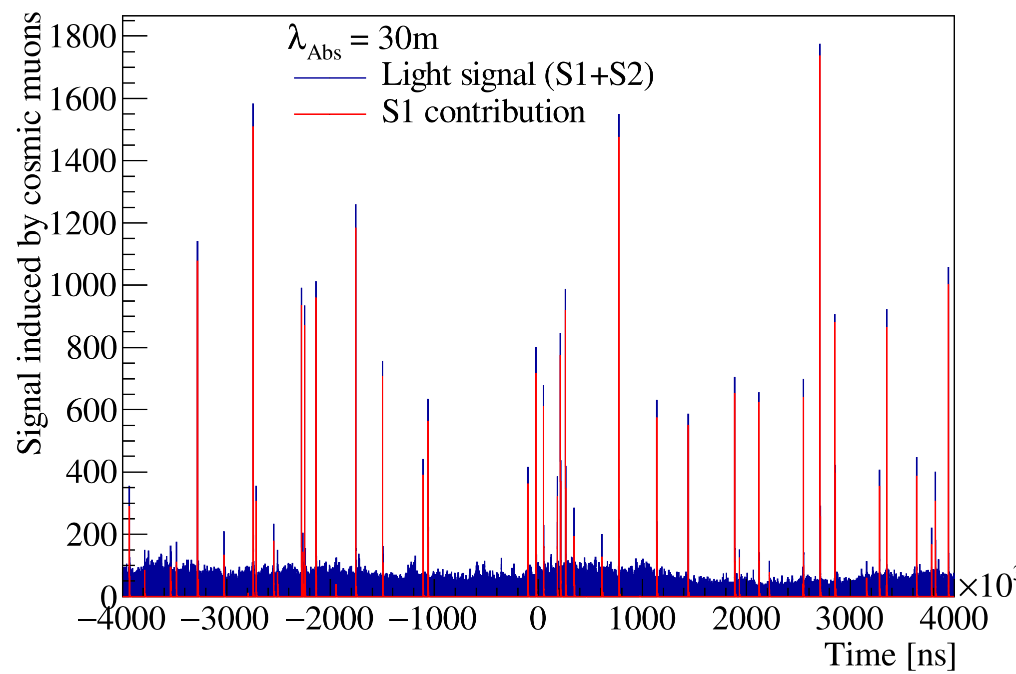
- **PMT quantum efficiency**: 0.20
- **PMT** and **electronics response** not taken into account

- **400ns** sampling
- PMTs **non-uniformly** distributed

G=300 ph/e



G=500 ph/e

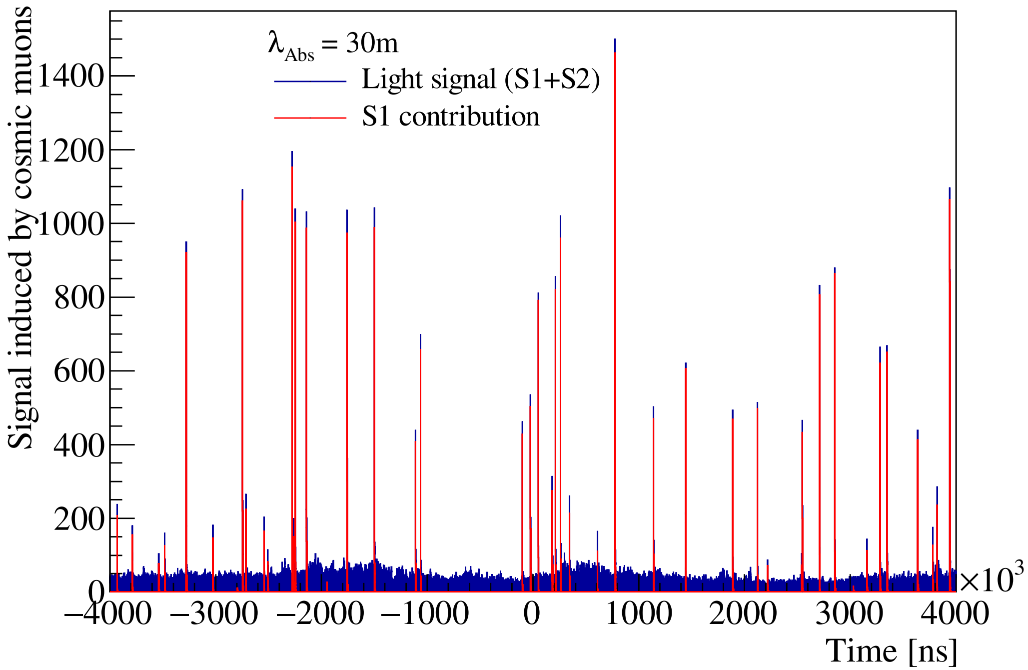


→ Needs additional **simulation** and **measurements** to determine the value of G

