Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias (ICTEA)

Universidad de Oviedo

Design of Geomagnetic field compensation system for Hyper Kamiokande

Local Workshop on HyperK physics

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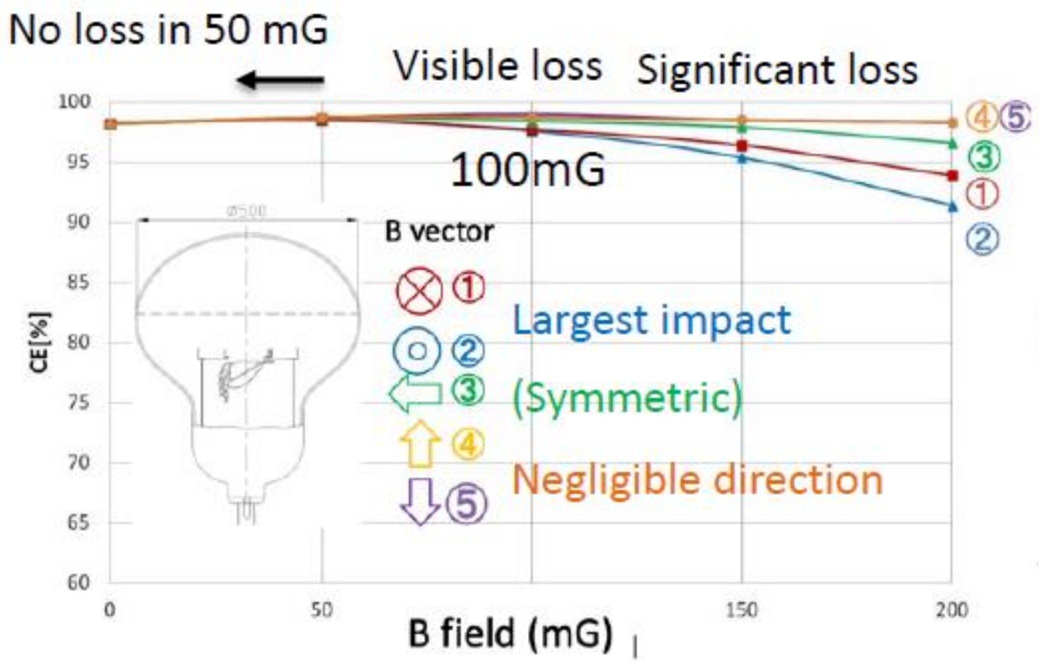
1. Problem Statement

Efficiency of Hyper-Kamiokande photomultipliers (PMTs) decreases by magnetic fields perpendicular to their axis.

- 100 mG in the perpendicular direction to the PMTs → Efficiency loss of 1%



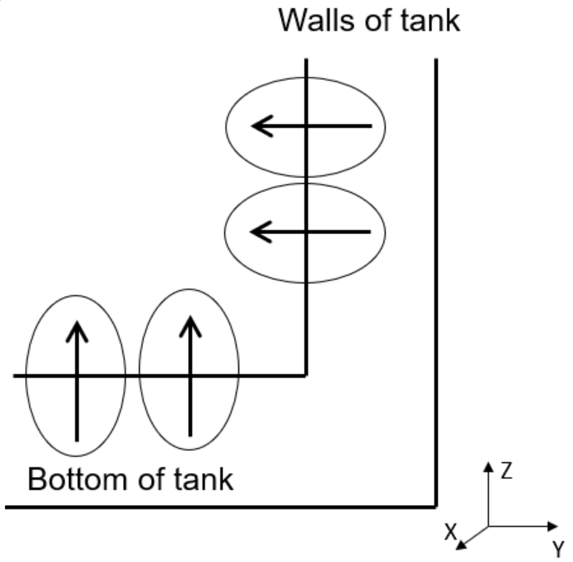
Problem: geomagnetic field on the location of Hyper-Kamiokande has a value of:

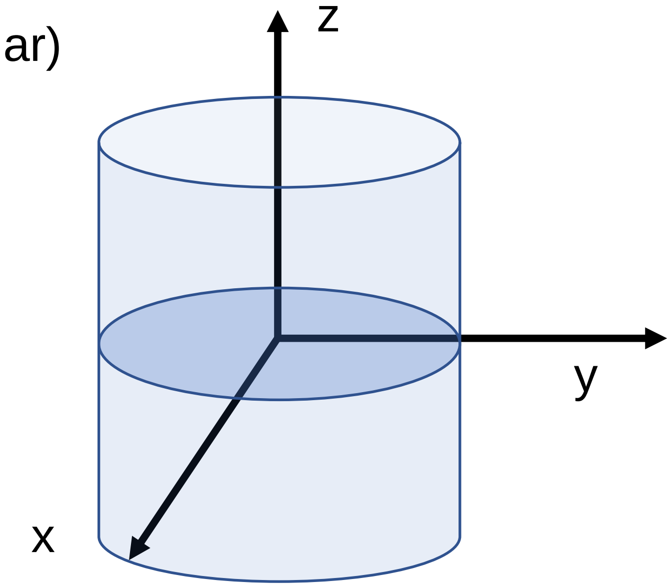
$$(B_x, B_y, B_z) = (0, 303, -366)\ \text{mG}$$

Goals: designing a compensation system of coils for the inner detector so that perpendicular magnetic field to the PMTs is lower than 100 mG for, at least, 99% of them. Average value of remanent perpendicular magnetic field is expected to be lower than 50 mG.

Calculation of magnetic field created by two types of coils (circular and rectangular)

Earth's Magnetic field: B_y=303mG; B_z= -366mG

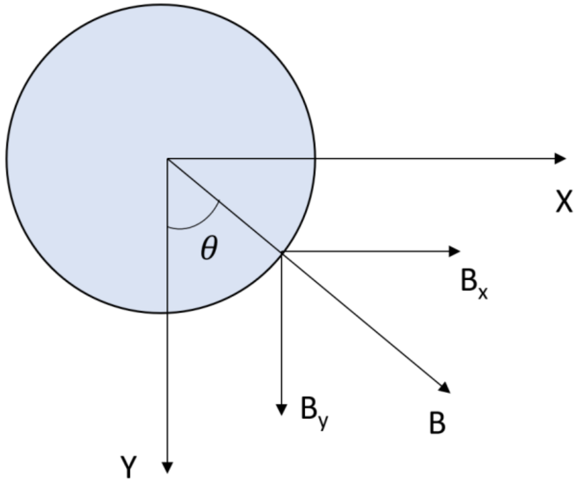




Calculation of ΔB_{perp} (mG)

