PMT crosstalk simulation for SBND

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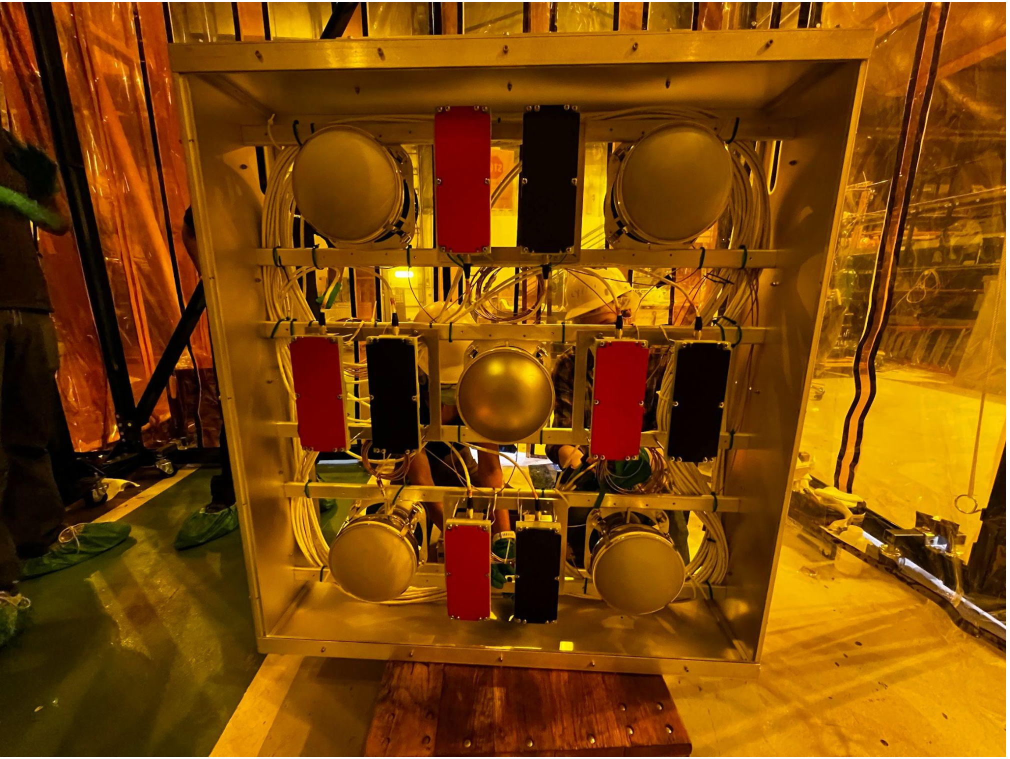
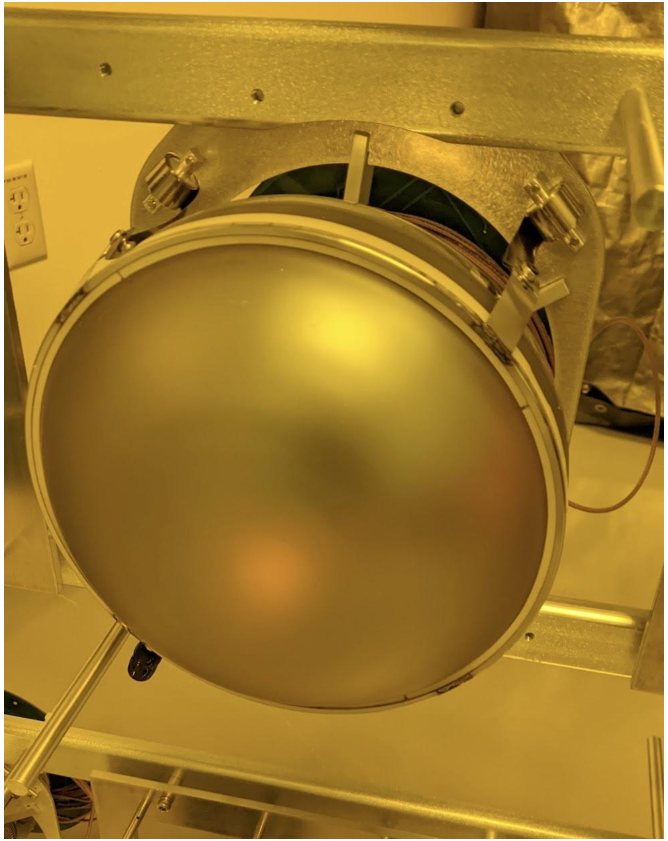
UNIVERSIDAD DE GRANADA

Motivation



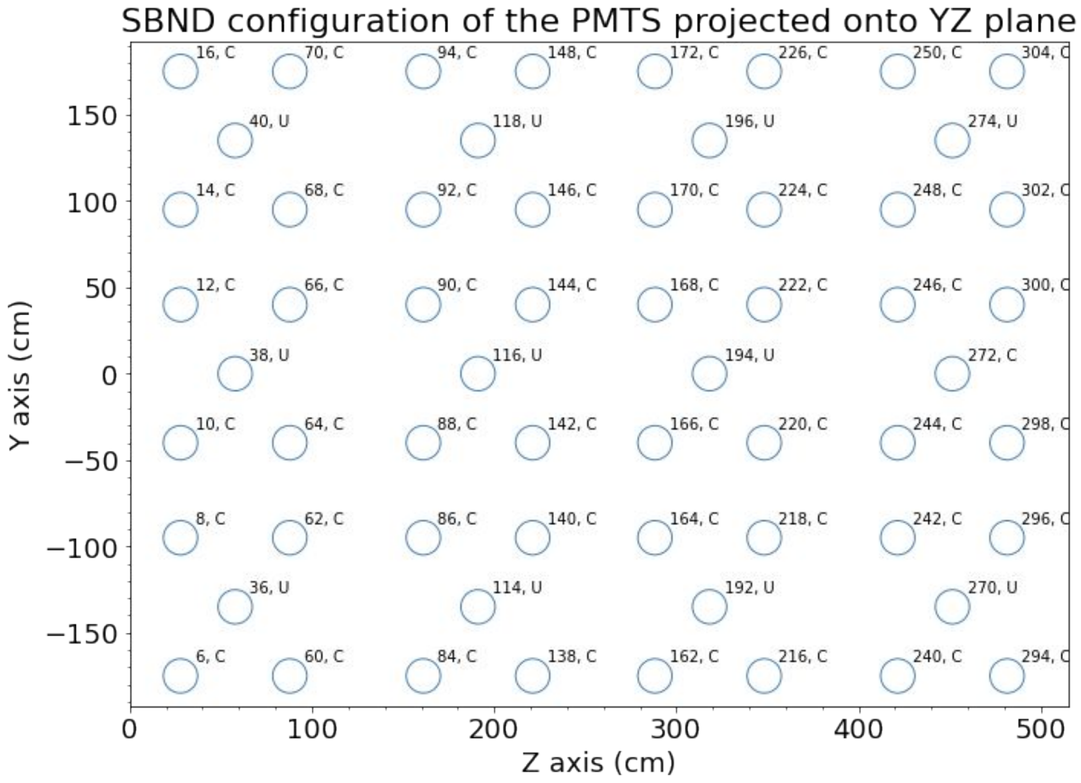
- SBND light detection system consists of 120 Photo Multiplier Tubes (PMTs) and 192 X-ARAPUCAS.
- PMTs and X-ARAPUCAS are mounted on Photon Detection System (PDS) boxes.

Motivation



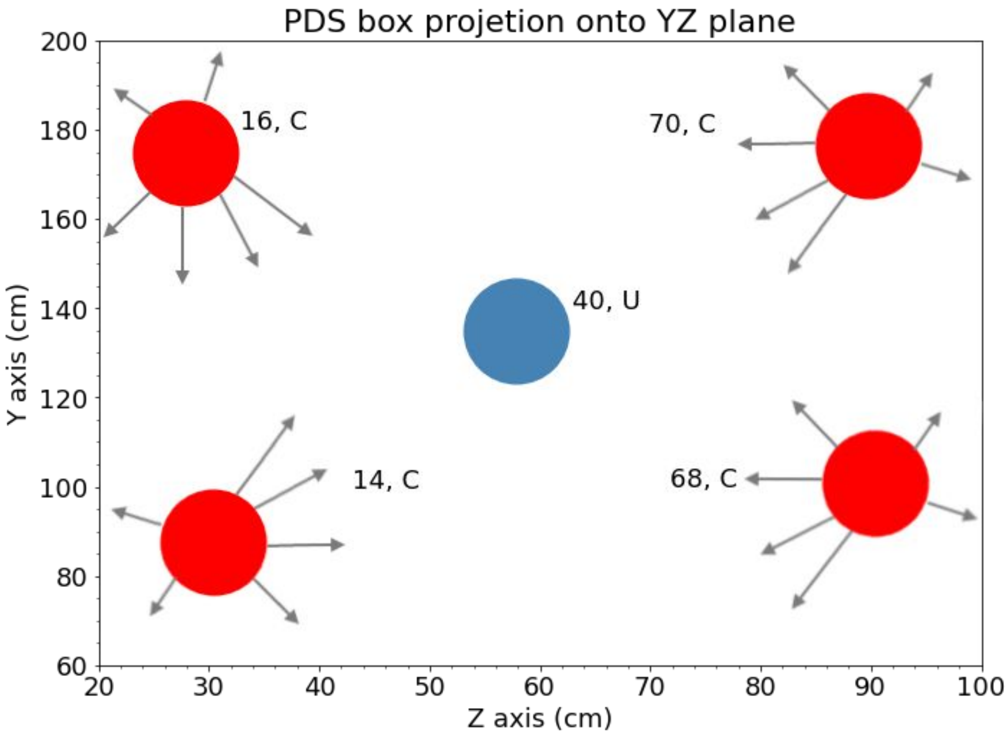
- Most of the PMTs are coated with a thin layer of a wavelength shifter material (TPB).
- TPB absorbs VUV photons and re-emits them with a higher wavelength (visible).
- TPB emission is isotropic.

Motivation



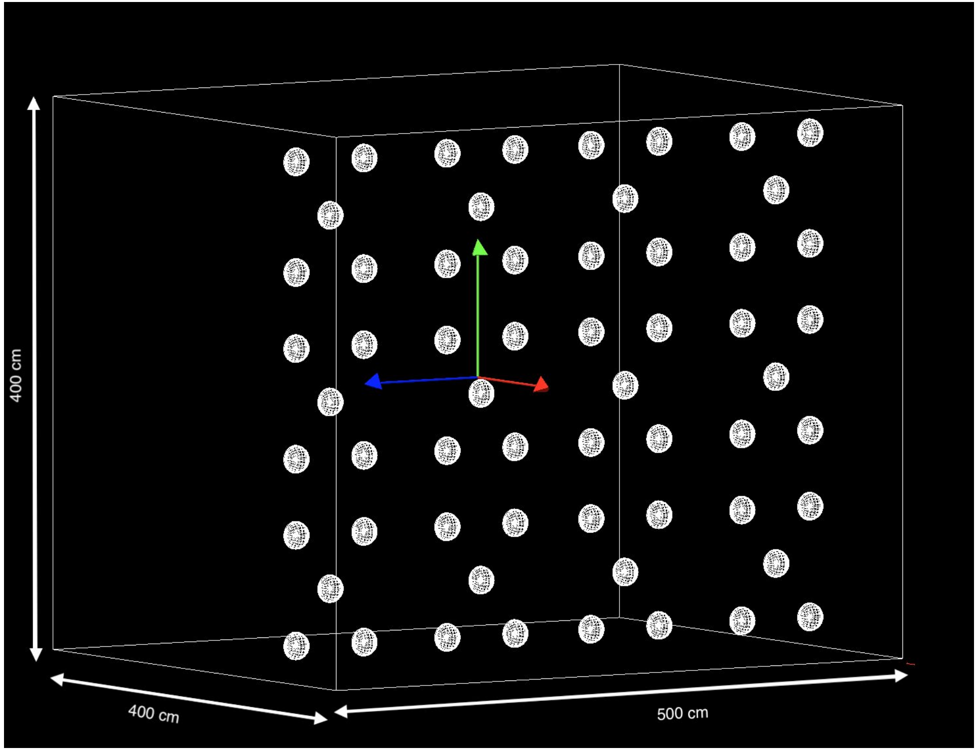
- The re-emission from coated PMTs might affect surrounding PMTs.

