Commissioning of protoDUNE DP
PEN/TPB studies

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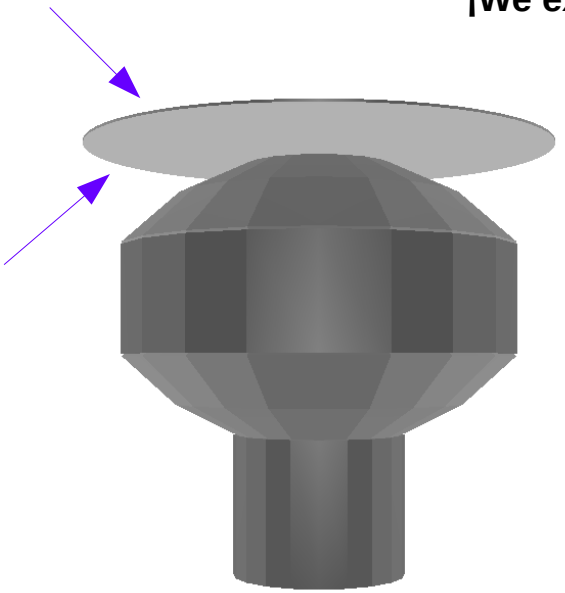
DPPD consortium
12th November 2019

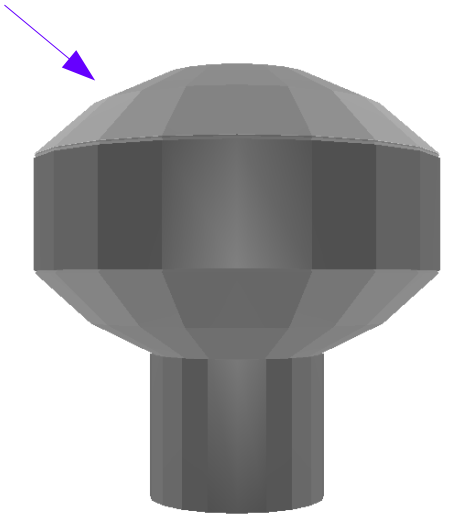
PEN/TPB WLS systems comparison

- PEN Foil
  - Light arrives to the foil.
- TPB Coating:
  - Light arrives to the coating.

Coating has a smaller active surface than foil.

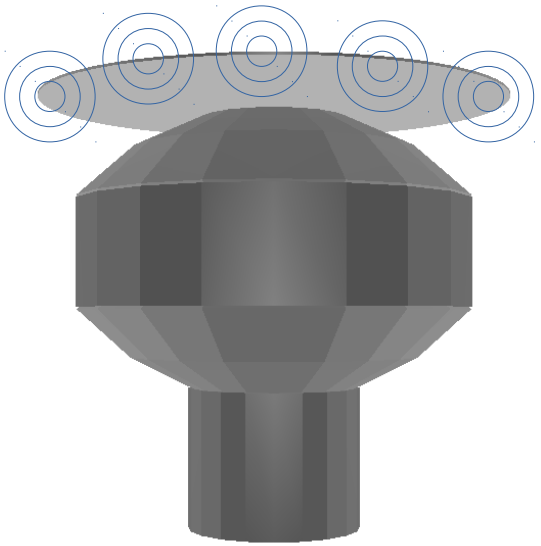
¡We expect more light arriving to the foil!

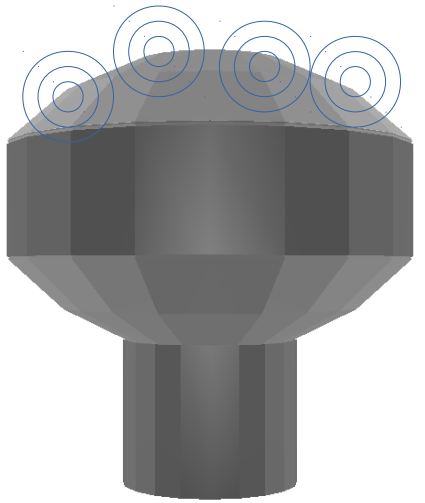




PEN/TPB WLS systems comparison

- PEN Foil
  - Light arrives to the foil.
  - Re-emission efficiency not known (**smaller than TPB**).
- TPB Coating:
  - Light arrives to the coating (**smaller active surface than foil**).
  - ~100% re-emission efficiency.