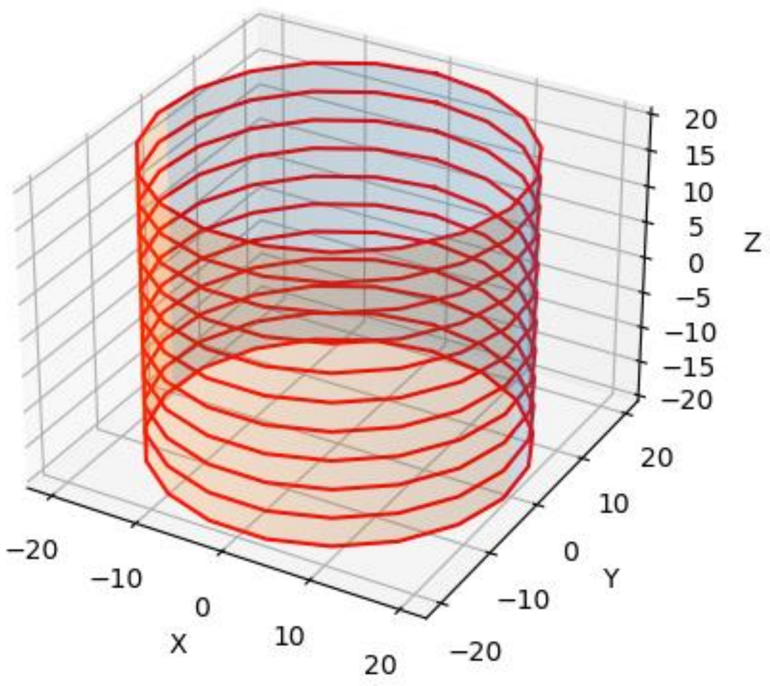
- in the barrel: $\Delta B_{perp} = \left[\left(B_x \sin\theta - B_y \cos\theta\right)^2 + B_z^2\right]^{1/2}$
- top and bottom lids: $\Delta B_{perp} = \left(B_x^2 + B_y^2\right)^{1/2}$

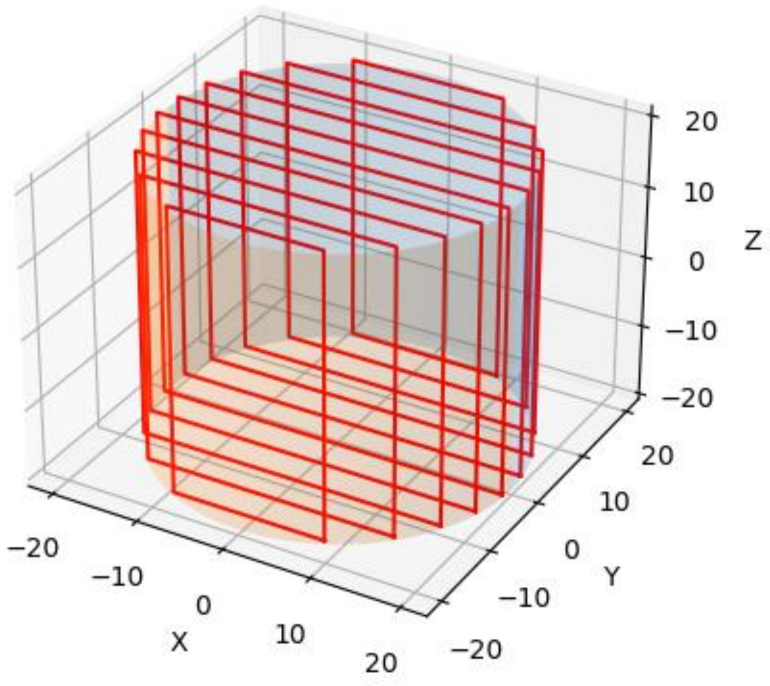
longitudinal direction of PMTs along z axis



3. Initial configuration

To compensate the geomagnetic field a coil-based system is designed. Coils are located at the inner surface of the tank





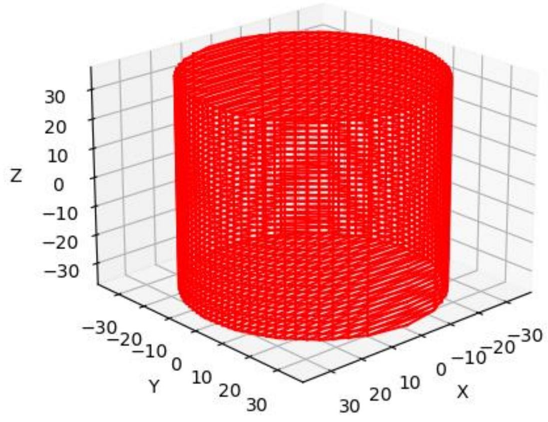
Circular coils centered in Z-axis compensate Bz component

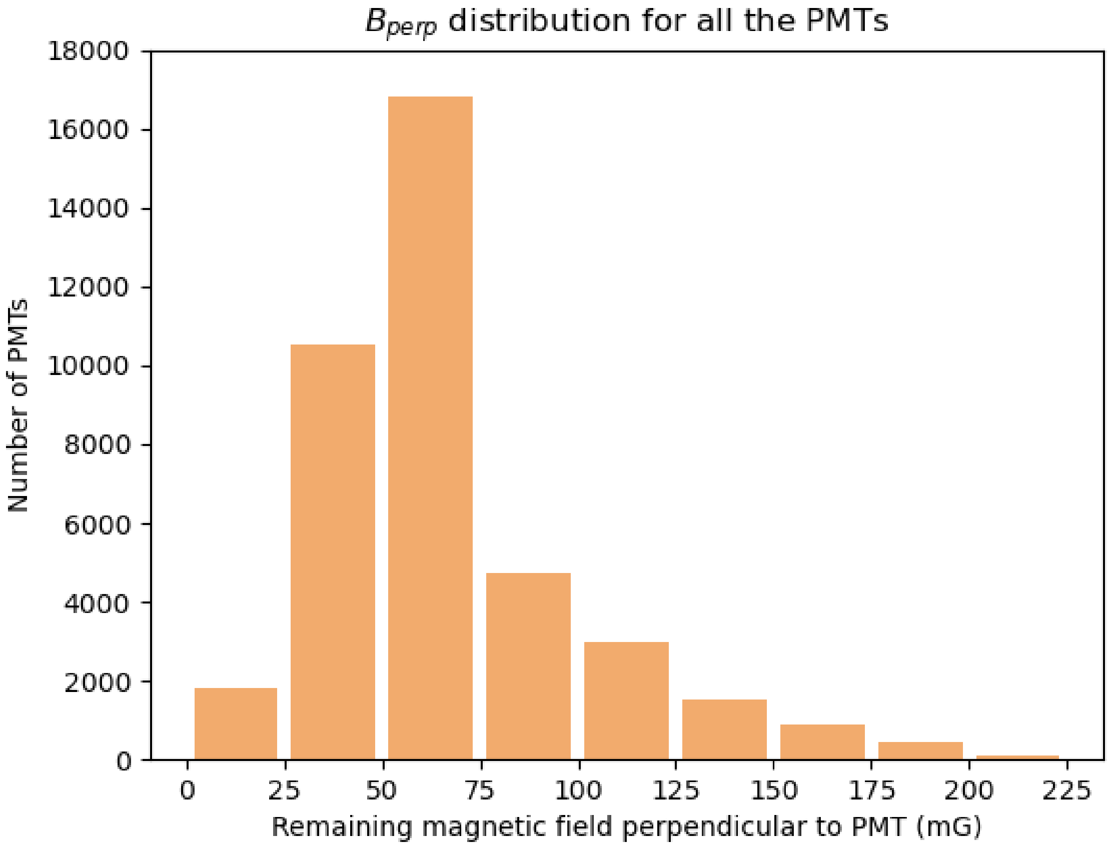
Rectangular coils centered in Y-axis compensate By component