Motivation



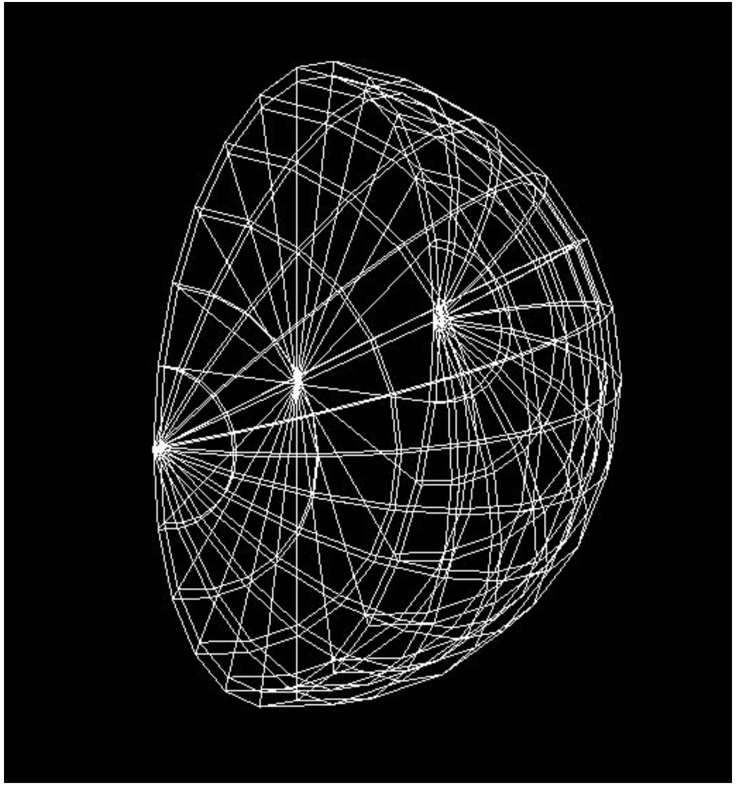
- If the photons are emitted outwards another neighbour PMT might detect it.
- Goal: quantify how many re-emitted photons reach surrounding PMTs.

Simulation



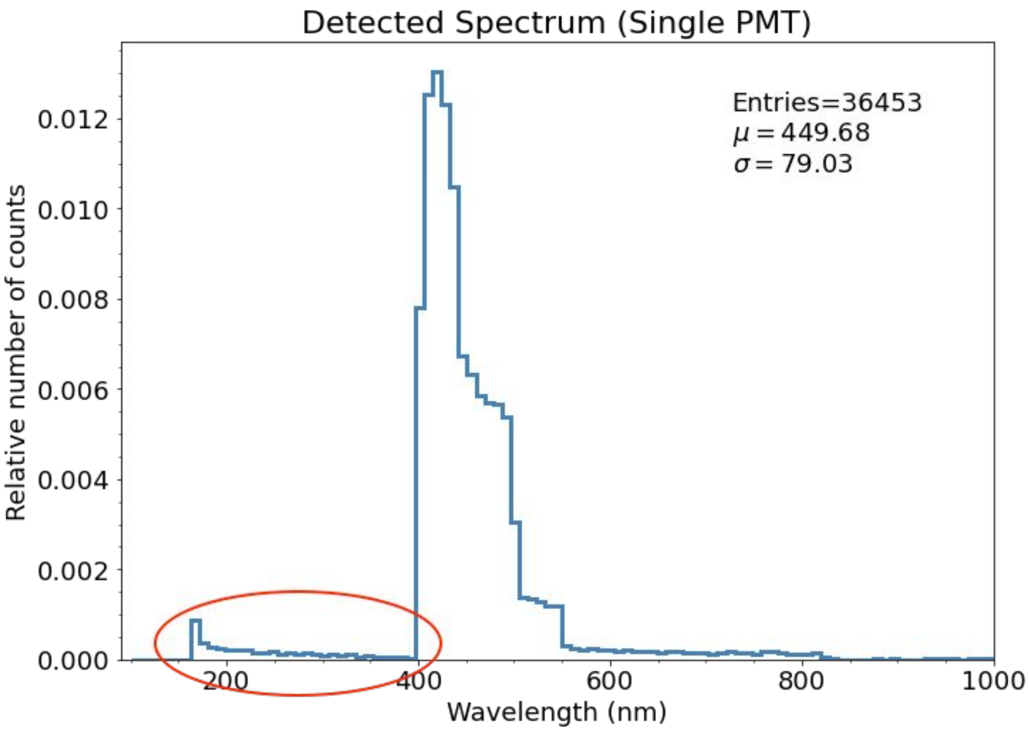
- G4 simulation to quantify how important this effect is.
- Actual SBND geometry implemented along with all the properties of the materials.

Simulation



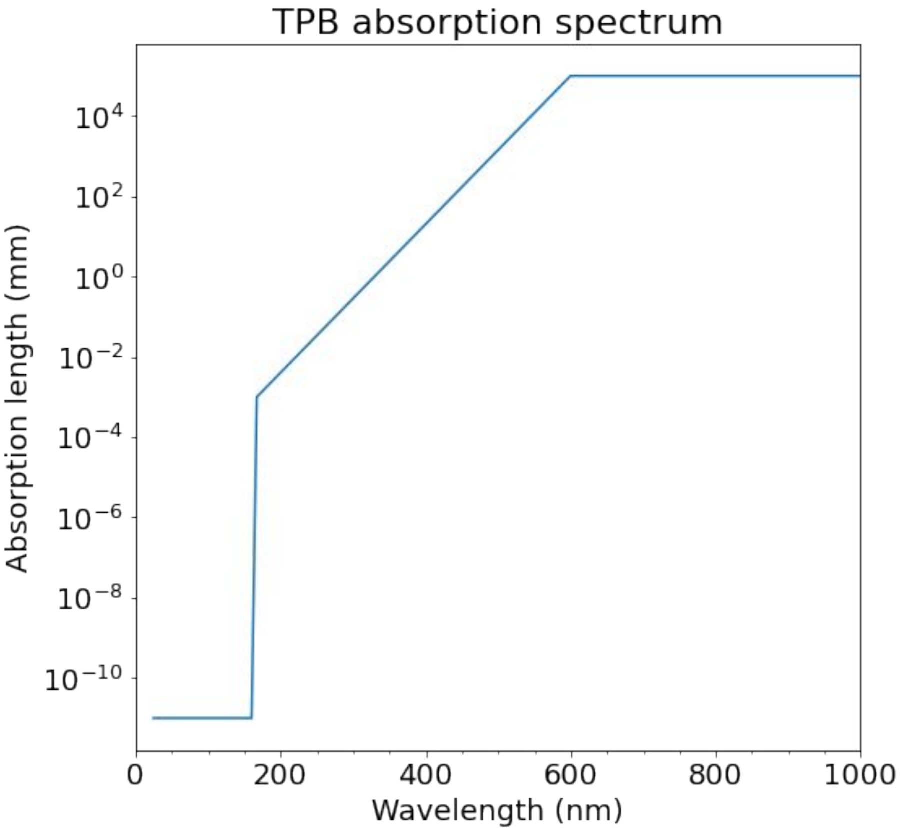
- Geometry of a single PMT. Two layers: TPB and sensitive detector, vacuum and a reflective material in the back.
- Some of the physics that are implemented: LAr scintillation spectrum, LAr fast/slow components, Cherenkov effect, Rayleigh scattering…

First crosscheck



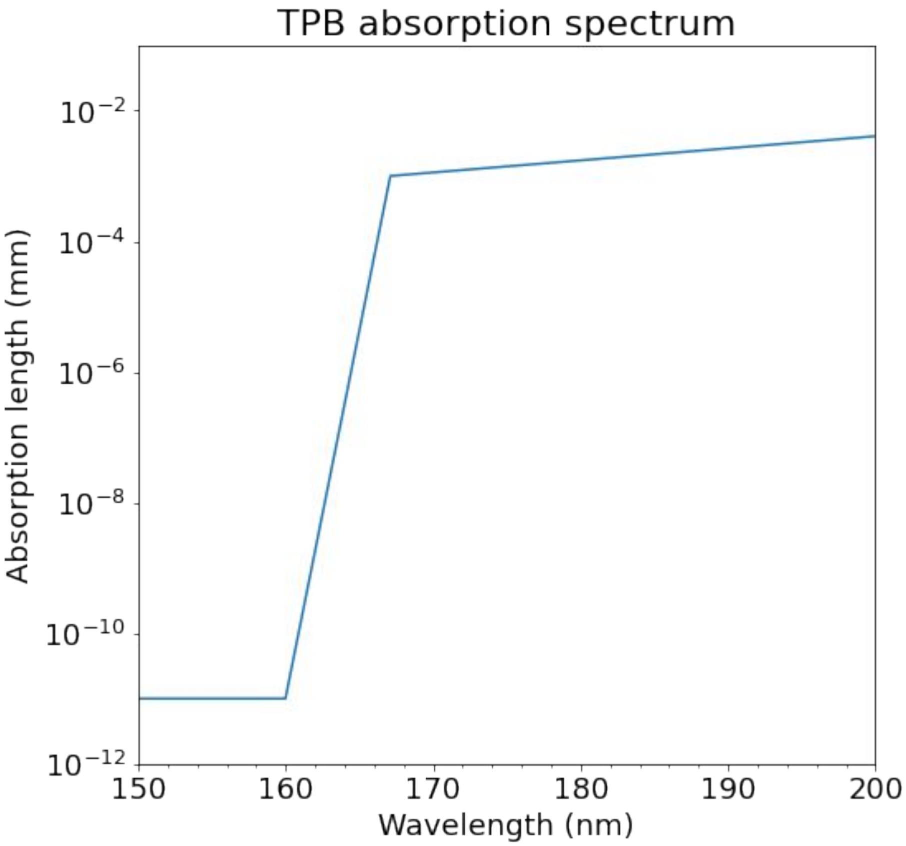
- We shoot an electron pointing towards the center of the PMT to check that the simulation works.
- Entries are: ~93% scintillation photons, ~7% Cherenkov photons.
- Most of the photons are wavelength-shifted but a small fraction is not.

First crosscheck



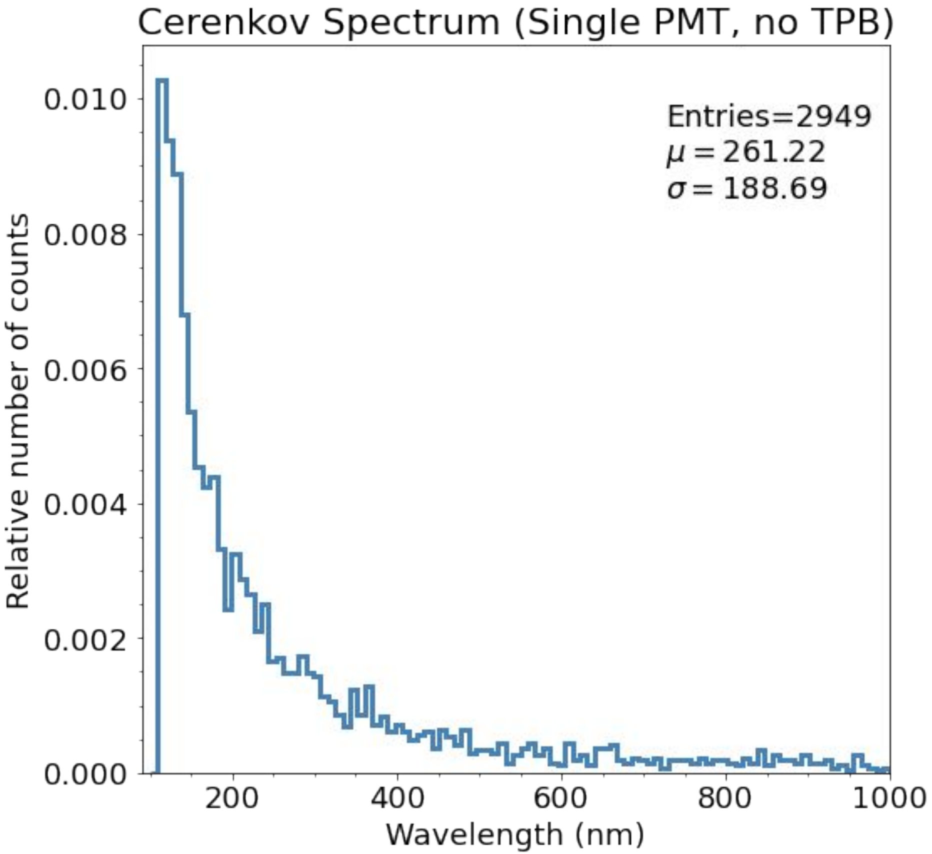
- This effect comes from the TPB absorption spectrum.
- There is an enormous step around λ=160nm.
- If we zoom in...