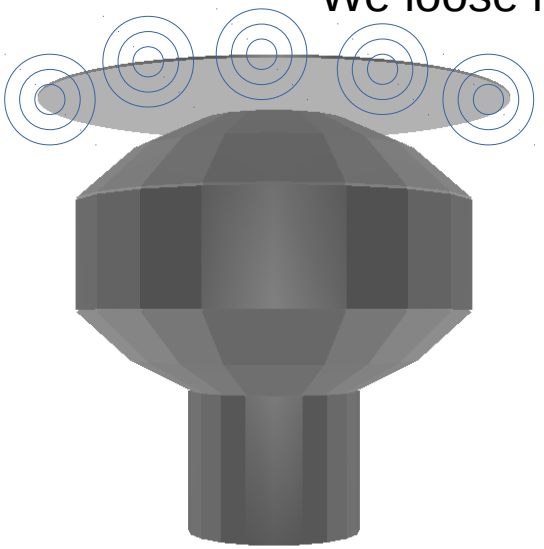


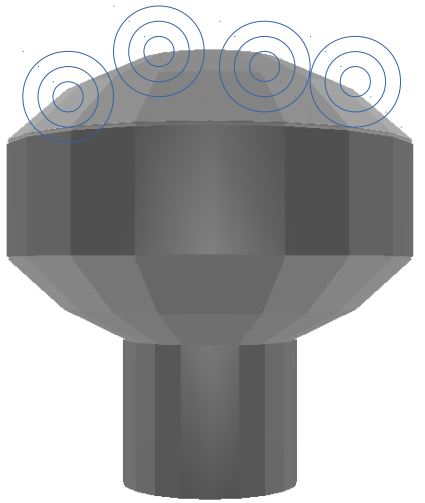


PEN/TPB WLS systems comparison

- PEN Foil
  - Light arrives to the foil.
  - Re-emission efficiency not known (**smaller than TPB**).
  - Geometrical looses PEN-PC (**larger**).
- TPB Coating:
  - Light arrives to the coating (**smaller active surface than foil**).
  - ~100% re-emission efficiency.
  - Geometrical looses Foil-PC.

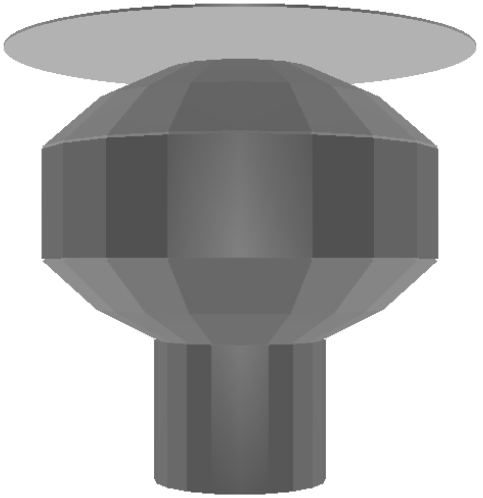
Light is re-emitted isotropically, and some arrives to the photocathode.
We loose more light in the foil w.r.t the coating.

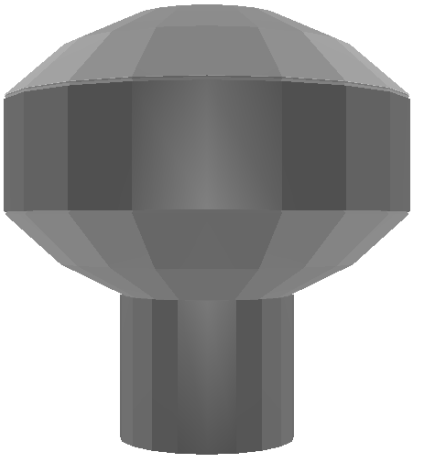




PEN/TPB WLS systems comparison

- PEN Foil
  - Light arrives to the foil.
  - Re-emission efficiency not known (**smaller than TPB**).
  - Geometrical looses PEN-PC (**larger**).
  - QE=0.2
- TPB Coating:
  - Light arrives to the coating (**smaller active surface than foil**).
  - ~100% re-emission efficiency.
  - Geometrical looses Foil-PC.
  - QE=0.2





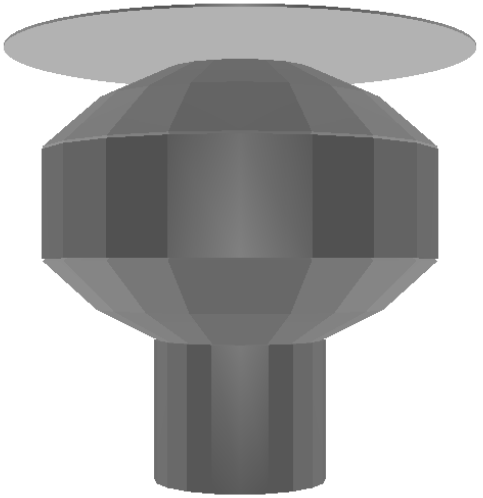
PEN/TPB WLS systems comparison

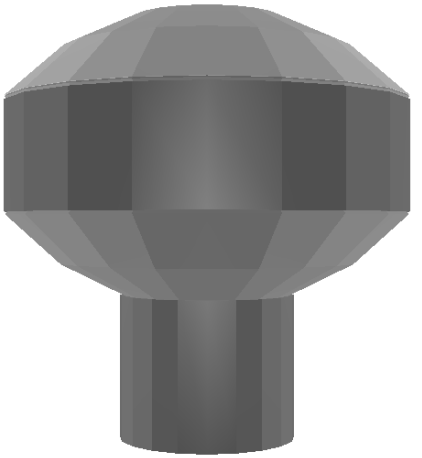
- PEN Foil
  - Light arrives to the foil. γ_{Foil}
  - Re-emission efficiency not known. ε_{PEN}
  - Geometrical looses Foil-PC. $\Delta_{Foil\text{-}PC}$
  - QE=0.2

$\#PE_{PEN\text{-}FOIL} = \gamma_{Foil}\ \varepsilon_{PEN}\ \Delta_{PEN\text{-}PC}\ QE$