3. Initial configuration

K. Abe, et al., Hyper-Kamiokande Design Report." arXiv:1805.04163v2

- 33 rectangular coils centered on Y axis separated 2 m (I_V = 62.50 A)
- 37 circular coils centered on Z axis separated 2 m (I_H = 75.87 A)





Average remanent perpendicular magnetic field: **68.06 mG**

- 2295 PMT on top above 100 mG (35.3%)
- 1097 PMTs on walls above 100 mG (4.06%)
- 2555 PMTs on bottom above 100 mG (39.3%)

5947 PMTs above 100 mG in the whole ID

14.93%

4. Genetic algorithm

To reduce the number of PMTs affected, we will be using a genetic algorithm, which can converge to one or more possible optimal configurations.

Genetic algorithm: programming technique used for the optimization of non-linear multivariate problems.

- Drawback: major computational cost and execution time. One run can take a few days for this specific simulation

Fitting function: our previous programm. It calculates the number of PMTs below 100 mG, the number we want to maximize

Genes: parameters to optimize. Intensity of current, number of coils, radius of coils…

Chromosome: set of all genes

→ Through selection, combination and mutations of genes, the algorithm converges to a optimal solution

5. Improved configuration

Circular horizontal coils (I_H= 75.87 A):

At z=+36.5 m,

n=2 loops, one with R_1=20 m and one with R_2=27m

n=6 loops with R=34 m

At z=-35.5 m,

n = 3 loops with R_1=27 m

n = 2 loops with R_2=20 m

n=3 loops with R=34 m

Coils at z = 34.5m and z = 32.5 m are removed

At z = 29.5 m, R = 34 m and I_H = 70 A

At z = -31.5 m, R = 34 m and I_H = 65 A

The rest of coils are separated 2m

Saving of 257.61 m of wire with this configuration and intensity of current is reduced for two coils. In contrast, intensity of current is highly increased for the two vertical coils of the extremes.

Rectangular vertical coils (I_V=62,5 A):

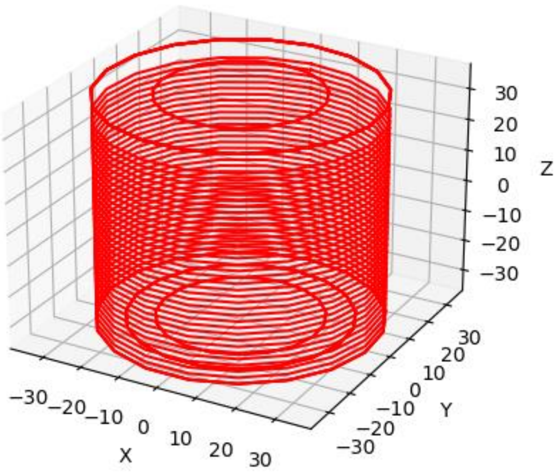
From y= -32 m to y= +32 m, separated 2 m