First crosscheck



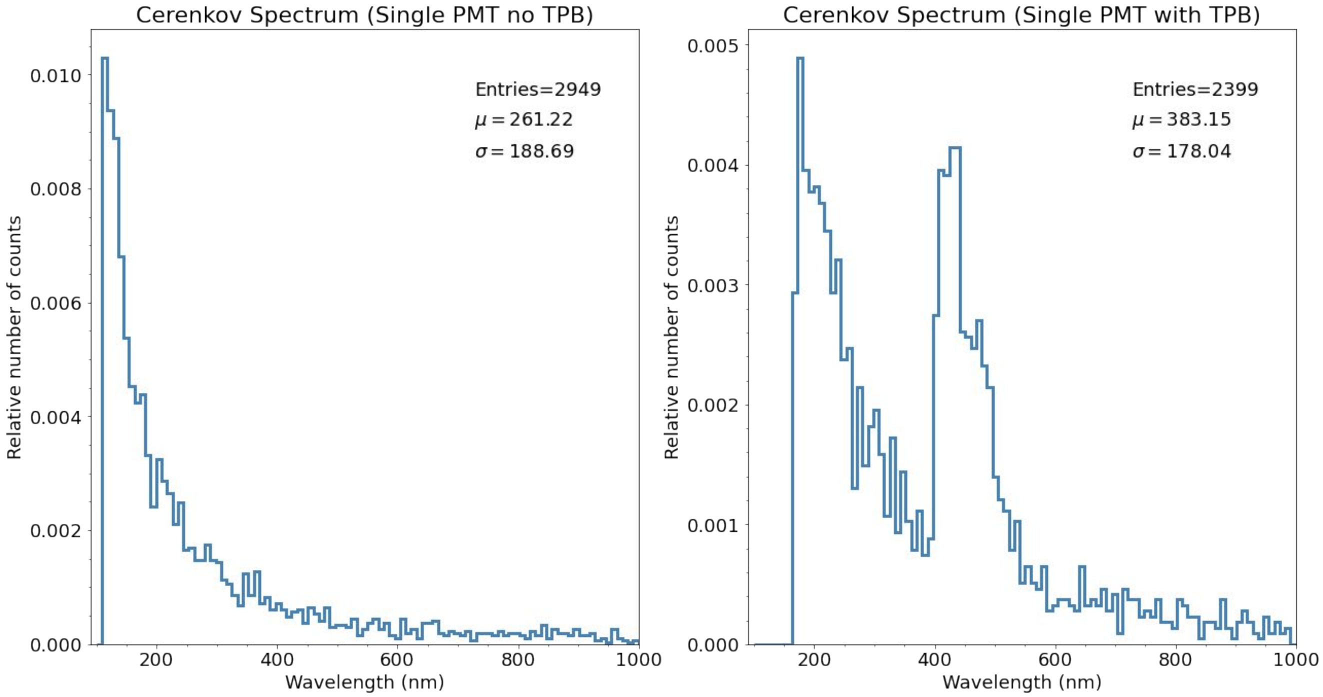
- The absorption length goes from ~10^{-11} mm at 160 nm to ~10^{-3} at 170 nm.
- This is the TPB absorption spectrum implemented by default in SBND.
- This was not noticed before because scintillation photons are produced around 128 nm.

First crosscheck



- We still have Cherenkov photons that were being ignored and cover a broader wavelength interval.
- The unshifted photons are Cherenkov photons with wavelengths over 160 nm.

First crosscheck

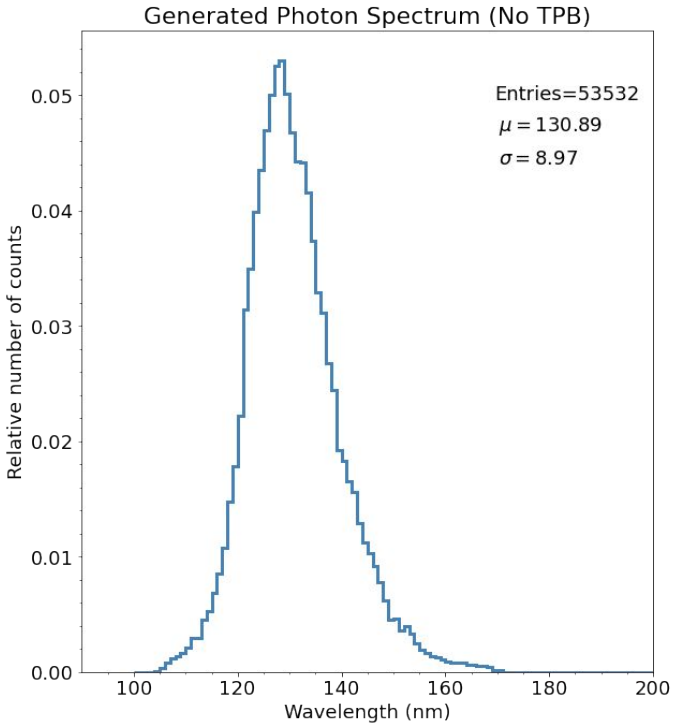


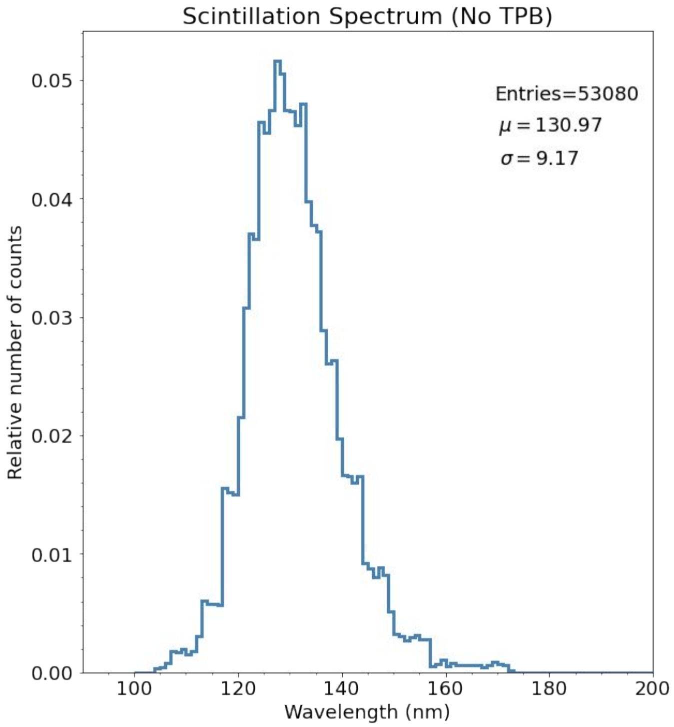
- This is how Cherenkov photons' spectrum looks like when including TPB coating in our construction.
- We see that the minimum has been shifted to ~160 nm (where the TPB absorption spectrum has a large step).

Possible solutions

- Find a realistic TPB absorption spectrum. (To be done)
- Turn off Cerenkov effect in our simulation. (Provisional solution)
- Generate photons equivalent to LAr scintillation. (Provisional solution)

Two ways of simulating scintillation photons

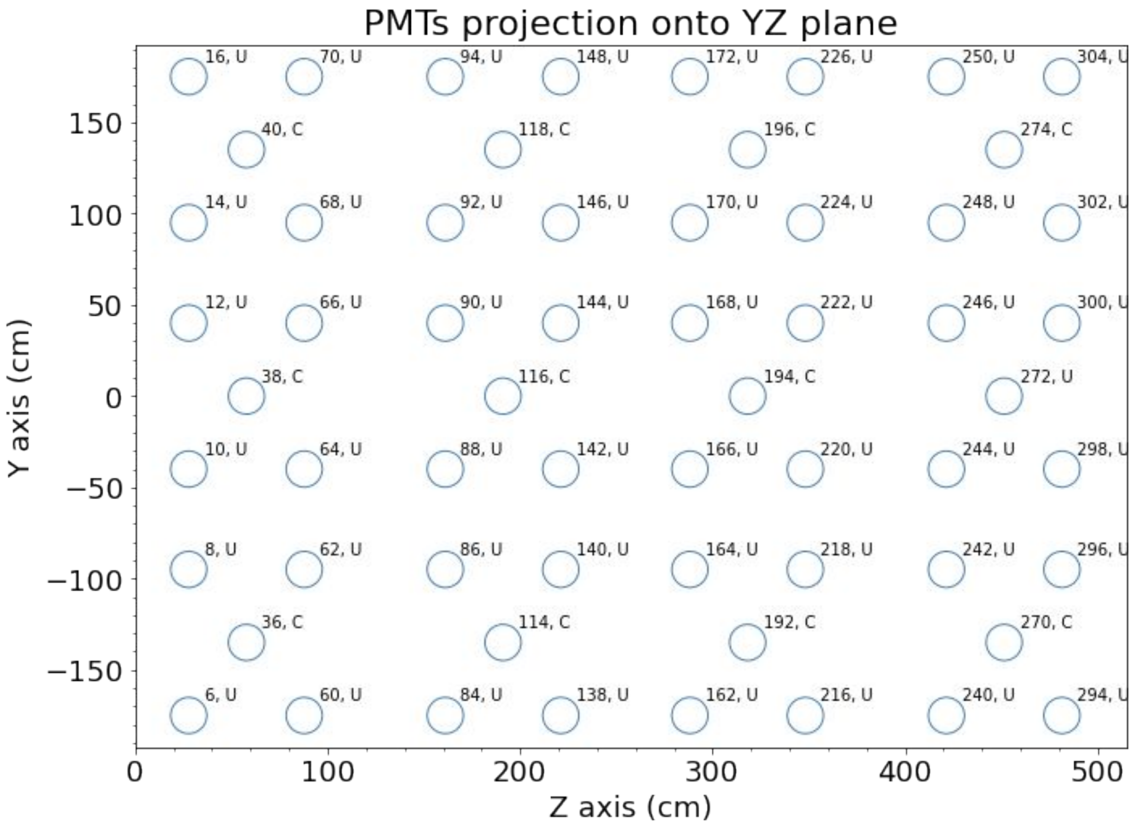




- Generate photons equivalent to a 10 MeV energy deposition. (Entries number)

- Compare scintillation and generated photon spectrum.

Current simulation



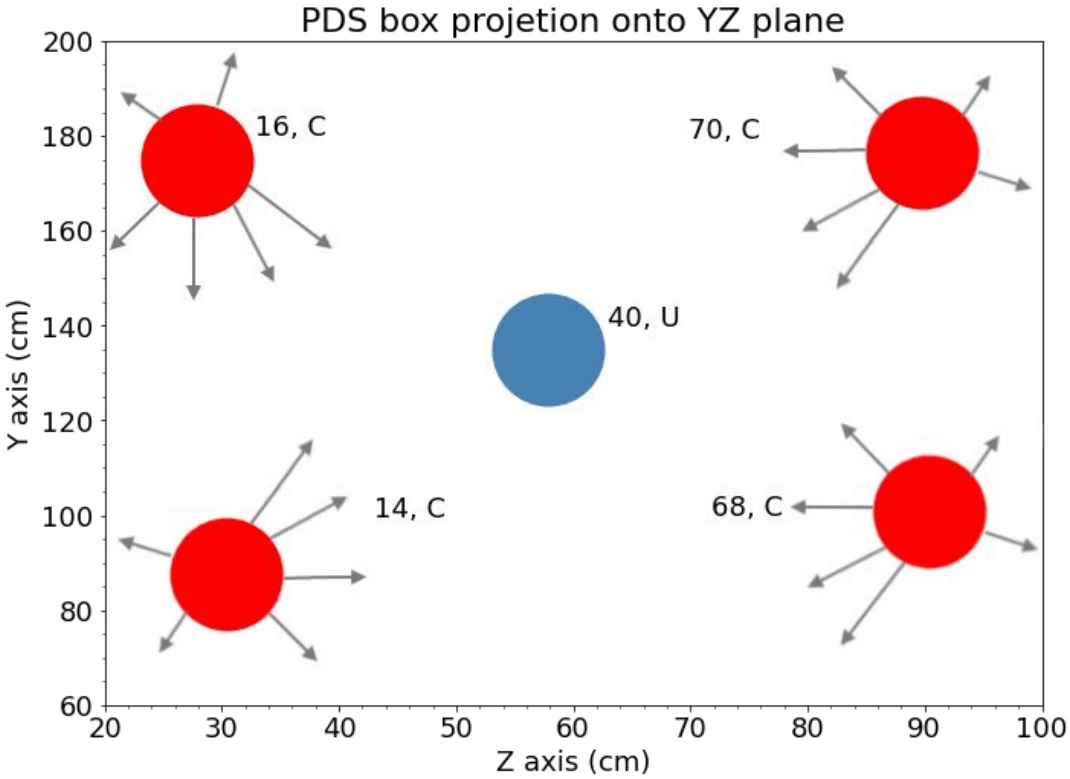
- Now the picture is slightly different. Swap coated and uncoated. We want to measure a geometric effect.
- We focus on one coated PMT and see how its emission affects other PMTs.