- TPB Coating:
  - Light arrives to the coating (**smaller active surface than foil**). γ_{coat}
  - ~100% re-emission efficiency. ε_{TPB}
  - Geometrical looses Coating-PC. $\Delta_{coat\text{-}PC}$
  - QE=0.2

$\#PE_{TPB\text{-}coat} = \gamma_{coat}\ \varepsilon_{TPB}\ \Delta_{coat\text{-}PC}\ QE$





PEN/TPB WLS systems comparison

- PEN Foil
  - Light arrives to the foil. γ_{Foil}
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$\#PE_{PEN\text{-}FOIL} = \gamma_{Foil}\ \varepsilon_{PEN}\ \Delta_{PEN\text{-}PC}\ QE$

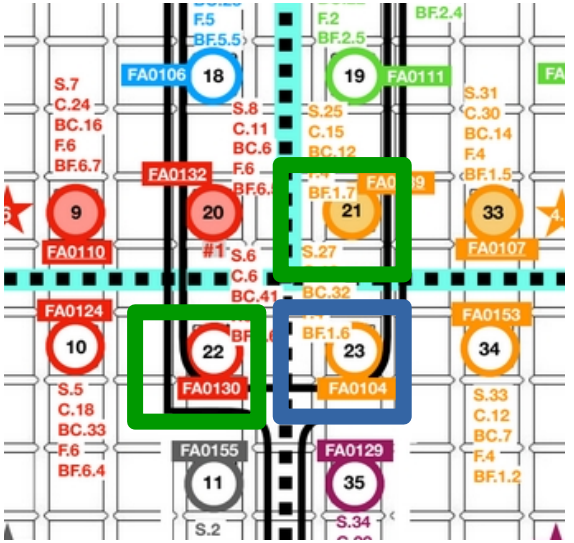
- TPB Coating:
  - Light arrives to the coating (**smaller active surface than foil**). γ_{coat}
  - ~100% re-emission efficiency. ε_{TPB}
  - Geometrical looses Coating-PC. $\Delta_{coat\text{-}PC}$
  - QE=0.2

$\#PE_{TPB\text{-}coat} = \gamma_{coat}\ \varepsilon_{TPB}\ \Delta_{coat\text{-}PC}\ QE$

How do we obtain ε_{PEN}?

- $\#PE_{PEN\text{-}Foil}$ / $\#PE_{TPB\text{-}coat}$ can be obtained from data.
- γ_{Foil} / γ_{coat} and $\Delta_{PEN\text{-}PC}$ can be simulated.
- $\#PE_{TPB\text{-}coat}$ / γ_{coat} = $\varepsilon_{TPB}\ \Delta_{coat\text{-}PC}\ QE$ = 0.12 . It has been already measured experimentally in Pavía.

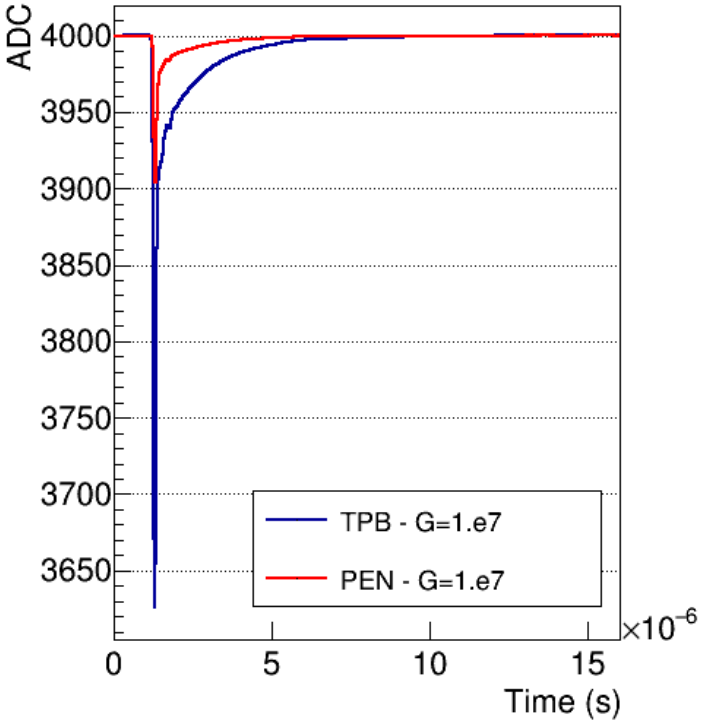
$\#PE_{PEN\text{-}Foil}$ / $\#PEN_{TPB\text{-}coat}$