PMT positioning impact on signal induced by cosmics muons

- **PMT quantum efficiency**: 0.20
- Electroluminescence gain **G=300**
- **PMT** and **electronics response** not taken into account
- **400ns** sampling

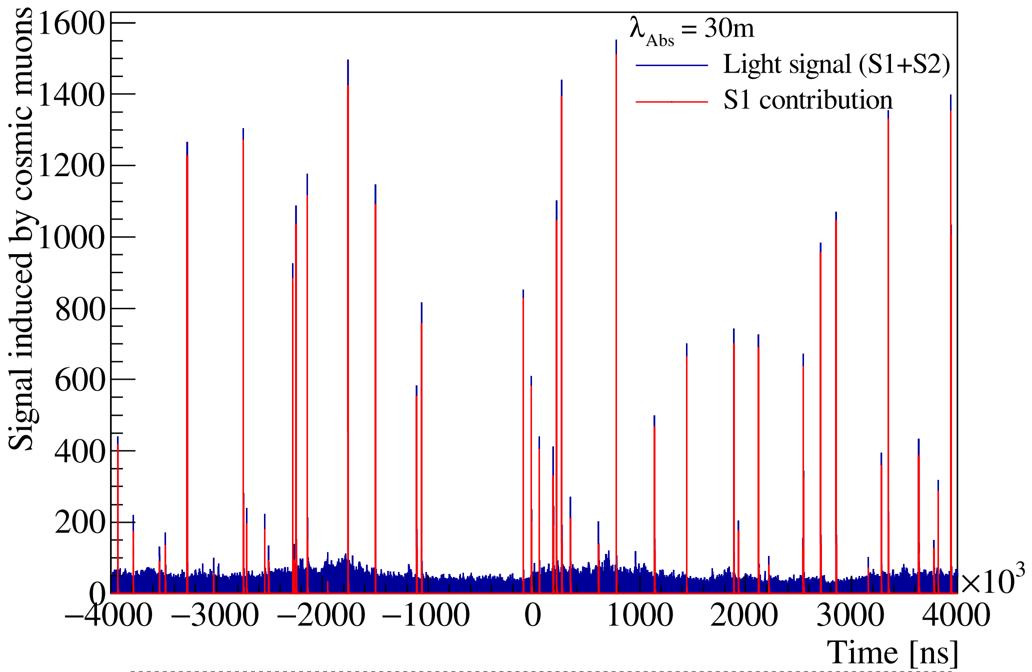
Non-uniformly spaced



$N_{S1} \sim 67.05 \times 10^3$
$N_{S2} \sim 705.5 \times 10^3$

$N_{S2}/N_{S1} \sim$ **10.5**

Uniformly spaced



$N_{S1} \sim 78.87 \times 10^3$
$N_{S2} \sim 804.5 \times 10^3$

$N_{S2}/N_{S1} \sim$ **10.2**

→ The two configurations are **quite similar** for **light collection**

→ The configuration with PMTs **spaced** by 65cm **slightly increases** the collected photon number

Conclusion and Perspectives

Conclusion

- The **LightSim** software has been developed to follow the 6x6x6 design evolution, and to perform studies about the **design impact** on light collection:
  - **PMT** configurations
  - Cathode **supporting** structure
  - **Transparent cathode** (ITO coated PMMA plates)
  - **Ground grid** and **LEM** plates implementation
- Optimization of the **photon travel time** distribution parametrisation
- Studies about the LAr absorption length impact on **light collection** in LightSim and QScan (with APC group)

> Maps **for the** 6x6x6 **are produced and are** now available **to the collaboration**
> QScan is **updated** to use these **new** light maps

Next steps

- Determination and validation of the electroluminescence gain G (simulation and data)
- **Cosmic** tagging **and** rejection using the maps (work in development)
- **Continue** the optimization of the **travel time distribution** parametrisation
- Maps for 3x1x1
  - Implementation of the **3x1x1 geometry** (on going)
  - Adaptation of the **voxel definition** to 3x1x1 volume