# Geomagnetic field compensation

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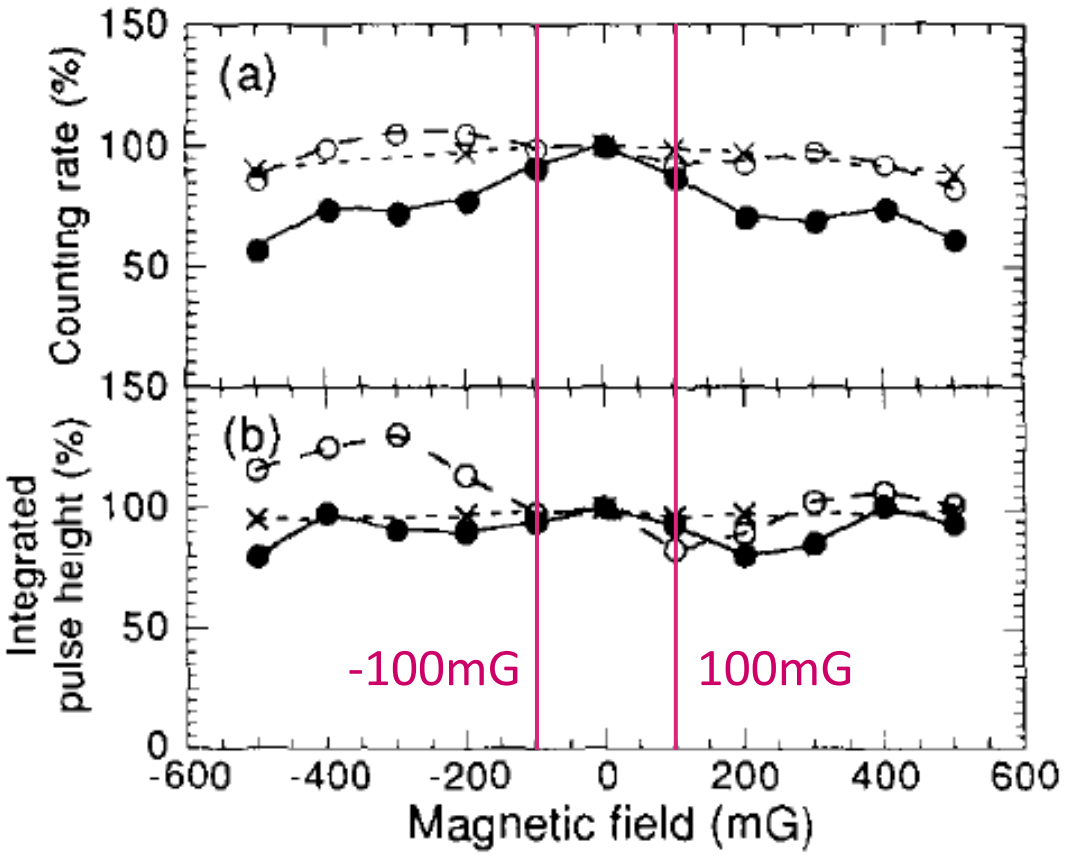
June 21, 2013

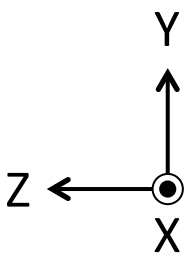
@ The 3rd open Hyper-K meeting

Slide at the last meeting

# PMT response in a magnetic field

20-inch PMT used in Super-K



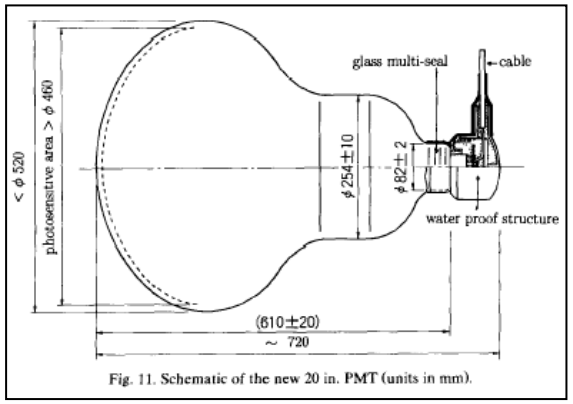



Fig. 11. Schematic of the new 20 in. PMT (units in mm).