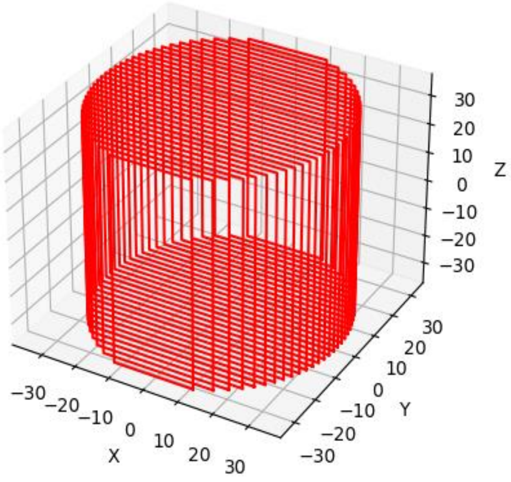
Coil at y = -32, I_V = 100 A

Coil at y = 32, I_V = 93.75 A

Height H=72m

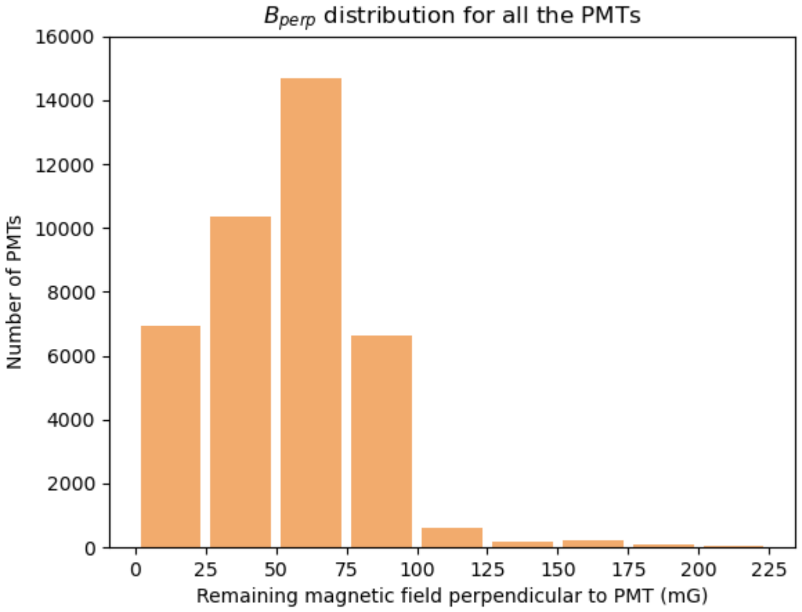
Circular horizontal coils

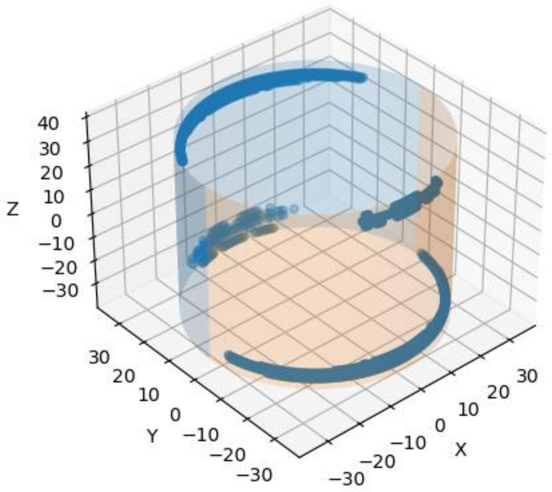




Rectangular vertical coils

5. Improved configuration





Average remanent perpendicular magnetic field: **54.45 mG**

- 0 PMT on top above 100 mG (0%)
- 1205 PMTs on walls above 100 mG (4.46%)
- 26 PMTs on bottom above 100 mG (0.40%)

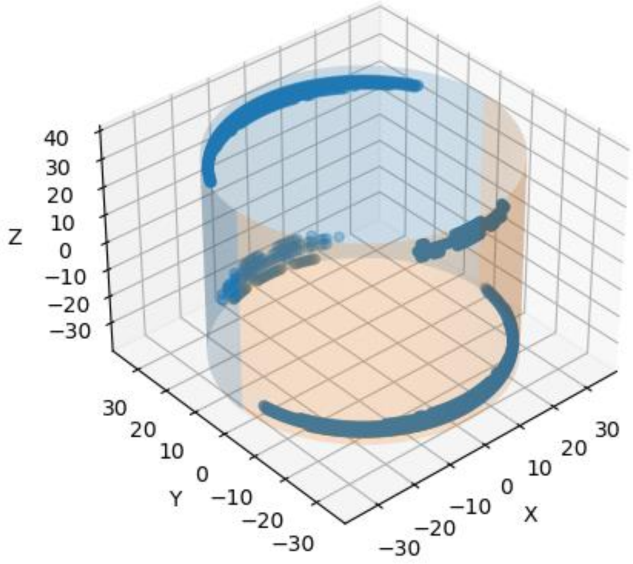
1231 PMTs above 100 mG in the whole ID

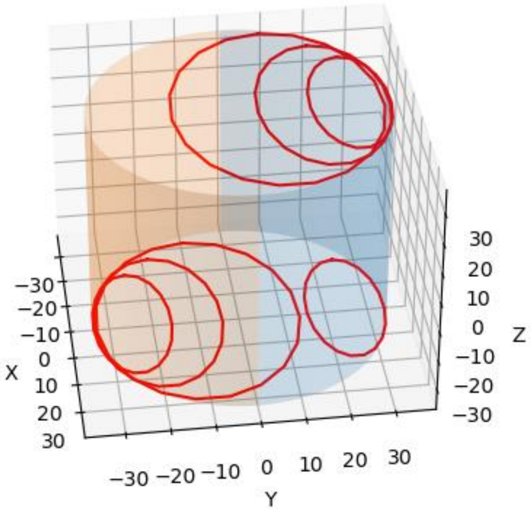
3.08%

6. Elliptical coils

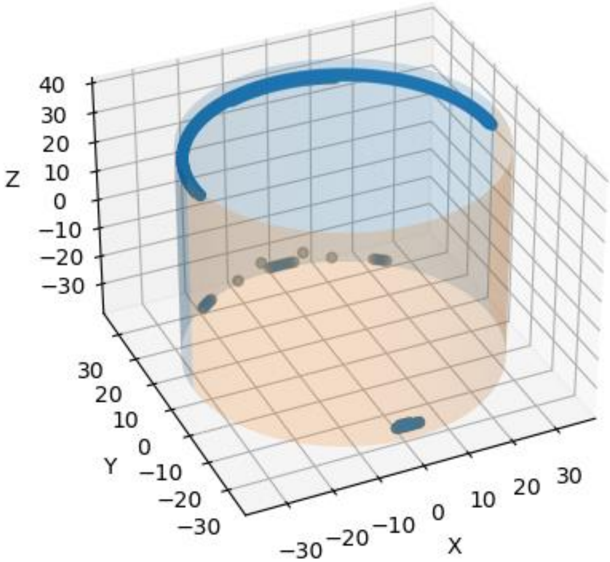
Basic configuration:

3.08 %





Elliptical coils at the bases



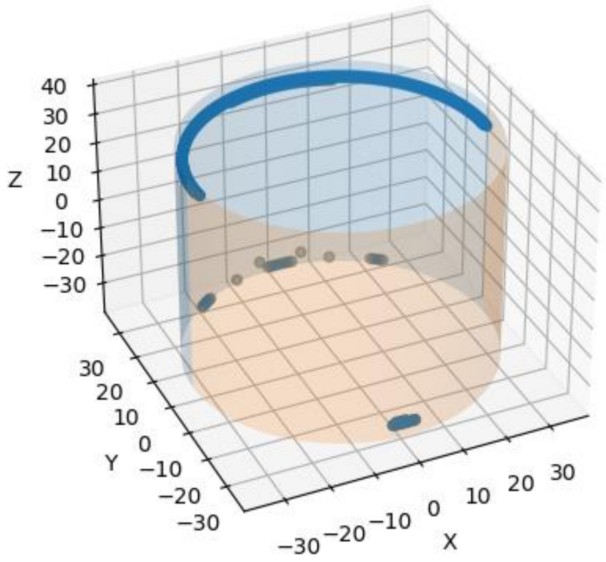
0.96 %

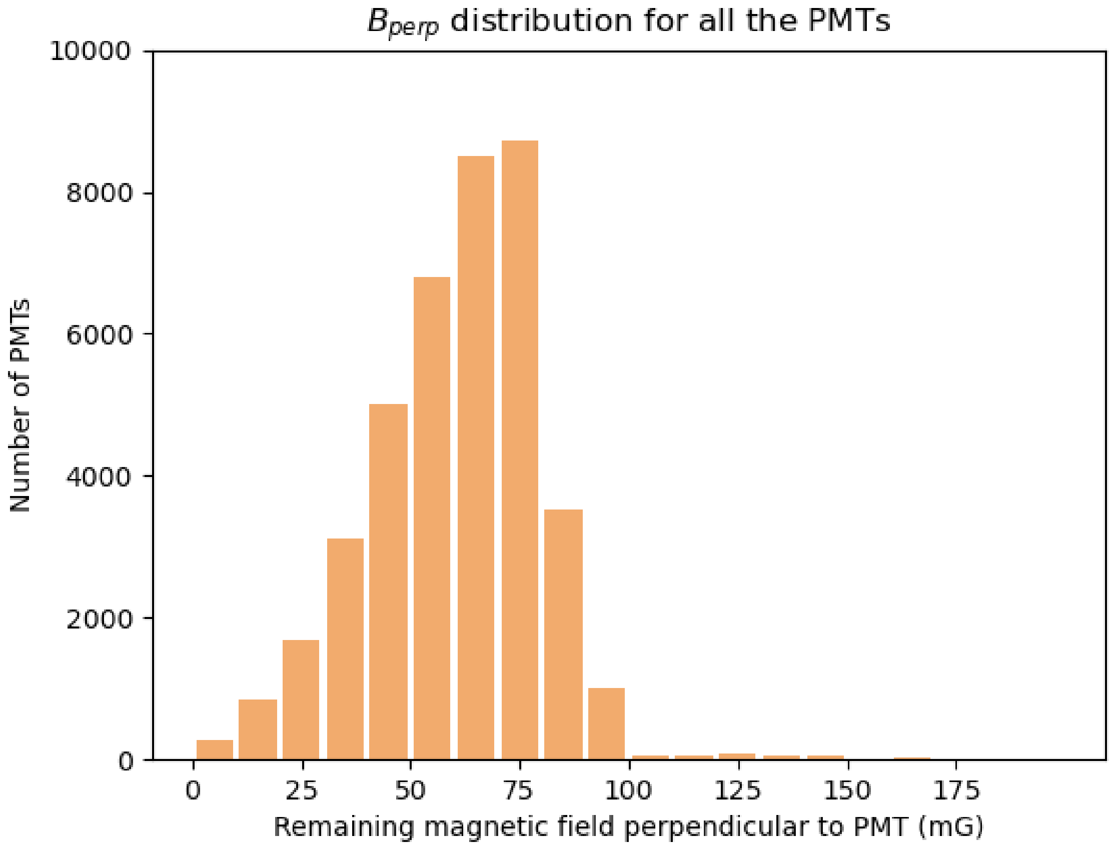
Distance between coils: 2m

$I_{coil} \approx 70$ A

Media B_{perp} = 61.35 mG

385 PMTs with excess → 0.96%





Top: 6 PMT
Bottom: 1 PMT
Walls: 378 PMT

Media top = 54.23 mG
Media bottom = 62.72 mG
Media walls = 62.74 mG

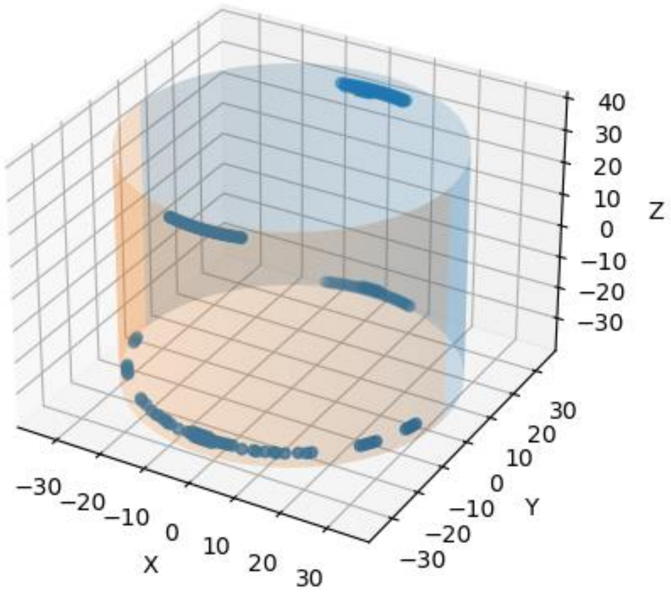
Total wire length = 18628.65 m

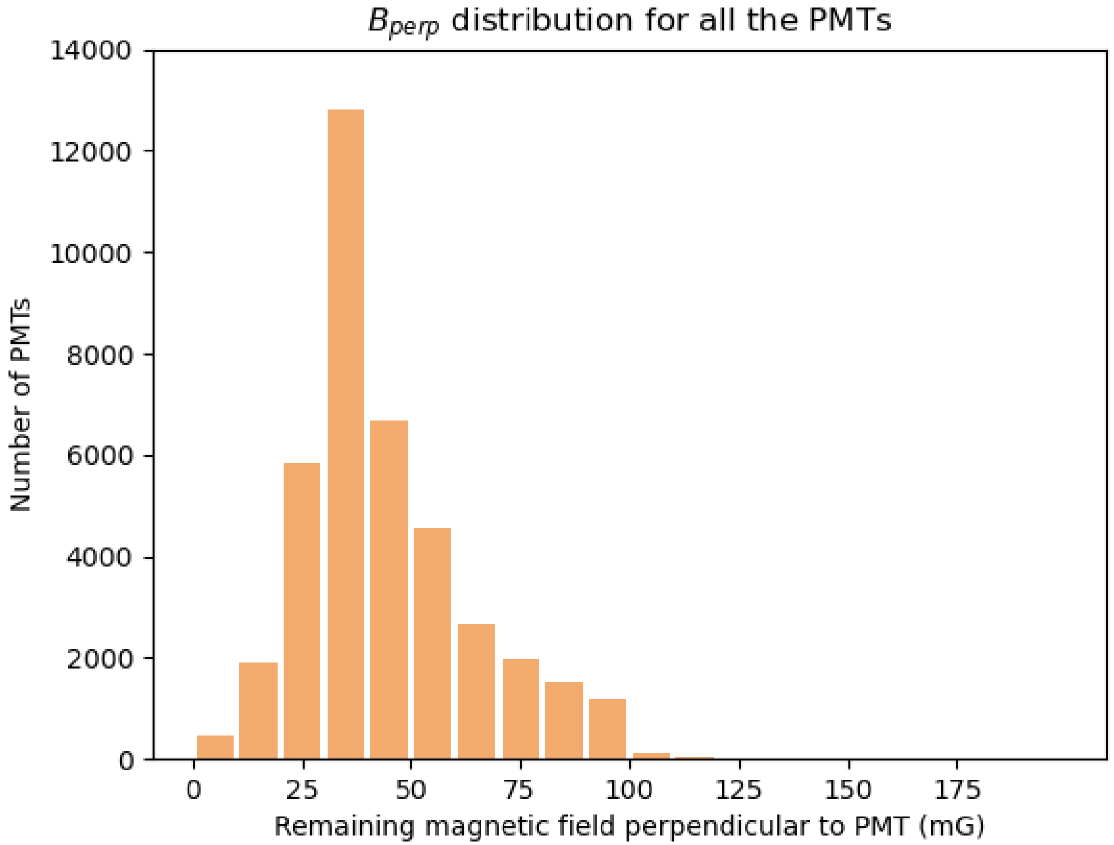
Distance between coils: 1m

$I_{coil} \approx 35$ A