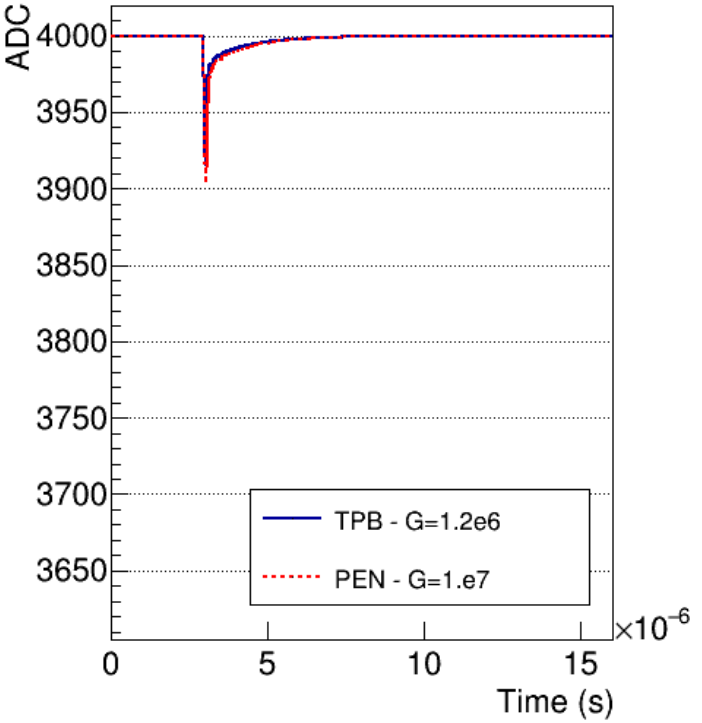


Triggering on channel 23.
Comparing channel 21 (TPB) w.r.t channel 22 (PEN), all placed at the centre of the detector.

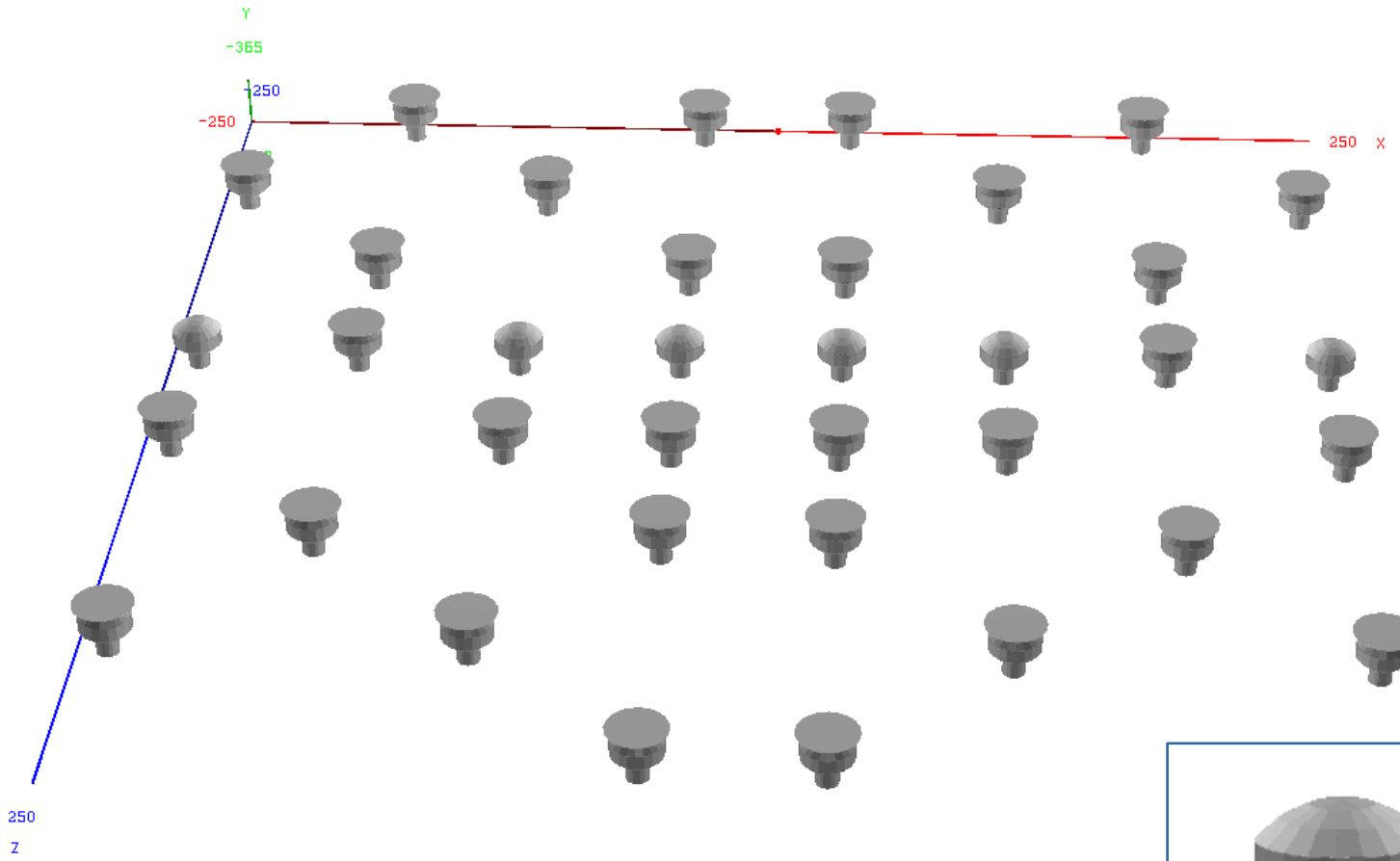
- Due to the symmetry of the PMT positions, if we consider that the cosmics arrive isotropically, both PEN & TPB PMTs should receive the same amount of light.