- ● Parallel to dynode (X)
- ○ Perpendicular to dynode (Y)
- × PMT facing direction (Z)

Magnetic field perpendicular to the PMT facing direction should be < 100mG.

A. Suzuki et al., NIM A329 (1993) 299-313

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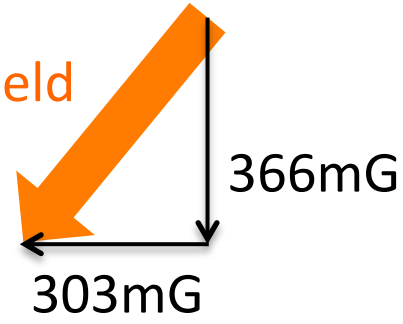
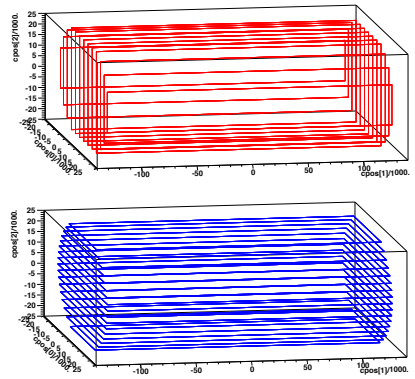
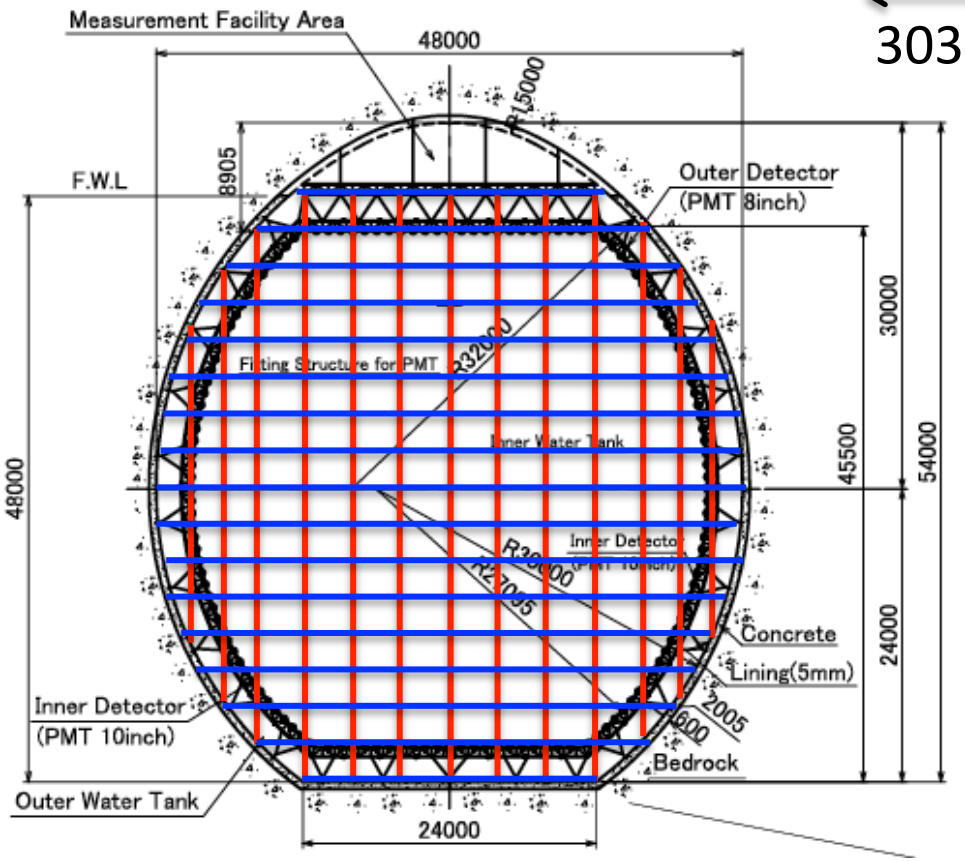
# Configuration after an initial optimization