Media B_{perp} = 42.50 mG

163 PMTs with excess → 0.41%



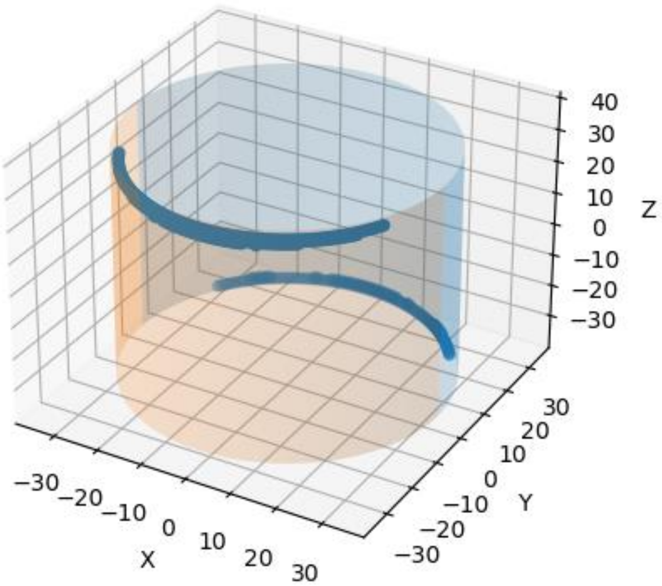


Total wire length
= 37486 m

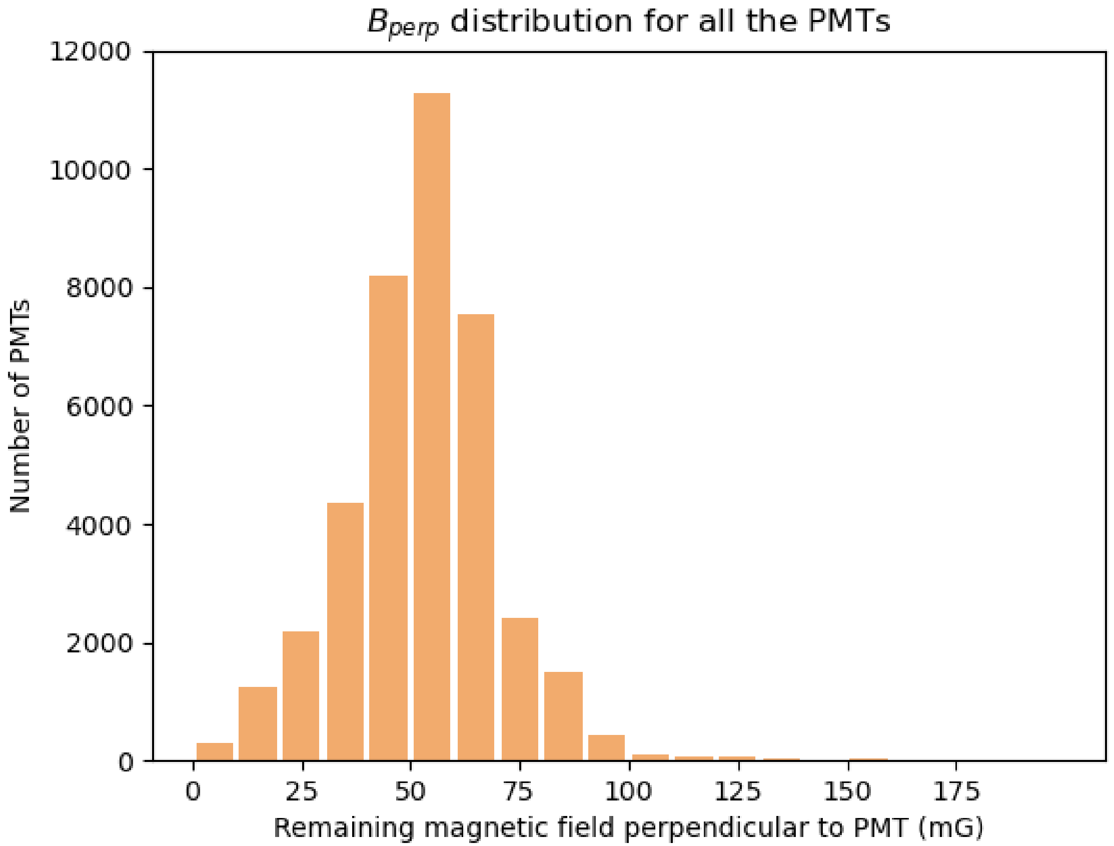
X Too much wire needed

1 m circular coils – 2 m rectangular coils

393 PMTs with excess → 0.98%



Media B_{perp} = 53.43 mG



Total wire length
= 26000 m

I_{coil} ≈ 35 A circular - 62 A rectangular

Conclusions

2 m between coils

- 0.96% PMTs with excess
- Media = 61.35 mG
- Intensity of current ≈ 70 A
- Amount of wire = 18.63 km