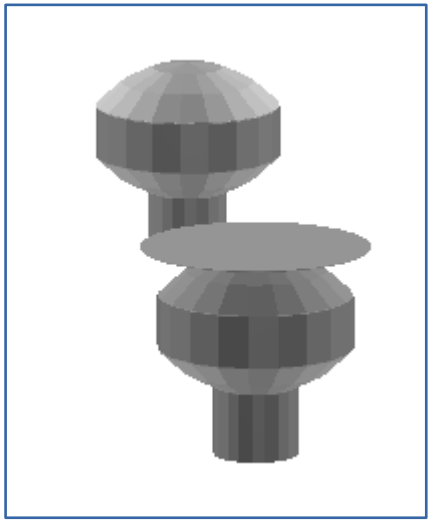
- TPB PMT provides a larger signal w.r.t PEN PMT when both operate at the same gain.
- Both responses are equalized when G_{PEN}/G_{TPB} = 12%





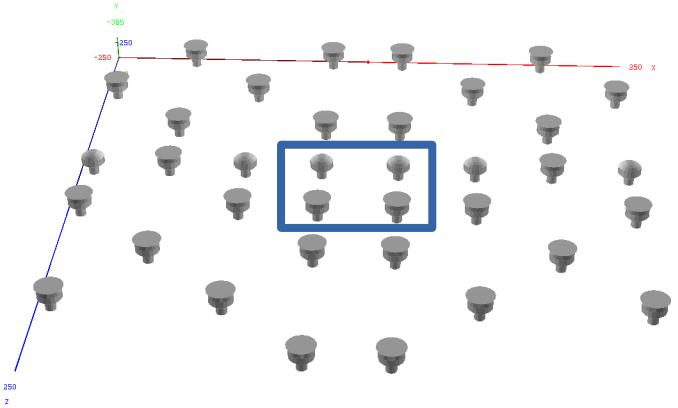
$\#PE_{PEN\text{-}Foil}$ / #/$PEN_{TPB\text{-}coat}$ = 12%





Monte Carlo simulation as is now

Photons are tracked until they reach a surface where they are killed → Al, Stainless steel, PEN plate, TPB coating, PMT crystal.
Detection from the plate/coating towards the cathode is not simulated.

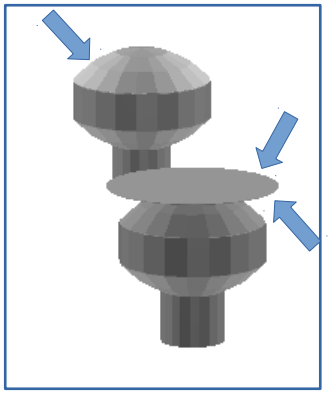


Computing γ_{Foil} / γ_{coat}

- 25M photons are generated **uniformly within the cryostat** (assuming cosmics are crossing uniformly in the LAr) → Including all LAr below the TPC active volume, and below the PMTs.
- We focus on the # of photons arriving to the 4 PMTs at the center → **<u>They should not have other geometrical effects operating due to the symmetry of their positions within the detector.</u>**

Geant4 Photon propagation

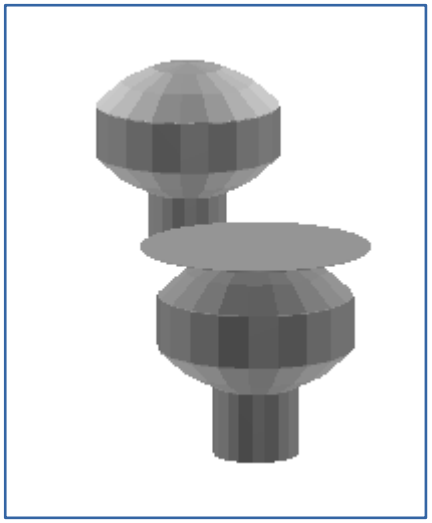
	# photons generated	# photons at the WLS (plate/coating)
PEN Foil 14	25M	**2158**
TPB Coat 15	25M	1525
PEN Foil 20	25M	**2098**
TPB Coat 21	25M	1482

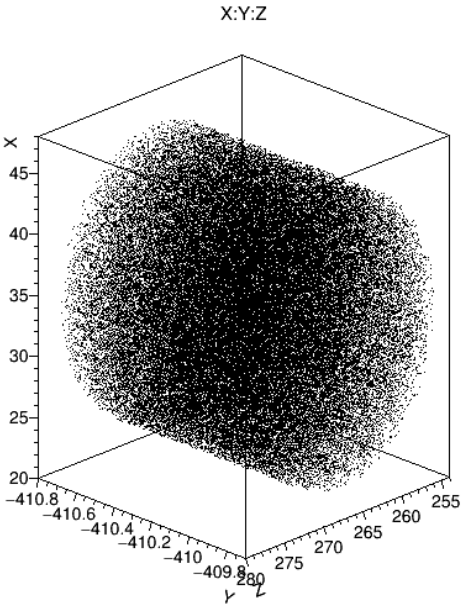


γ_{coat} / γ_{foil} = 70.56%

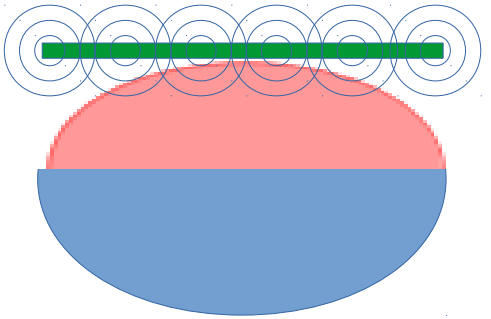
Comments:
- **Foils** do receive more direct light than **coating** (42% more):
  - → Foils do have more active surface exposed to LAr than the TPB coating.
  - → BUT! This number refers to the number of photons arriving to the WLS, not to the PMT.