Analysis going on

```
(base) alejandrosanchez@cvi136078 build % ls analysis
output0.root   output150.root output202.root output255.root output307.root output36.root  output52.root
output1.root   output151.root output203.root output256.root output308.root output360.root output53.root
output10.root  output152.root output204.root output257.root output309.root output361.root output54.root
output100.root output153.root output205.root output258.root output31.root  output362.root output55.root
output101.root output154.root output206.root output259.root output310.root output363.root output56.root
output102.root output155.root output207.root output26.root  output311.root output364.root output57.root
output103.root output156.root output208.root output260.root output312.root output365.root output58.root
output104.root output157.root output209.root output261.root output313.root output366.root output59.root
output105.root output158.root output21.root  output262.root output314.root output367.root output6.root
output106.root output159.root output210.root output263.root output315.root output368.root output60.root
output107.root output16.root  output211.root output264.root output316.root output369.root output61.root
output108.root output160.root output212.root output265.root output317.root output37.root  output62.root
output109.root output161.root output213.root output266.root output318.root output370.root output63.root
output11.root  output162.root output214.root output267.root output319.root output371.root output64.root
output110.root output163.root output215.root output268.root output32.root  output372.root output65.root
output111.root output164.root output216.root output269.root output320.root output373.root output66.root
output112.root output165.root output217.root output27.root  output321.root output374.root output67.root
output113.root output166.root output218.root output270.root output322.root output375.root output68.root
output114.root output167.root output219.root output271.root output323.root output376.root output69.root
output115.root output168.root output22.root  output272.root output324.root output377.root output7.root
output116.root output169.root output220.root output273.root output325.root output378.root output70.root
output117.root output17.root  output221.root output274.root output326.root output379.root output71.root
output118.root output170.root output222.root output275.root output327.root output38.root  output72.root
output119.root output171.root output223.root output276.root output328.root output380.root output73.root
output12.root  output172.root output224.root output277.root output329.root output381.root output74.root
output120.root output173.root output225.root output278.root output33.root  output382.root output75.root
```

- Files already prepared. To be analysed.

Reminder

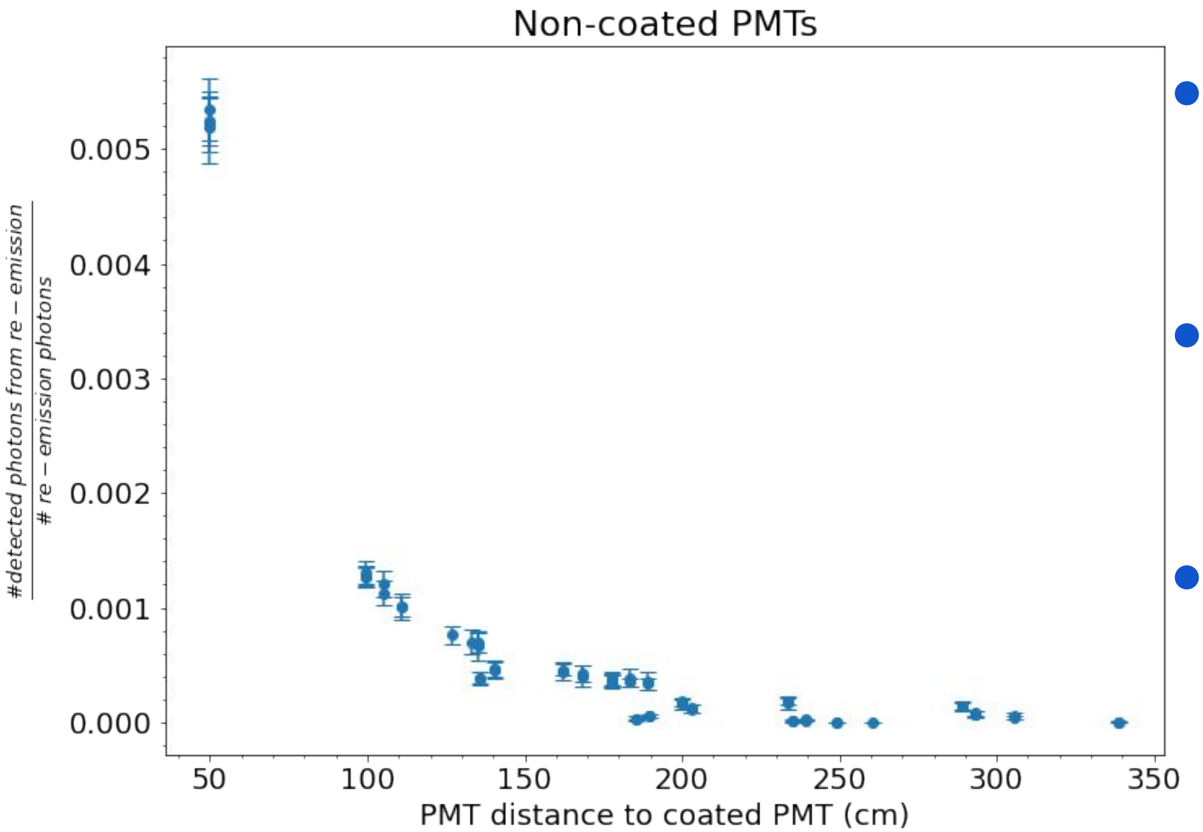


- We want to quantify the effect that TPB re-emission has on surrounding PMTs.

Simulation

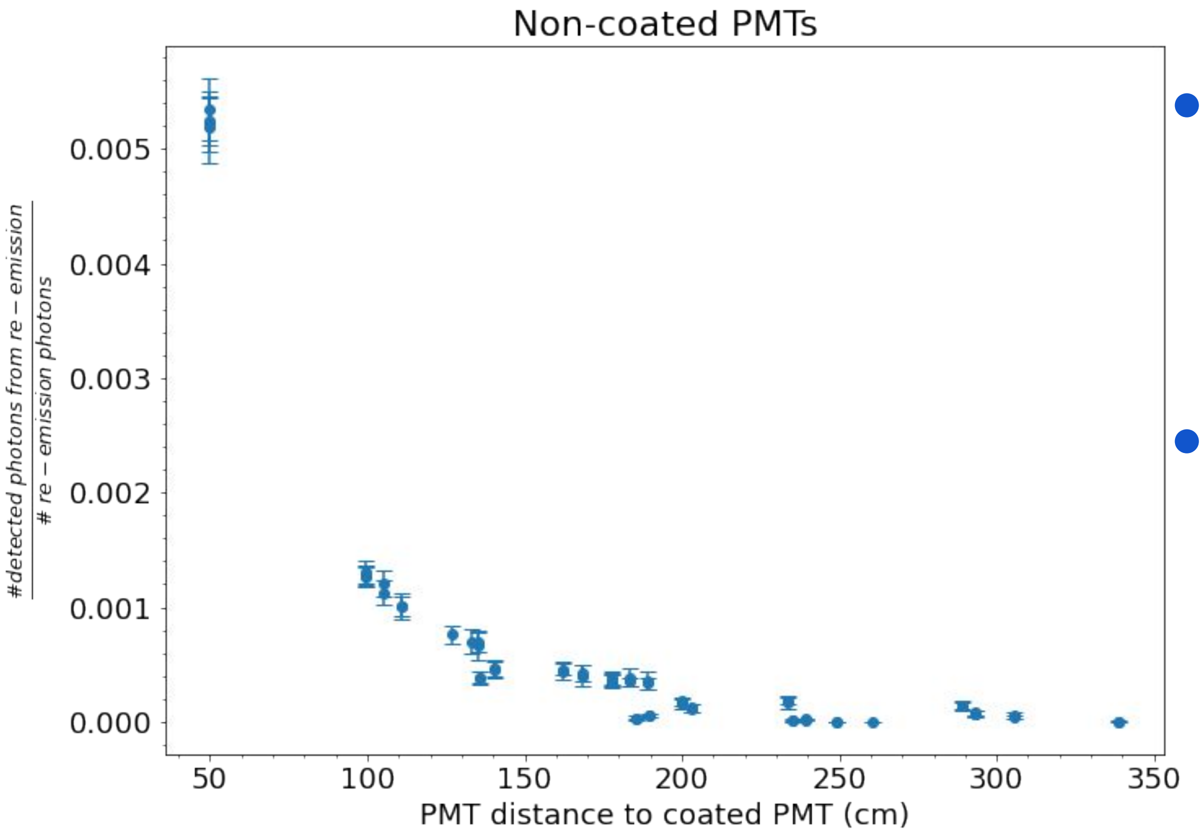
- Complete SBND geometry, with one single coated PMT.
- Shoot a number of photons equivalent to 100 MeV energy deposition at a distance of 10 cm from the coated PMT.
- Run the same simulation 100 times so we have enough statistics.

Results



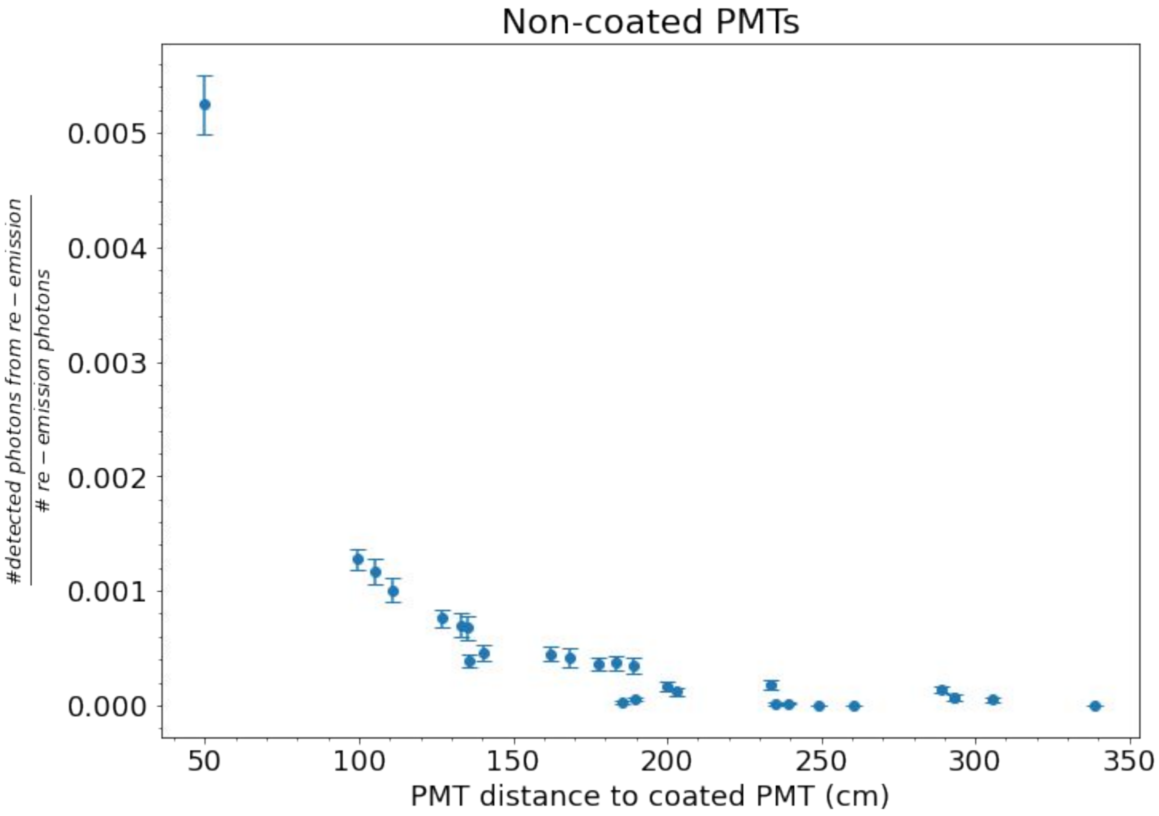
- Compute the number of re-emission photons as a function of the distance to the coated PMT.
- Divide by the total number of photons re-emitted (by the only coated PMT).
- Each point in the plot corresponds to a PMT in the simulation.