1 m between coils

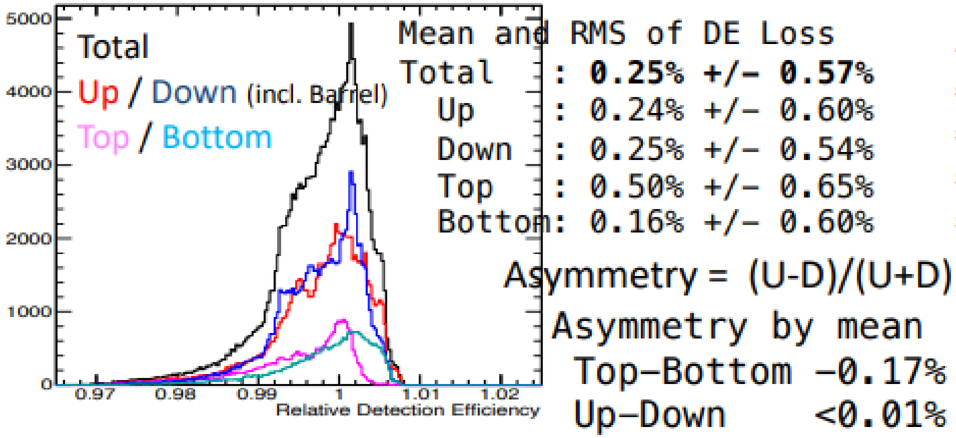
- 0.41% PMTs with excess
- Media = 42.50 mG
- Intensity of current ≈ 35 A
- Amount of wire = 37.48 km

1 m circular coils – 2 m rectangular coils

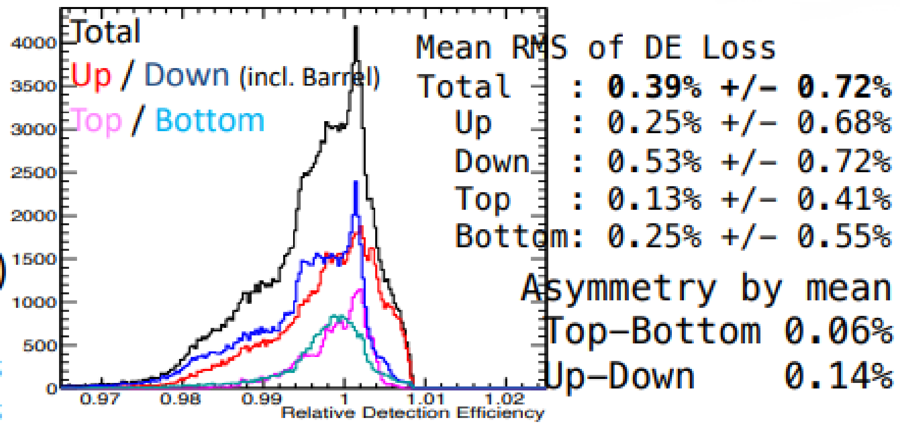
- 0.98% PMTs with excess
- Media = 53.43 mG
- Intensity of current ≈ 35 A circular – 62 A rectangular
- Amount of wire = 26 km

Loss of eficiency

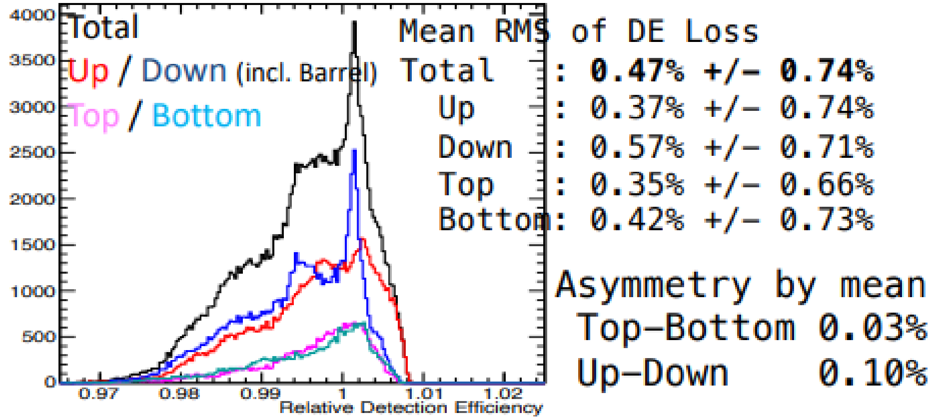
Distance between coils : 1m



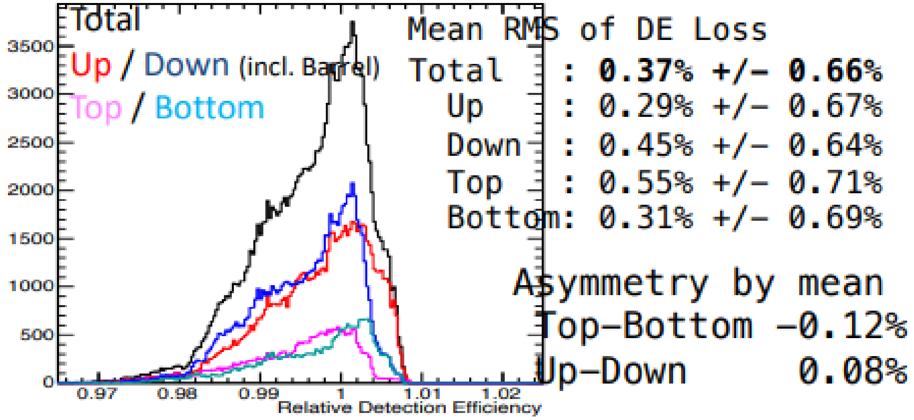
Distance between coils : 2m



Distance between coils : 2m + elliptical coils



1m circular + 2m rectangular coils



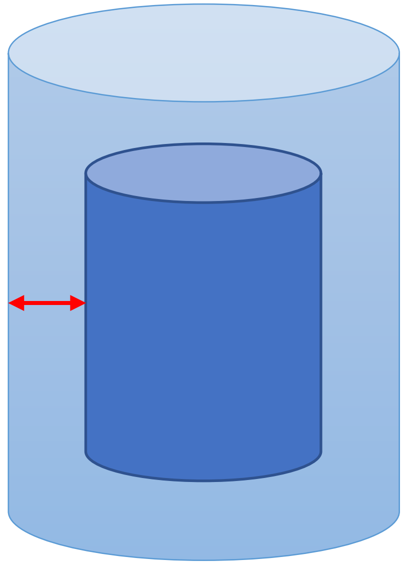
→ Less variation and tail

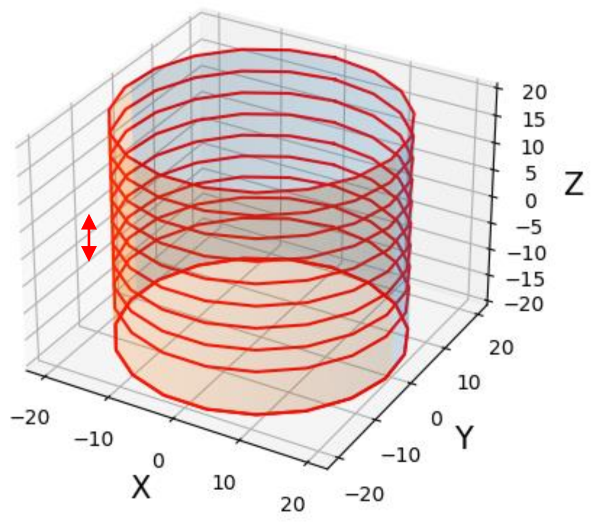
(Y. Nishimura, 2023)