Computing Δ_{PEN-PC}:

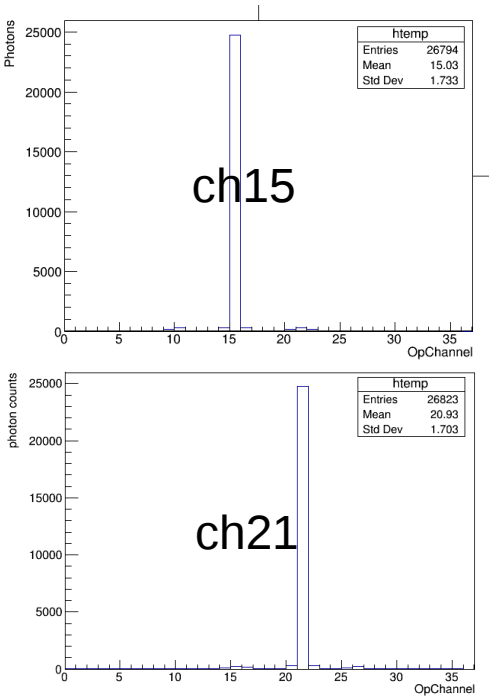




Above: Initial position of simulated photons (within the PEN-Foil geometry).



*Not at scale



Above: # arrival photons per channel. Photons simulated above channel 15 (top), 21 (bottom).

How many photons emmited by the PEN foil (green zone) do arrive to the PMT surface /PhotoCathode (red zone)?
To simulate this, I use TPB coated PMTs (the active volume is in the glass), and generate photons in the position where the PEN foil would be placed.

1e5 photons generated on top of LArSoftChannel 15 (PEN-like)
24753 photons arrive to the red area of the pmt.
Geometry factor: 24.75±0.16%

1e5 photons generated on top of LArSoftChannel 21 (PEN-like)
24738 photons arrive to the red area of the pmt.
Geometry factor: 24.74±0.16%

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- PEN Foil
  - Light arrives to the foil. γ_{Foil}
  - Re-emission efficiency not known. ε_{PEN}
  - Geometrical looses Foil-PC. $\Delta_{Foil\text{-}PC}$
  - QE=0.2

$$\#PE_{PEN\text{-}FOIL} = \gamma_{Foil}\ \varepsilon_{PEN}\ \Delta_{PEN\text{-}PC}\ QE$$

- TPB Coating:
  - Light arrives to the coating (**smaller active surface than foil**). γ_{coat}
  - ~100% re-emission efficiency. ε_{TPB}
  - Geometrical looses Coating-PC. $\Delta_{coat\text{-}PC}$
  - QE=0.2

$$\#PE_{TPB\text{-}coat} = \gamma_{coat}\ \varepsilon_{TPB}\ \Delta_{coat\text{-}PC}\ QE$$

$$\frac{\#PE_{TPB\text{-}coat}}{\#PE_{PEN\text{-}FOIL}} = \frac{\gamma_{coat}\ 0.12}{\gamma_{Foil}\ \varepsilon_{PEN}\ \Delta_{PEN\text{-}PC}\ QE}$$

How do we obtain ε_{PEN}?

- $\#PE_{PEN\text{-}Foil} / \#PE_{TPB\text{-}coat} \rightarrow 0.12$
- $\gamma_{coat} / \gamma_{Foil} \rightarrow 0.706$
- $\Delta_{PEN\text{-}PC} \rightarrow 0.247$
- $\#PE_{TPB\text{-}coat} / \gamma_{coat} = \varepsilon_{TPB}\ \Delta_{coat\text{-}PC}\ QE = 0.12$ (Pavía measurement)