Results



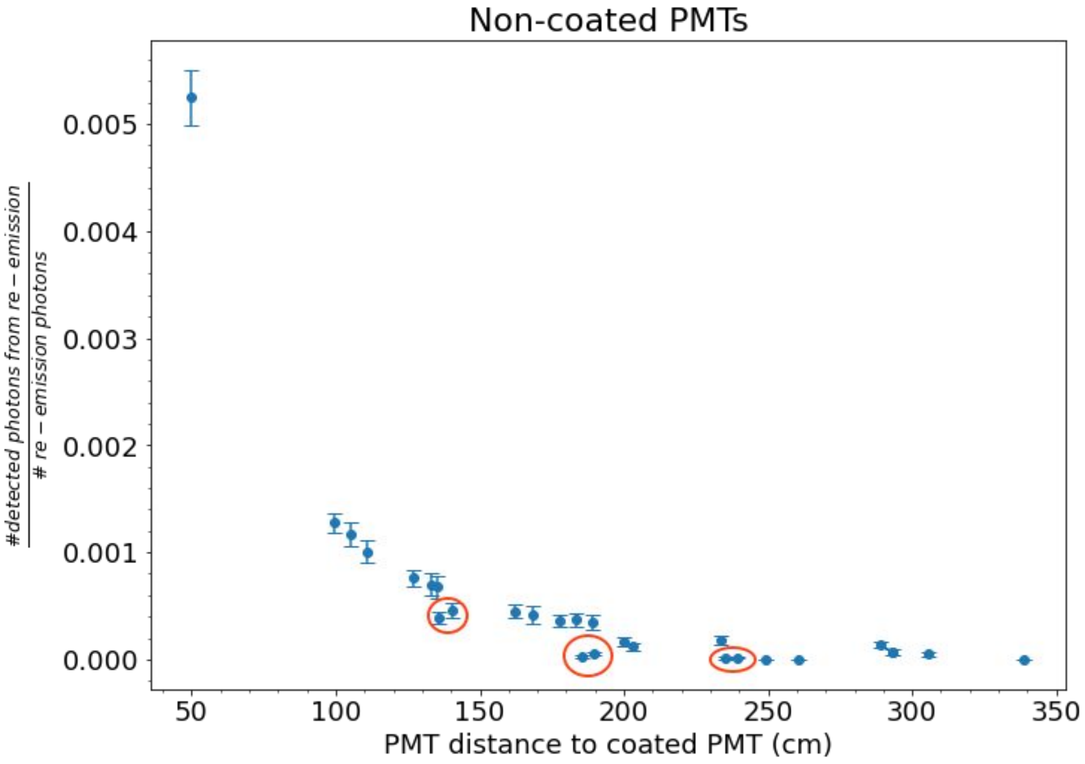
- This tells us how many 'extra' photons we need to count as a function of the distance to the coated PMT.
- Equivalent: probability that a re-emission photon is detected by another PMT at a certain distance.

Results



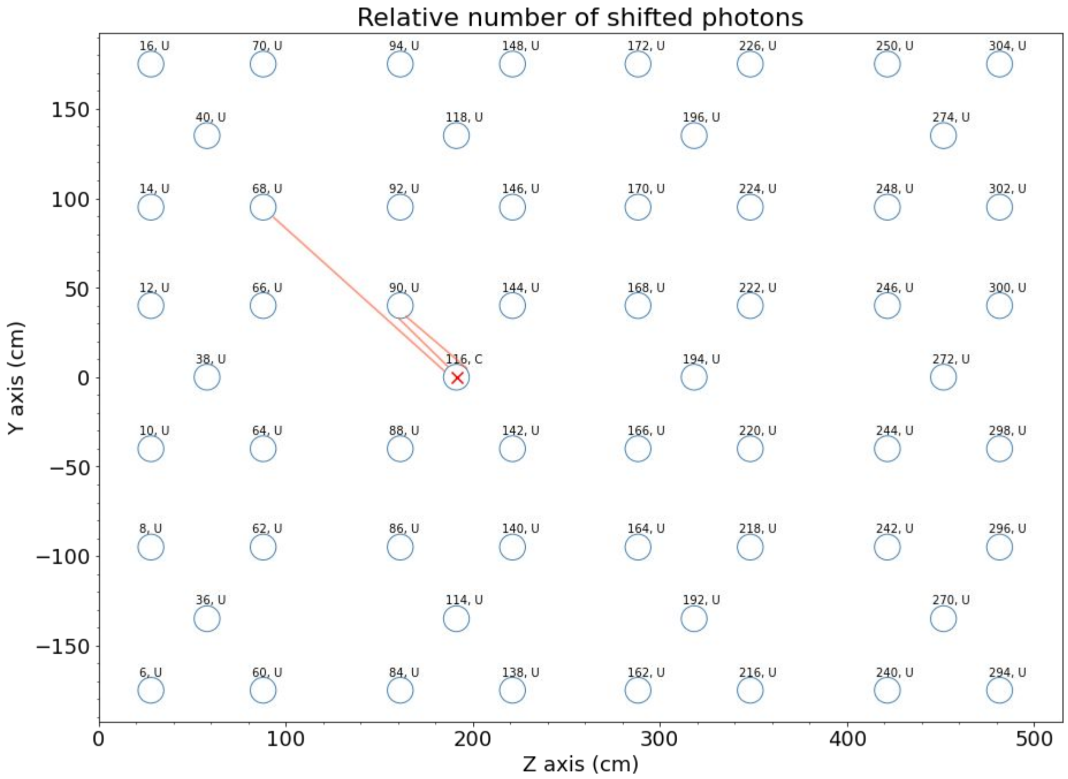
- Some distances are the same for different PMTs.
- We can average over PMTs with same distance to the coated PMT.

Results



- There are some PMTs that receive a lower number of re-emission photons than expected.
- There is a ‘shadowing’ effect between PMTs.

Results



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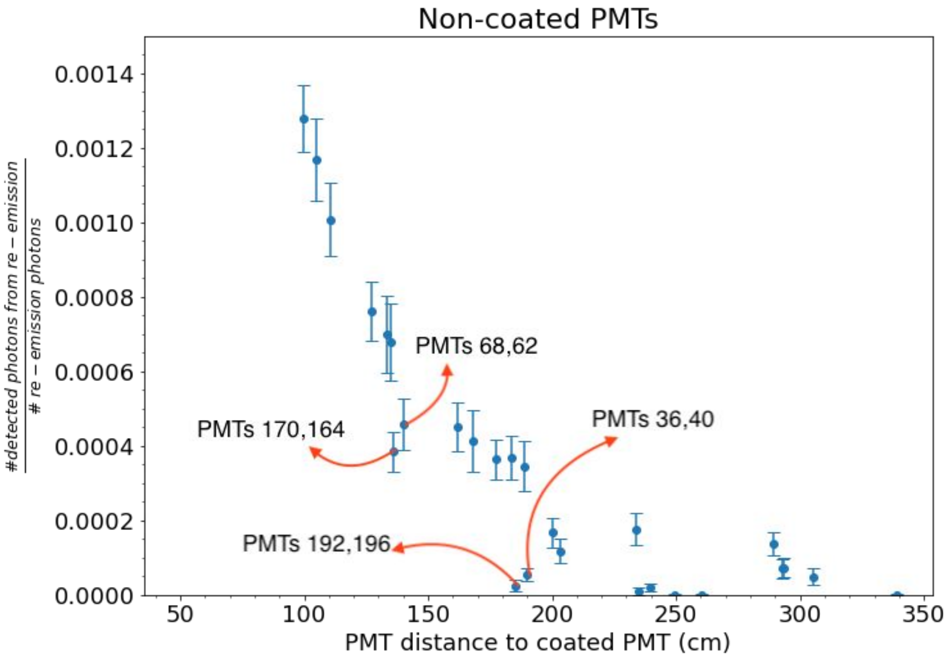
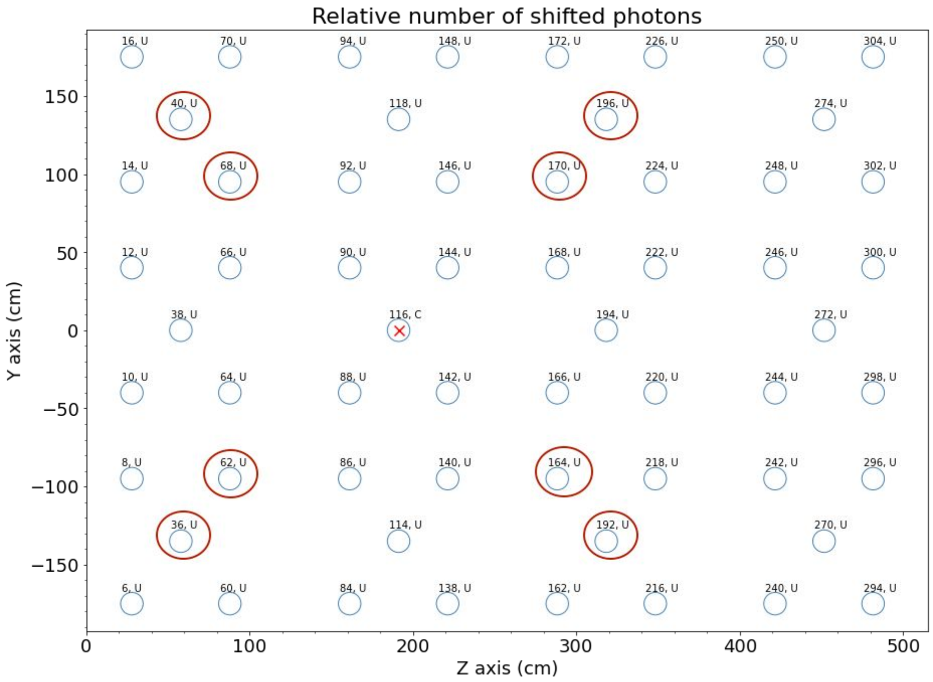


- Zoom in and crosscheck some of the fishy points.

Results



- Indeed, they coincide with the PMTs that are shadowed by another PMT.

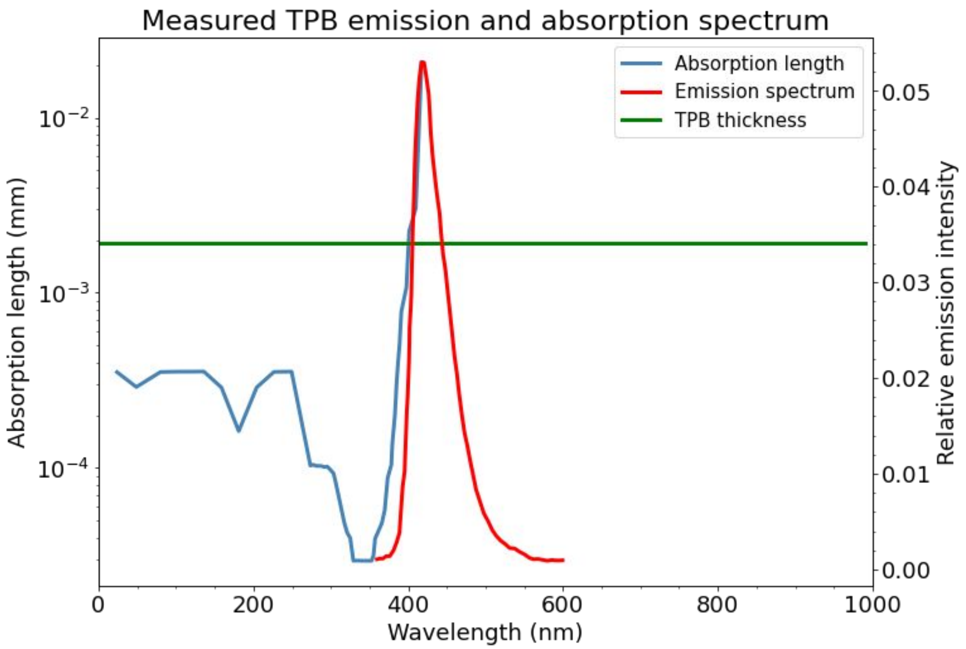
Next Steps

- Run a simulation without coated PMTs
  - Compute the number of photons as received photons/2 (as is done in LArSoft).
  - Compute the number of photons as received photons/2 and apply the previous correction for each PMT.

- Run a simulation with the outright SBND coated/uncoated configuration.