## 13 vertical coils :

- 3~4m spacing
- 150 A

## 17 horizontal coils :

- 3m spacing
- 135 A (200 A only for the most top and bottom coils)

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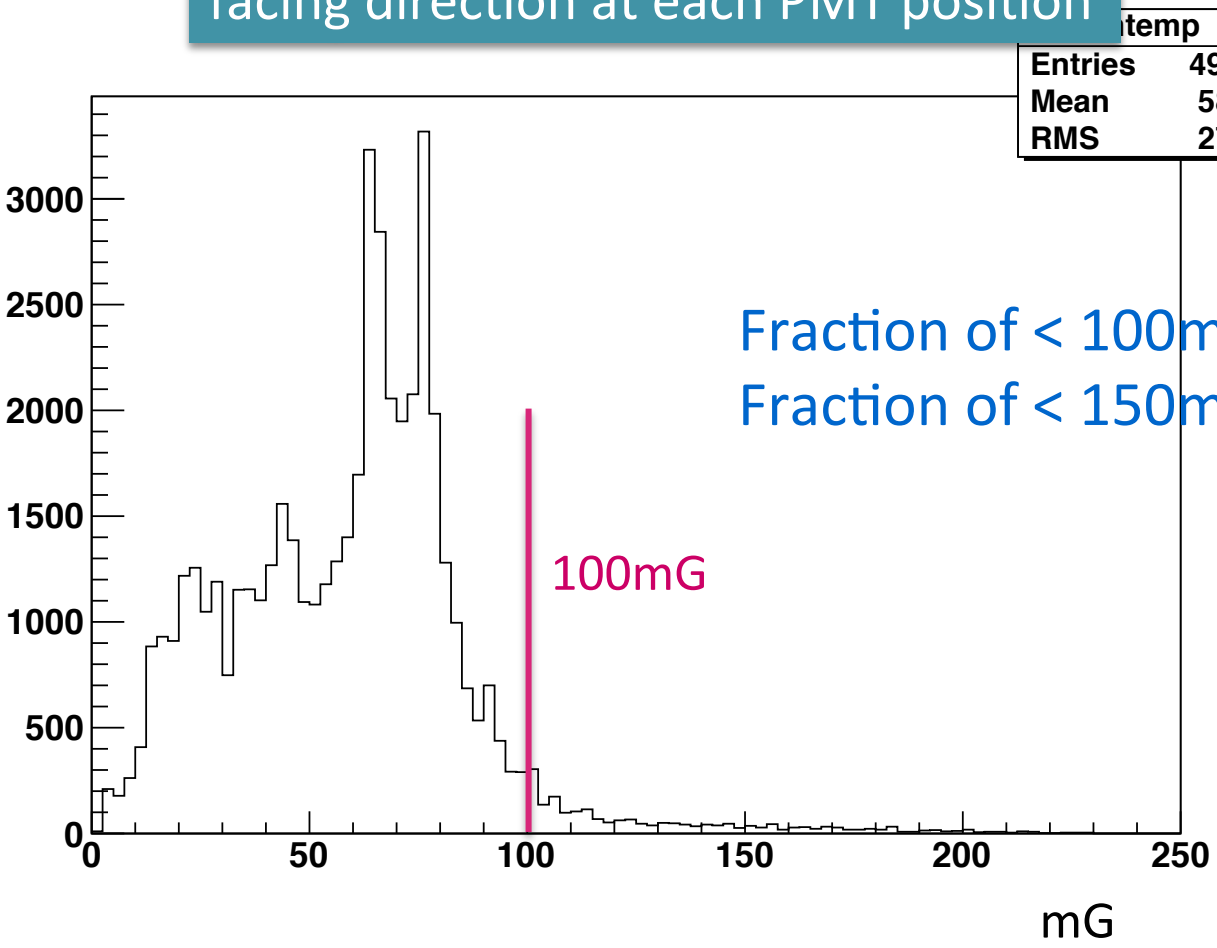
# Results