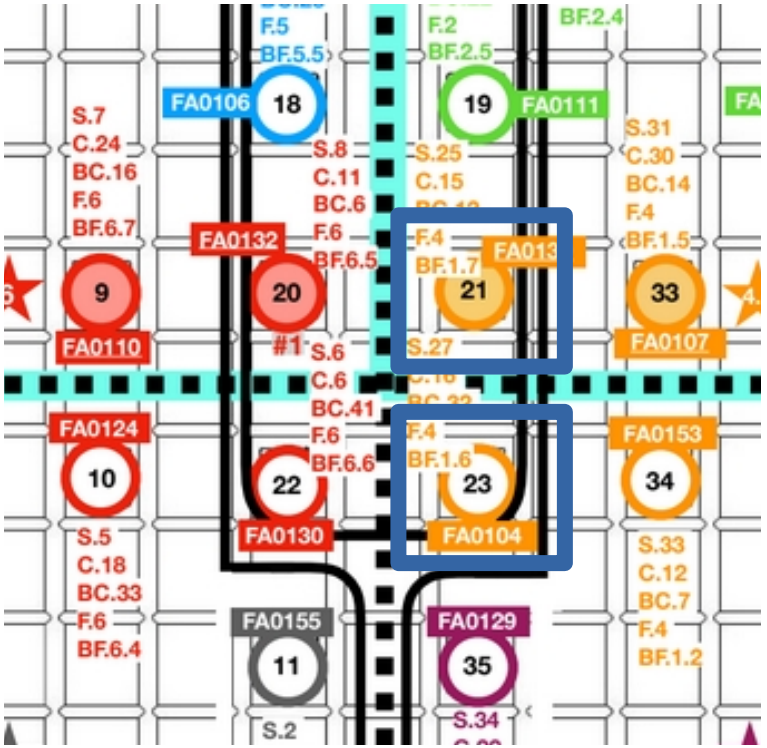
$$\varepsilon_{PEN} = \frac{0.12\ (\gamma_{coat} / \gamma_{Foil})\ (\#PE_{PEN\text{-}FOIL} / \#PE_{TPB\text{-}coat})}{\Delta_{PEN\text{-}PC}\ QE} = 20.6\%$$

Comments and next steps

- Effective response of the PEN-Foil system gives a ~12% of the amplitude w.r.t the TPB-coating.
- If we de-convolute the geometrical effect due to the foil, we obtain a PEN wavelength shifting efficiency of ~21%.
- Next steps:
  - Extend the analysis using all TPB PMTs (now only those placed in the center are used), and compute errors.
  - Are there non-linearity or photocathode saturation effects applying? Since both PMTs are receiving different amount of light, those can be affecting differently both PMTs, also when we tune the gain.
  - Is the WLS efficiency dependent on the amount of light received?

Backup

Run	Gain_PEN/ Gain_TPB	PMT trigger	Threshold
1474	0.12	21	5
1475	0.12	21	10
1476	0.12	21	20
1477	0.12	21	50
1478	0.12	23	5
1479	0.12	23	10
1480	0.12	23	20
1481	0.12	23	50
1483	0.14	21	5
1484	0.14	21	10
1485	0.14	21	20
1486	0.14	21	50
1487	0.14	23	5
1488	0.14	23	10
1489	0.14	23	20
1490	0.14	23	50
1491	0.16	21	5
1492	0.16	21	10
1542	0.16	21	20
1543	0.16	21	50
1544	0.16	23	5
1545	0.16	23	10
1546	0.16	23	20
1547	0.16	23	50



https://pddpelog.web.cern.ch/elisa/display/585

PEN gains are adjusted to be 1.e7.
TPB gains are adjusted to be 1.2e6/1.4e6/1.6e6

Trigger on ch 21TPB / 23PEN
Threshold scan: 5-10-20-50 ADC

				Saturated (%)		Average amplitude		
Run	Trigger channel	Pedestal of the trigger channel (ADC)	Gain	ch21 TPB	Ch23 PEN	21 TPB	23 PEN	**Ratio PEN/TPB**
1474	21 TPB	5	0.12	0.0%	0.1%	67.3	68.8	**1.02**
1475	21 TPB	10	0.12	0.0%	0.1%	92.7	93.0	**1.00**
1476	21 TPB	20	0.12	0.0%	0.1%	133.2	127.2	**0.95**
1477	21 TPB	50	0.12	0.0%	0.3%	233.3	212.0	**0.91**
1478	23 PEN	5	0.12	0.0%	0.0%	7.1	13.3	**1.87**
1479	23 PEN	10	0.12	0.0%	0.0%	37.4	44.8	**1.20**
1480	23 PEN	20	0.12	0.0%	0.1%	89.0	95.4	**1.07**
1481	23 PEN	50	0.12	0.0%	0.2%	166.0	174.3	**1.05**
1483	21 TPB	5	0.14	0.0%	0.1%	74.8	68.2	**0.91**
1484	21 TPB	10	0.14	0.0%	0.1%	100.1	86.5	**0.86**
1485	21 TPB	20	0.14	0.0%	0.1%	138.5	118.5	**0.86**
1486	21 TPB	50	0.14	0.0%	0.2%	242.1	195.6	**0.81**
1487	23 PEN	5	0.14	0.0%	0.0%	8.1	13.2	**1.63**
1488	23 PEN	10	0.14	0.0%	0.0%	41.2	43.9	**1.07**
1489	23 PEN	20	0.14	0.0%	0.1%	100.9	95.4	**0.94**
1490	23 PEN	50	0.14	0.0%	0.2%	193.6	173.9	**0.90**
1491	21 TPB	5	0.16	0.0%	0.1%	76.8	61.4	**0.80**
1492	21 TPB	10	0.16	0.0%	0.1%	105.4	83.3	**0.79**
1542	21 TPB	20	0.16	0.0%	0.1%	149.6	116.7	**0.78**
1543	21 TPB	50	0.16	0.0%	0.2%	255.7	184.4	**0.72**
1544	23PEN	5	0.16	0.0%	0.0%	4.5	9.9	**2.20**
1545	23PEN	10	0.16	0.0%	0.0%	32.0	33.0	**1.03**
1546	23PEN	20	0.16	0.0%	0.1%	107.1	94.2	**0.88**
1547	23PEN	50	0.16	0.0%	0.2%	202.9	168.2	**0.83**