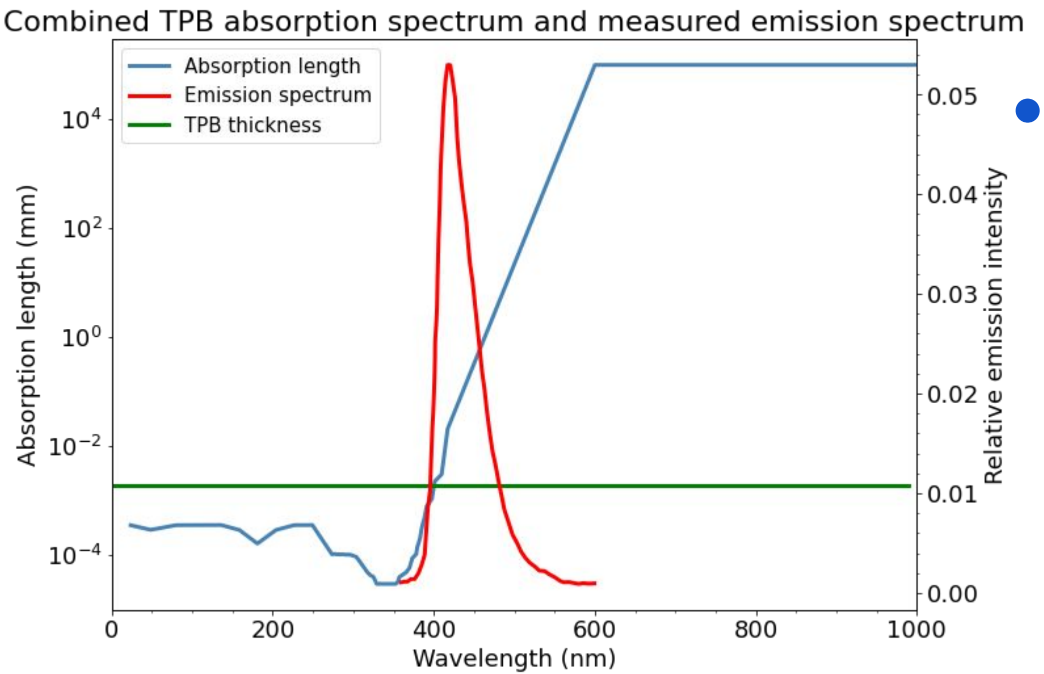
- Compare all three results.

In parallel



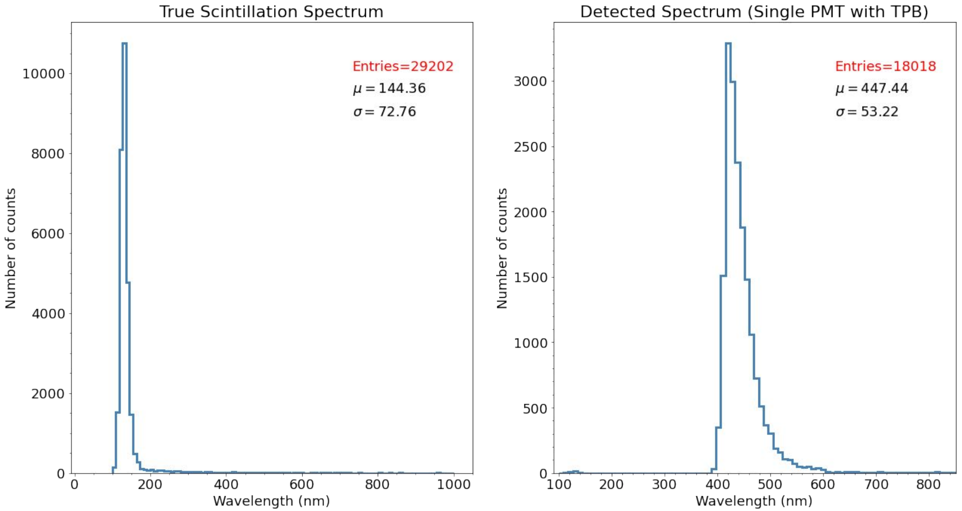
- Found a measured TPB absorption spectrum. [S.E. Wallace-Williams et al., J. Phys. Chem. 98, 60–67 (1994)]
- Combine it with a measured emission spectrum. [1709.05002]
- Need a broader wavelength interval to account for Cherenkov photons.

In parallel



- Combine old absorption spectrum with the measured to cover all the wavelength range.

In parallel



- Cherenkov photons which were not being shifted with the old spectrum now are.
- Now there are some unshifted photons around 120 nm because the absorption length is much lower than it was for that wavelength (~30 photons).
- Ready to turn Cherenkov effect on again

Summary 7/10-14/10

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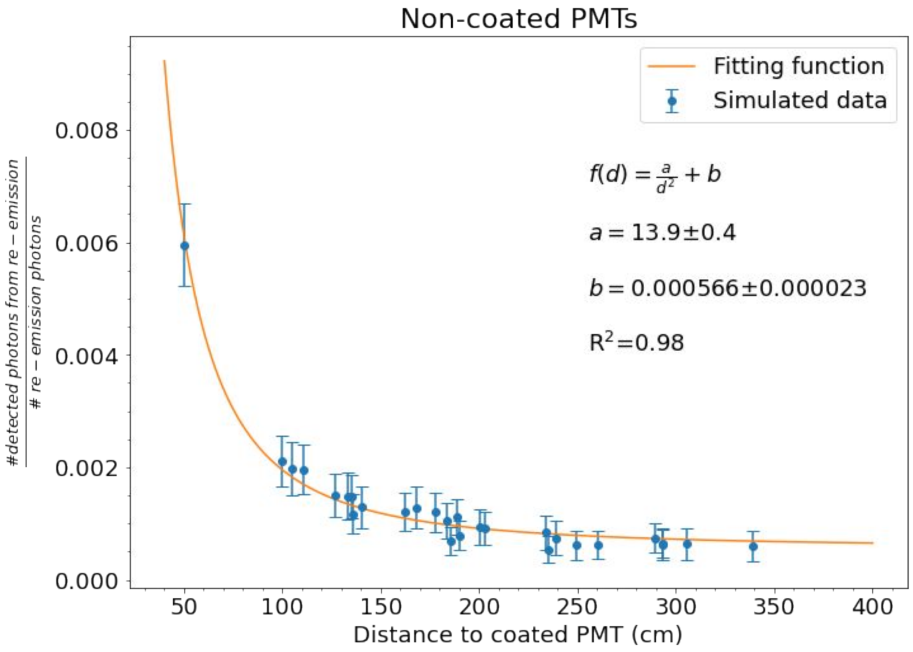
Results

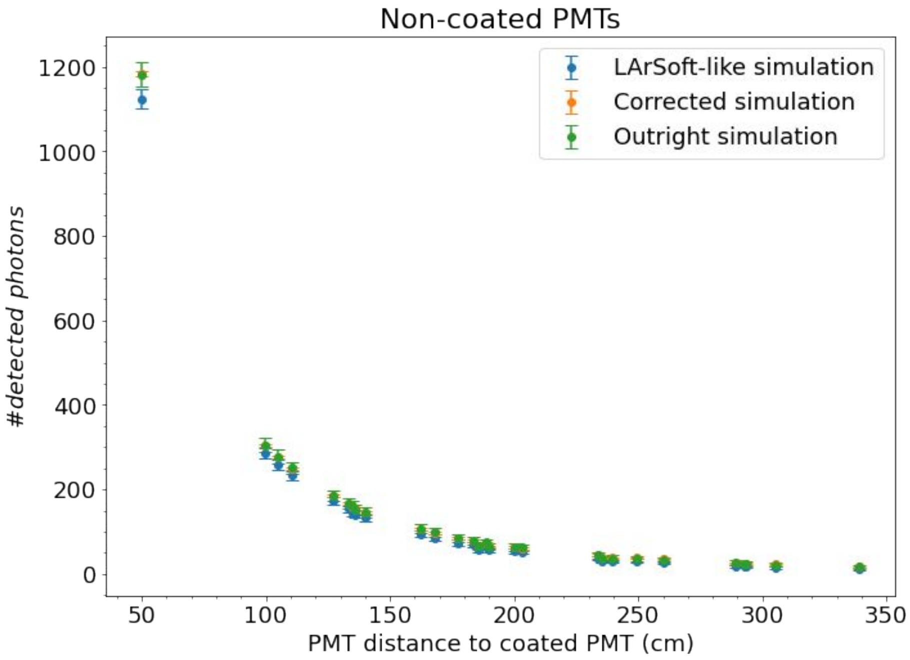


- Reminder: probability that a re-emission photon is detected by another PMT at a certain distance.
- Find a fitting function that we can use to parameterize this effect.

Results

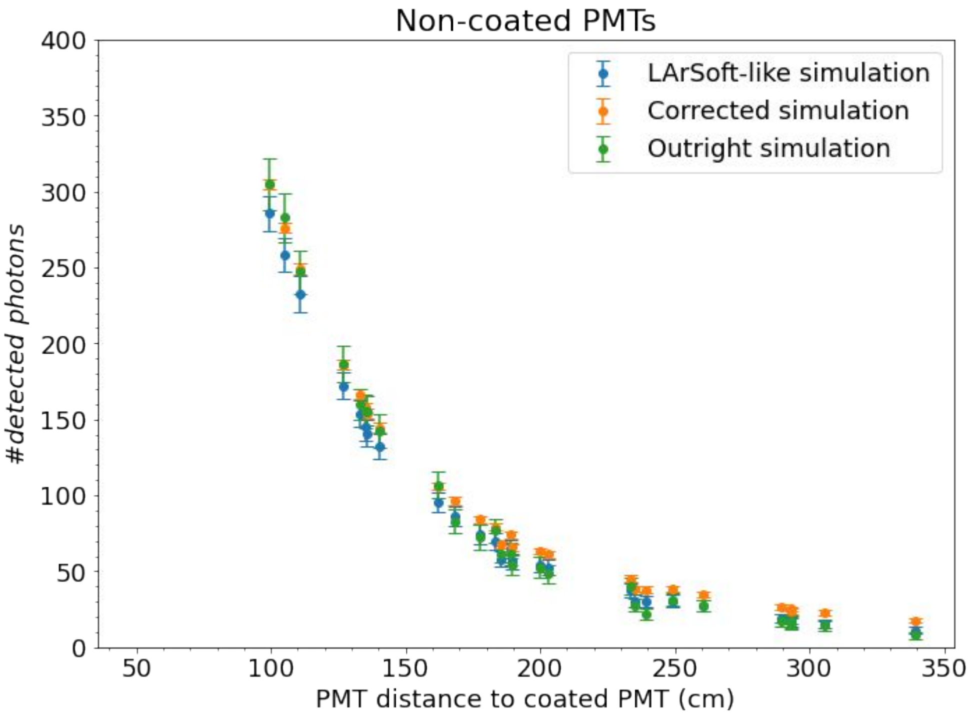
- Evaluate performance of each simulation with our toy model.
- Simulation without coated PMTs
  - Compute the number of photons as received photons/2 (as is done in LArSoft).
  - Compute the number of photons as received photons/2 and apply the previous correction for each PMT.
- Simulation with one coated PMT in the center.

Results



- Similar results for three cases.
- As expected less photons for the LArSoft-like simulation.
- How well is the correction doing?