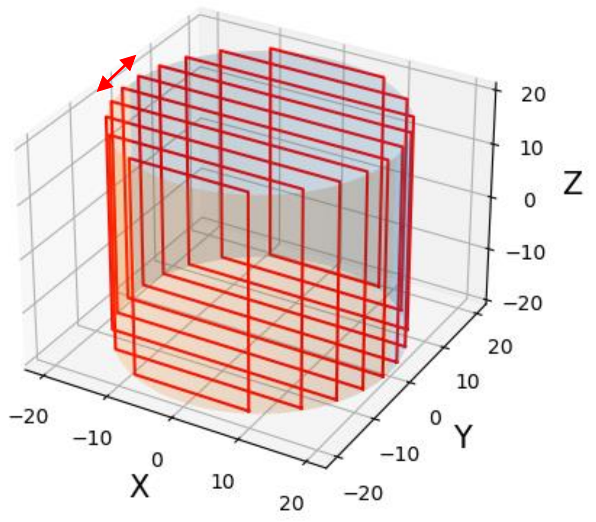
7. Comparison with Super-K

Distance between coils

Distance to walls

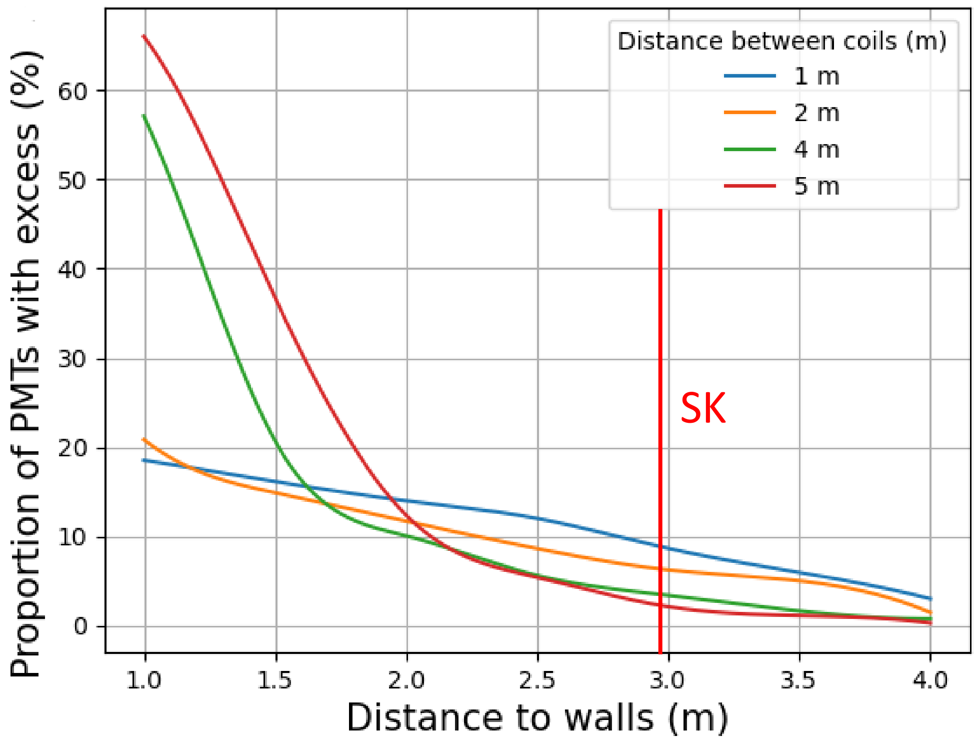




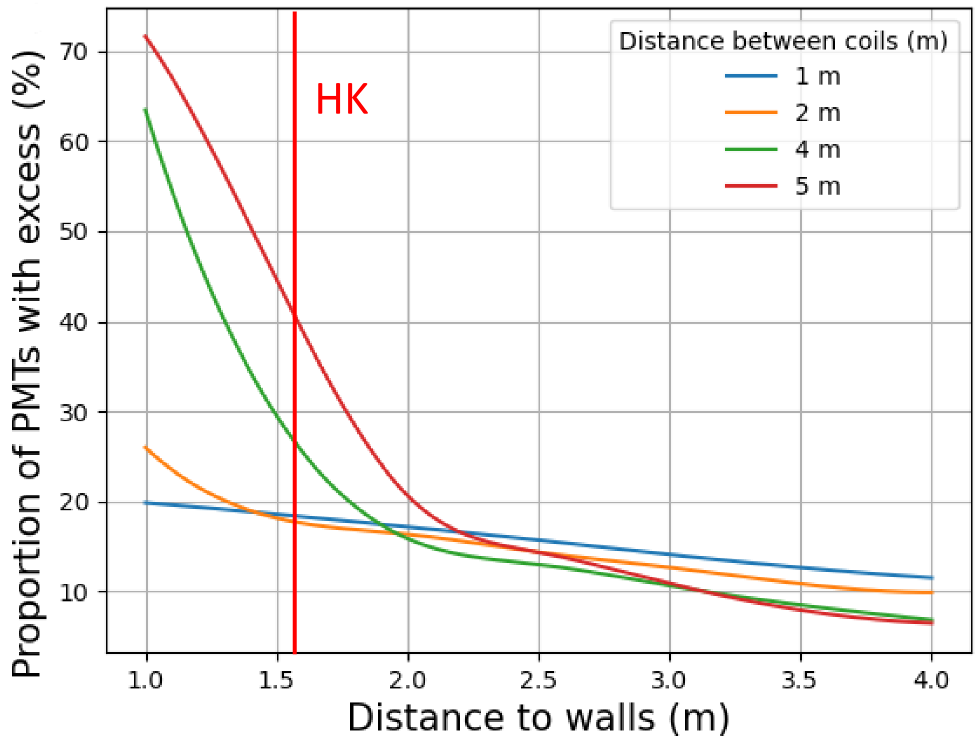


7. Comparison with Super-K

Super-Kamiokande



Hyper-Kamiokande



Distance to walls SK = 2.95 m

Distance to walls HK = 1.60 m

Thank you for your attention