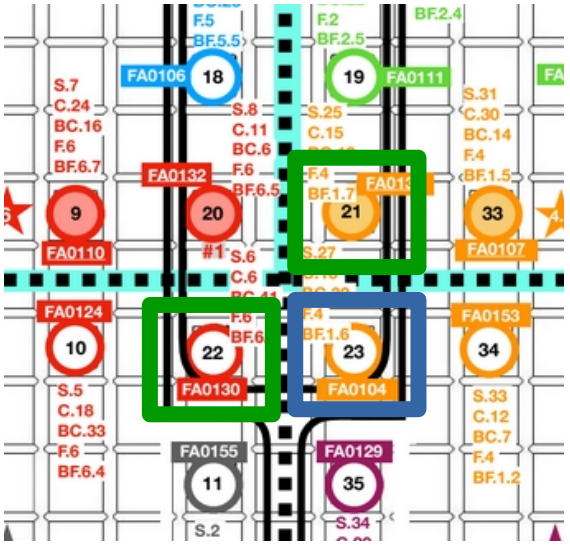
If we trigger on PEN, we are biased by the SPE amplitude close to the amplitude threshold.

Factor 0.12 seems to fit better

https://pddpelog.web.cern.ch/elisa/display/585

PEN gains are adjusted to be 1.e7.
TPB gains are adjusted to be 1.2e6/1.4e6/1.6e6

Trigger on ch 23 (PEN), comparing ch 21TPB / 22PEN
Threshold scan: 5-10-20-50 ADC

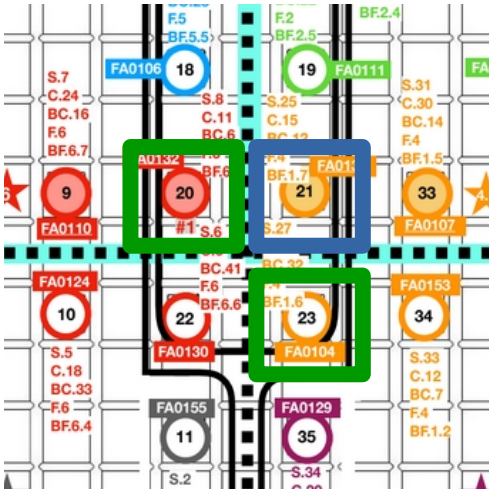


run	Threhold (ADC)	Ratio	Saturated		Average Amplitude (ADC)			PEN/TPB
			21 TPB	22 PEN	23 Trigger	21 TPB	22 PEN	
1478	5	0.12	0.0%	0.0%	13.3	7.1	7.7	**1.09**
1479	10	0.12	0.0%	0.0%	44.8	37.4	36.8	**0.98**
1480	20	0.12	0.0%	0.1%	95.4	89.0	87.0	**0.98**
1481	50	0.12	0.0%	0.2%	174.3	166.0	152.8	**0.92**
1487	5	0.14	0.0%	0.0%	13.2	8.1	7.5	**0.93**
1488	10	0.14	0.0%	0.0%	43.9	41.2	36.5	0.89
1489	20	0.14	0.0%	0.1%	95.4	100.9	86.3	0.85
1490	50	0.14	0.0%	0.2%	173.9	193.6	153.6	0.79
1544	5	0.16	0.0%	0.0%	9.9	4.5	4.1	**0.92**
1545	10	0.16	0.0%	0.0%	33.0	32.0	24.3	0.76
1546	20	0.16	0.0%	0.1%	94.2	107.1	82.4	0.77
1547	50	0.16	0.0%	0.1%	168.2	202.9	144.1	0.71

https://pddpelog.web.cern.ch/elisa/display/585

PEN gains are adjusted to be 1.e7.
TPB gains are adjusted to be 1.2e6/1.4e6/1.6e6

Trigger on ch 21TPB, comparing ch 20TPB / 23PEN
Threshold scan: 5-10-20-50 ADC



run	Minimum amplitude (ADC)	ratio	Saturated		Average Amplitude (ADC)			
			20 TPB	23 PEN	21 trigger	20 TPB	23 PEN	PEN/TPB
1474	5	0.12	0.0%	0.1%	67.3	69.1	68.8	**1.00**
1475	10	0.12	0.0%	0.1%	92.7	96.4	93.0	**0.96**
1476	20	0.12	0.0%	0.1%	133.2	136.7	127.2	**0.93**
1477	50	0.12	0.0%	0.3%	233.3	235.6	212.0	**0.90**
1483	5	0.14	0.0%	0.1%	74.8	74.4	68.2	**0.92**
1484	10	0.14	0.0%	0.1%	100.1	101.8	86.5	0.85
1485	20	0.14	0.0%	0.1%	138.5	141.0	118.5	0.84
1486	50	0.14	0.0%	0.2%	242.1	244.5	195.6	0.80
1491	5	0.16	0.0%	0.1%	76.8	77.2	61.4	0.80
1492	10	0.16	0.0%	0.1%	105.4	107.7	83.3	0.77
1542	20	0.16	0.0%	0.1%	149.6	153.7	116.7	0.76
1543	50	0.16	0.0%	0.2%	255.7	254.3	184.4	0.73