Results



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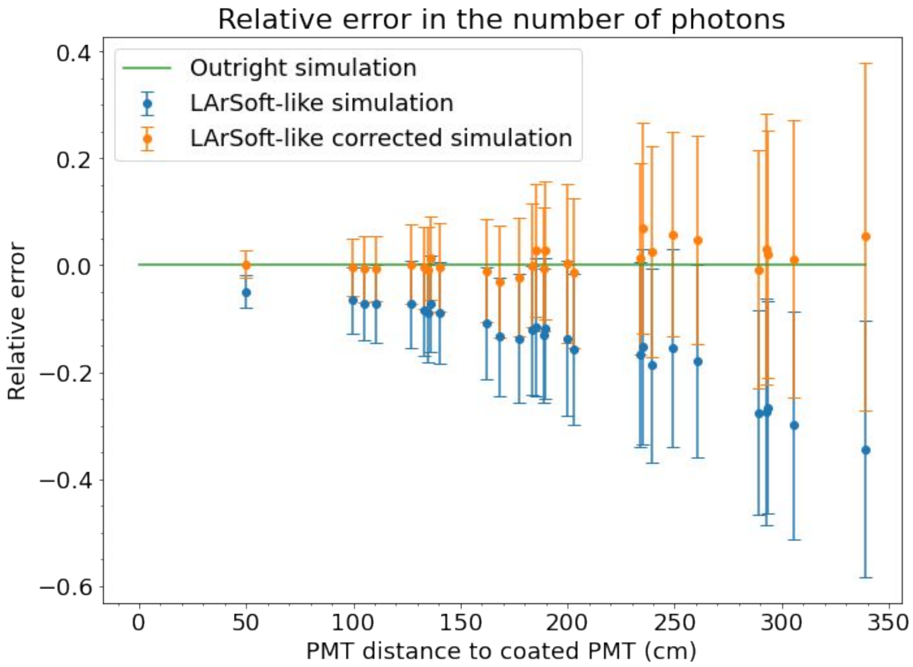
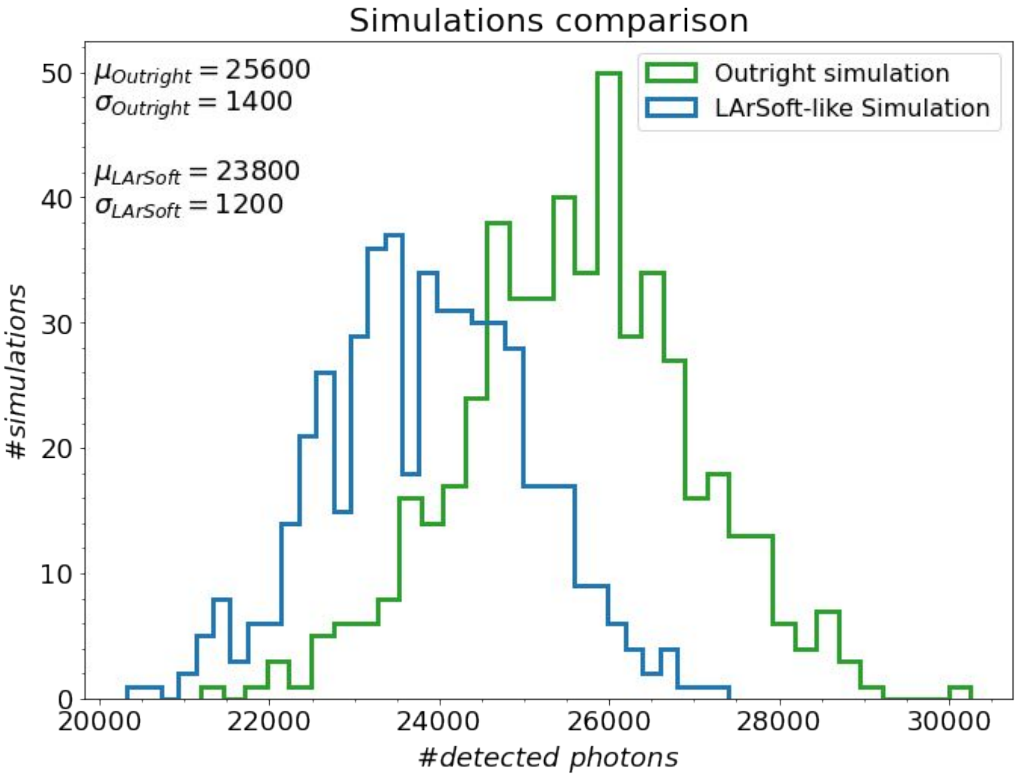


- Relative error <10% for corrected simulation at any distance.
- LArSoft-like simulation has a larger relative error for larger distances.
- For distances >230 cm we find <35 photons for each PMT.

Complete SBND geometry

- This was for a single coated PMT in the center of the geometry.
- Now try with the outright SBND coated-uncoated PMT geometry.
- Start by simply comparing the number of events for LArSoft-like simulation and the outright simulation.
- Shoot fifty 1.2 MeV electrons randomly distributed through the active volume. Repeat the same simulation 500 times for both configurations.

Results



- Histogram of the number of photons per run.
- Similar distribution for both configurations.

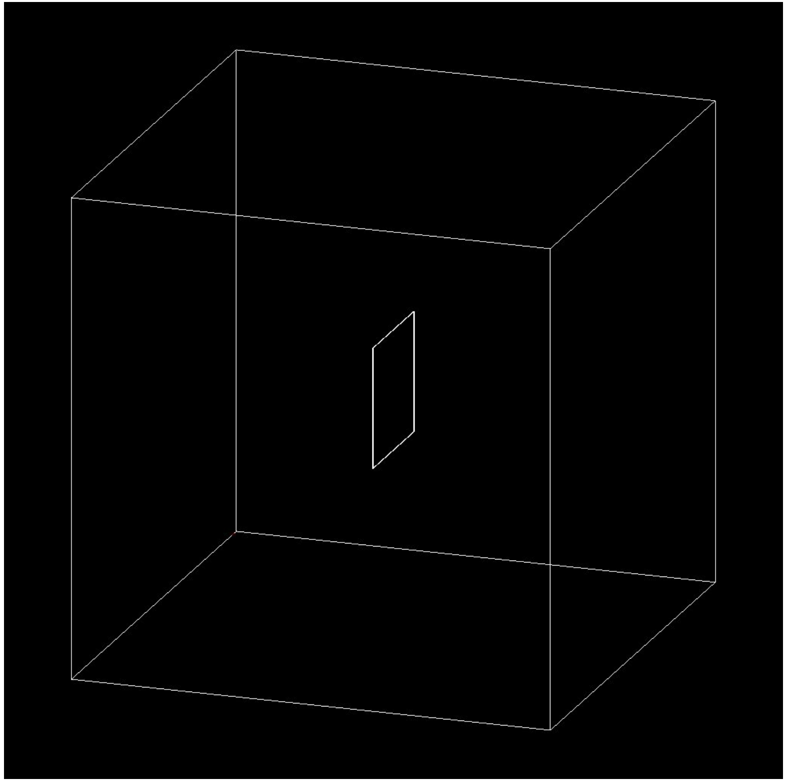
In parallel

gain lowers in cold. All in all we estimate that the efficiency of one PMT for a direct incident VUV photon is:

$$\text{Eff-PMT}^{\text{VUV}}_{\text{coated}} = 0.25|_{\text{QE}} \times 0.5|_{\text{FW}} \times 0.65|_{\text{TPB @ } \theta > 0^\circ} \times 0.75|_{\text{relative}} \approx 6\%. \tag{3.1}$$

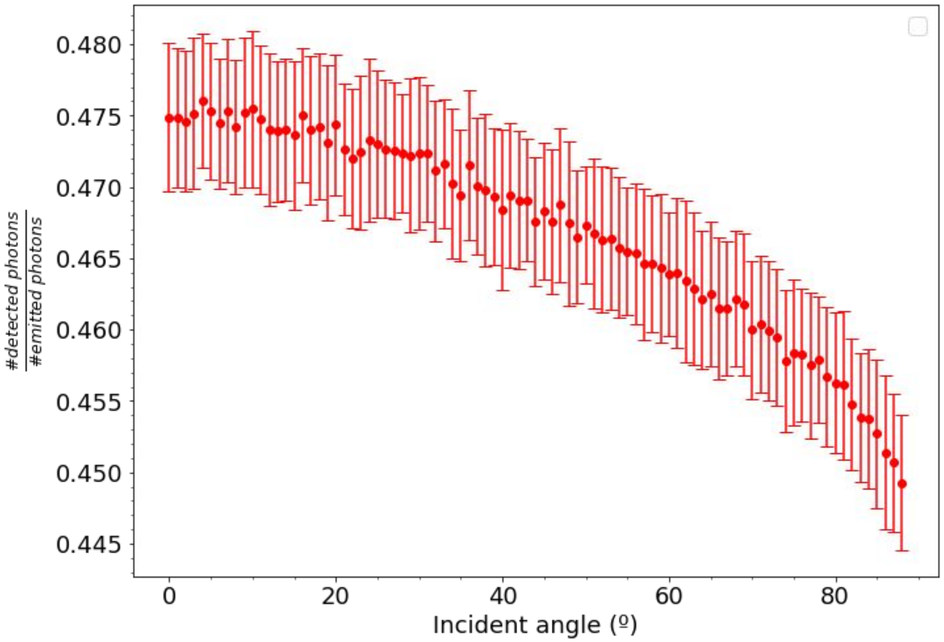
- Does the detection efficiency of the TPB depends on the incidence angle?

Simulation



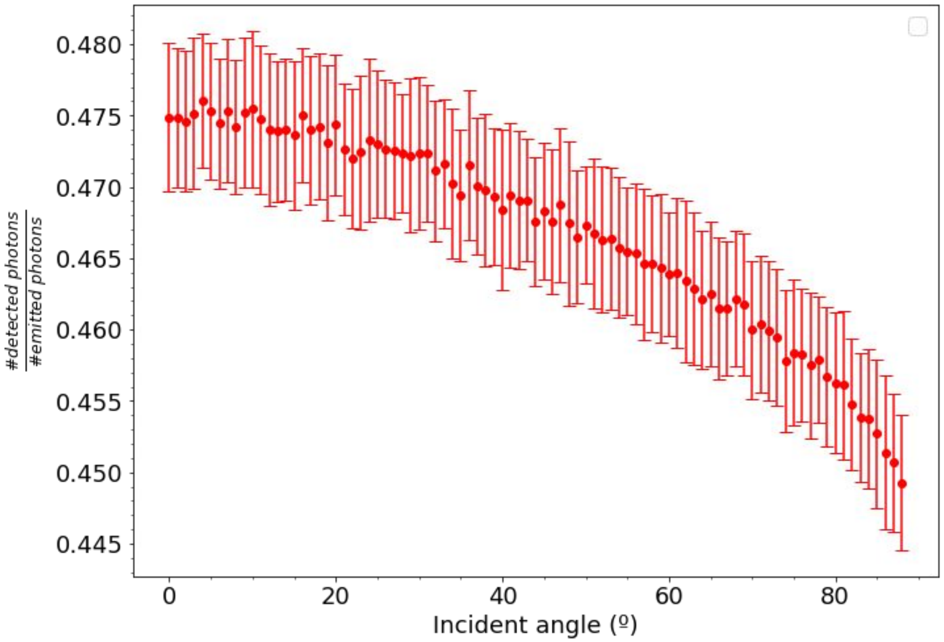
- One squared slab of TPB.
- Start with same thickness as SBND PMTs (0.00191 mm).
- Absorption spectrum from [S.E. Wallace-Williams et al., J. Phys. Chem. 98, 60–67 (1994)].
- Emission spectrum form [1709.05002].

Simulation



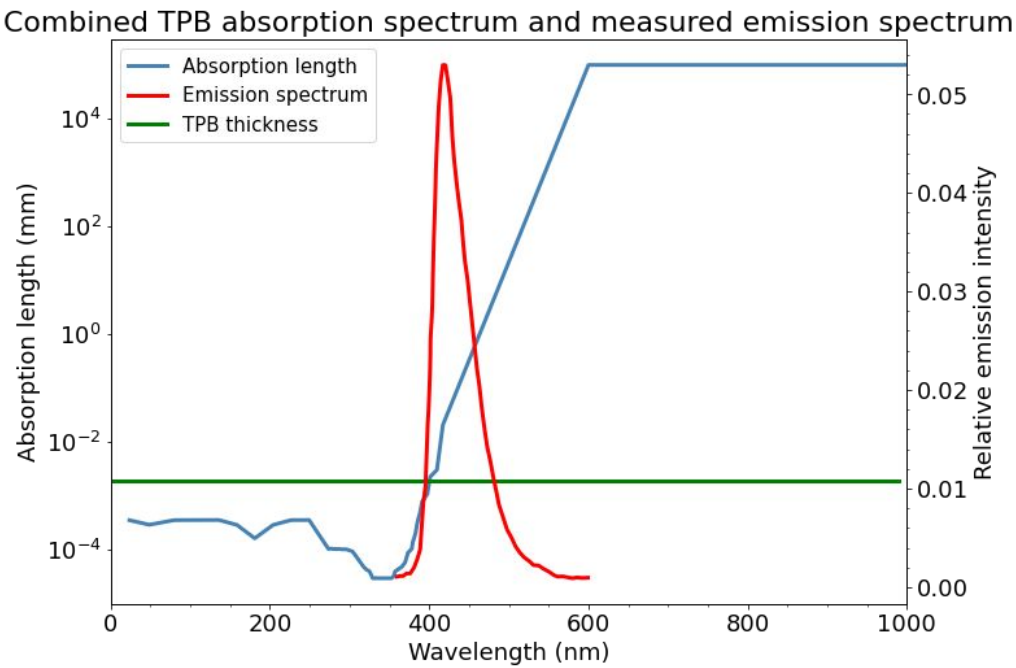
- Shoot 10000 photons with an incident angle, from 0º to 89º.
- Reach only half width of the slab to avoid boundary effects.
- Repeat the simulation for each angle 100 times

Simulation



- Re-emitted (visible) photons for larger angles have to go through the TPB slab again and might be reabsorbed.
- Recall: with the new absorption spectrum TPB is not transparent to visible photons.

Simulation



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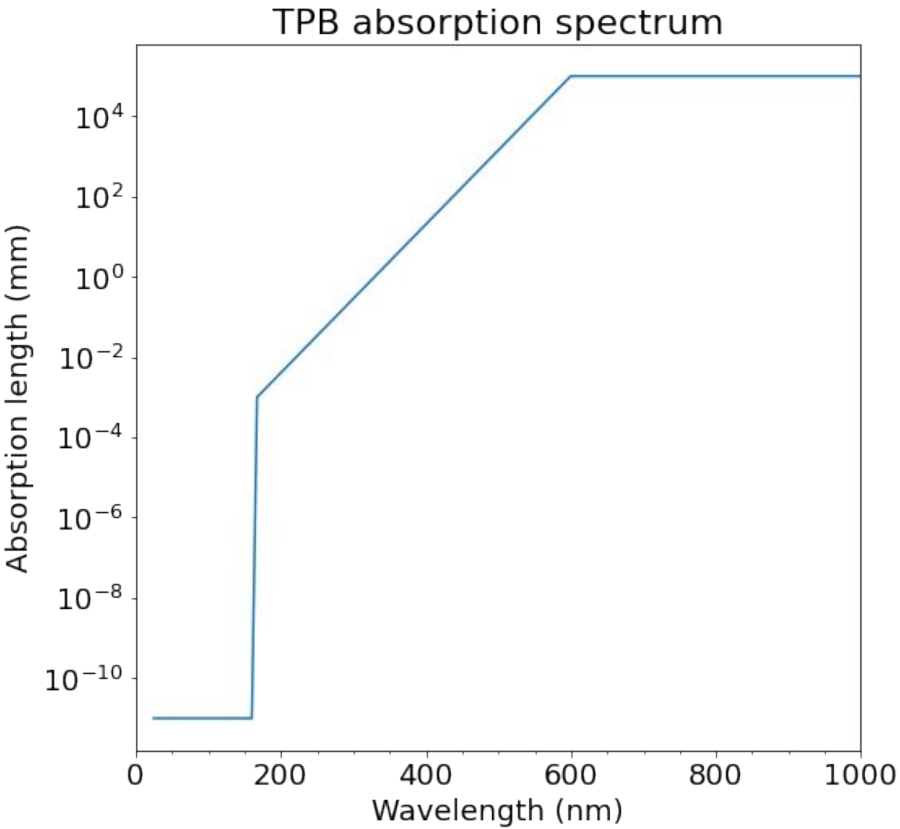
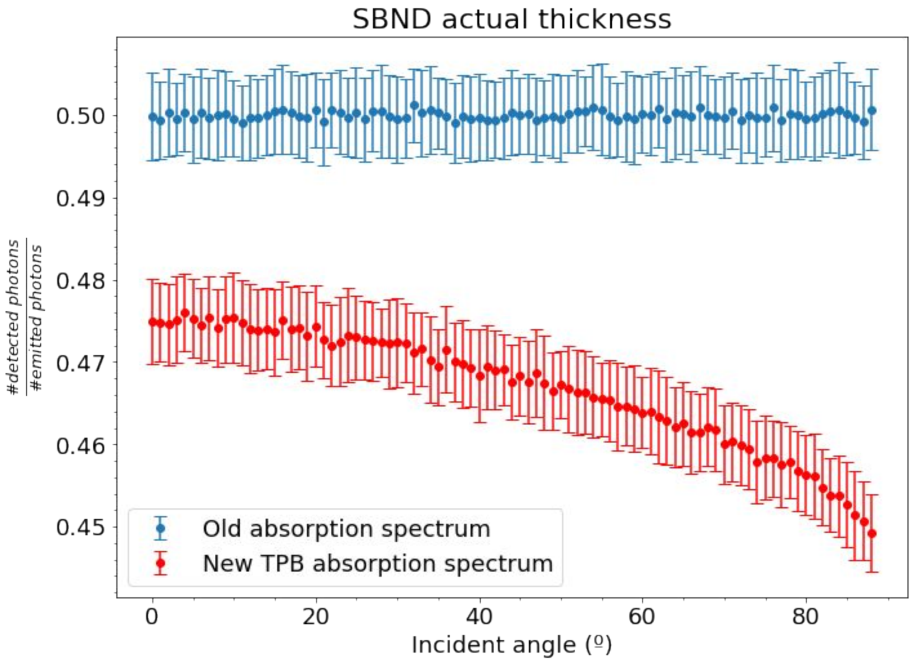


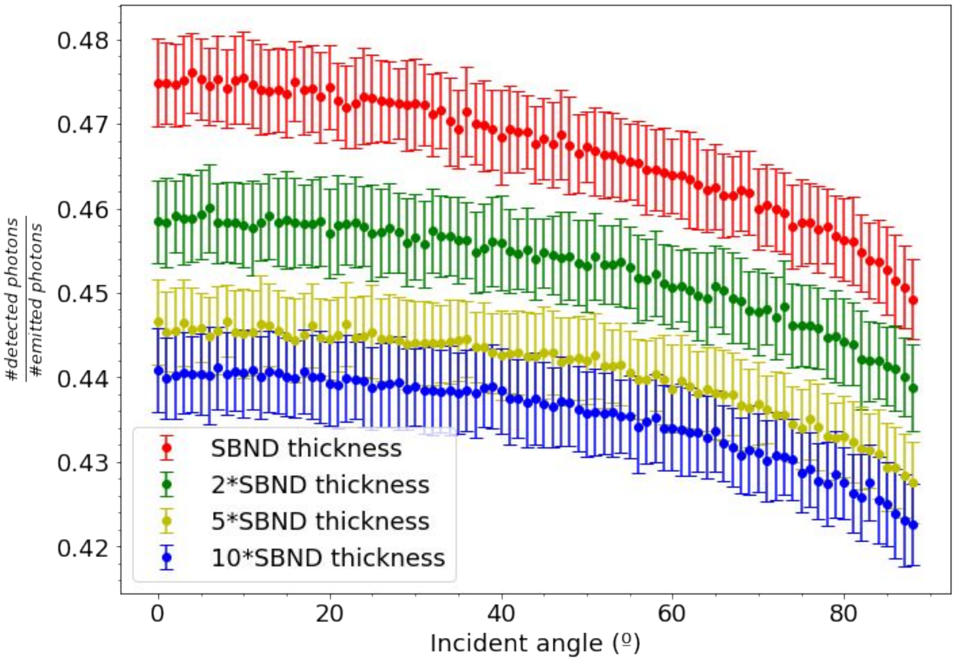
- This was not an issue for the previous absorption spectrum.

Simulation



- Indeed, there is no angle dependency for previous absorption spectrum.

Simulation



- Angle dependence shows up regardless of the thickness.
- As long as the thickness allows to have VIS re-absorption there will be angle dependence.

Next Steps

- This effect strongly depends on the refractive index of TPB (not considered in our simulation) as well as on the geometry.
- Implement the actual PMT geometry instead of a squared slab.
- Try with different refractive indices and see how the efficiency changes.

Lab work

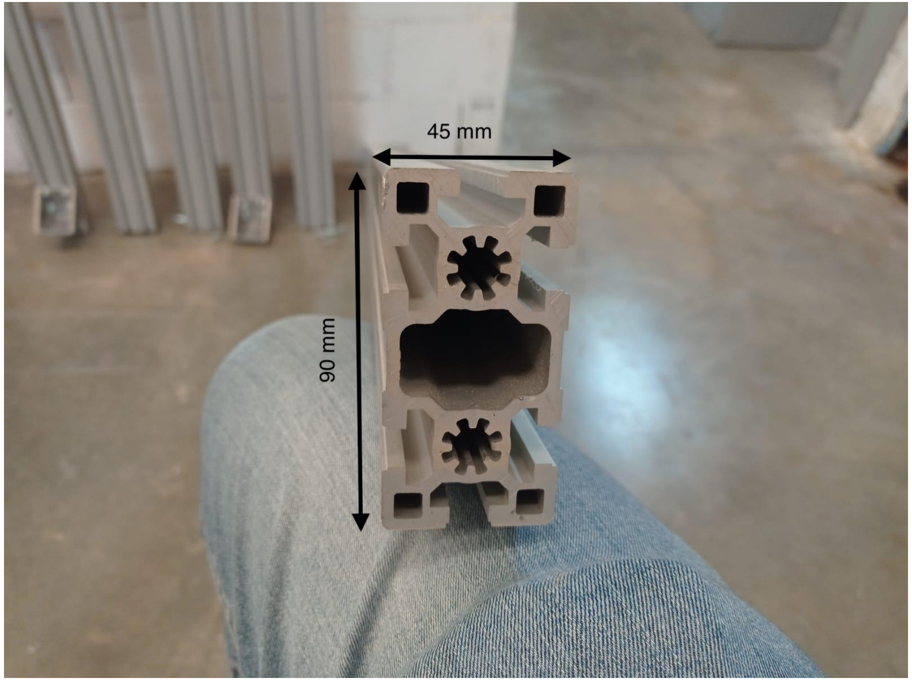
- Replicate the structure of the set-up for massive test in the italian labs.

Lab work

- Current inventory

- Six aluminium profiles:
  - 2310mmx90mmx45mm: 2
  - 2000mmx90mmx45mm: 4

Lab work



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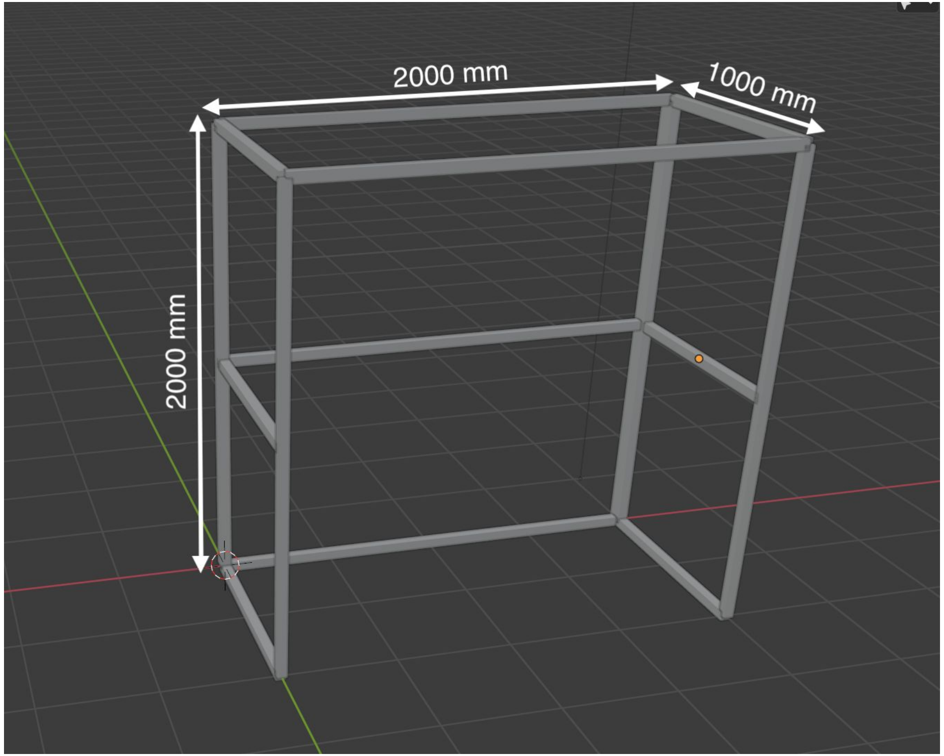
Lab work



- Envisioned structure
- Need:
  - 1000mmx45mmx45mm: 6
  - 2000mmx45mmx45mm: 4
- Screws, T-nuts and corners.

Lab work

Aluminio Plateado, perfil de 45 x 45 mm x 1000mm de longitud
Nº ref. fabric.: 3842992425/1000
Fabricante: Bosch Rexroth
ENVÍO 3-4 DÍAS
Requiere transporte especial
17 Entrega en 24 horas
93 Disponible para entrega en 2
1
unidades
Añadir
Disponibilidad de stock
Precio Unidad
36,95 €
(exc. IVA)
unidades
1 - 4
3D
La imagen representada puede no ser la del producto

Aluminio Plateado, perfil de 45 x 45 mm x 2000mm de longitud
Nº ref. fabric.: 3842992425/2000
Fabricante: Bosch Rexroth
122 Disponible para entre
día(s) laborable(s).
1
unidades
Añadir
Disponibilidad de stock
Precio Unidad
63,39 €
(exc. IVA)
unidades
1 - 4
La imagen representada puede no ser la del producto