Size of magnetic field ⊥ to the PMT facing direction at each PMT position




Fraction of < 100mG = 95.7%

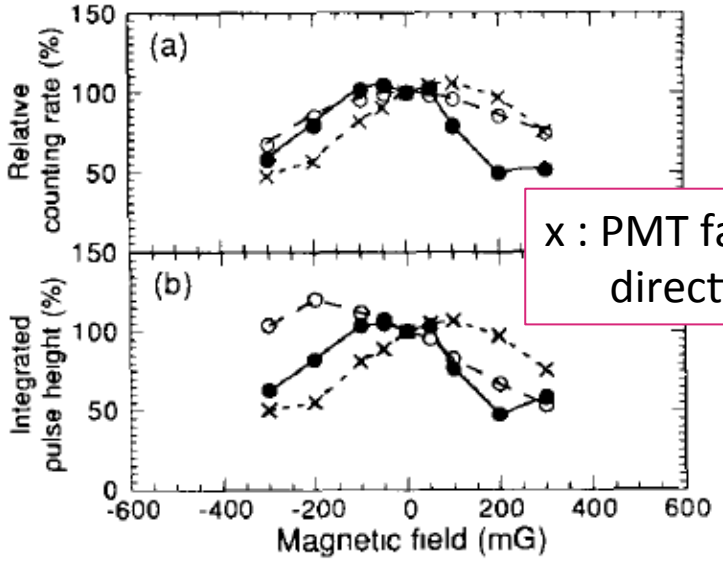
Fraction of < 150mG = 98.9%

Mostly satisfies the requirement

# The result looks good, but …

- The fraction of sensors with 50-100mG $B_{\perp}$ is large.
  - ~30mG in Super-K
- Magnetic field parallel to the PMT facing direction also affect the PMT response
  - depending on position where a photon hits a PMT
- I have tried to find a better configuration, but am not yet successful.
  - due to the very long tank shape
  - more difficult if the tanks are not // nor ⊥ to the horizontal geomagnetic field

Lighting position is at $60^{o}$ w.r.t the PMT axis



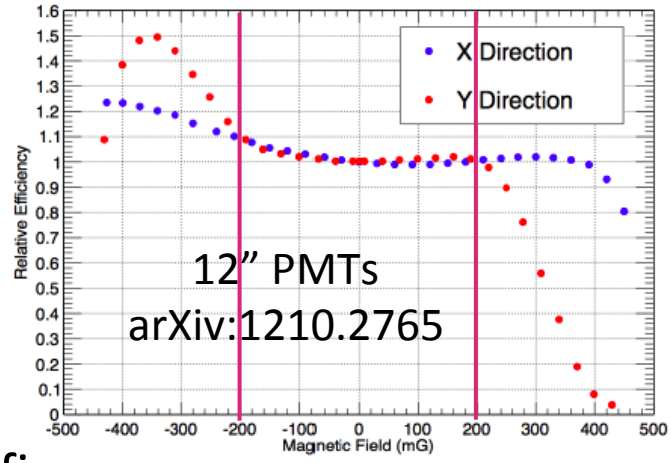

x : PMT facing direction

# Coil study prospects

- Coil configurations which provide $B_{total}$<100mG at most of the ID sensor positions have not yet been found
  - Need to estimate possible detector asymmetry (positional / directional) if we use current 20” PMTs

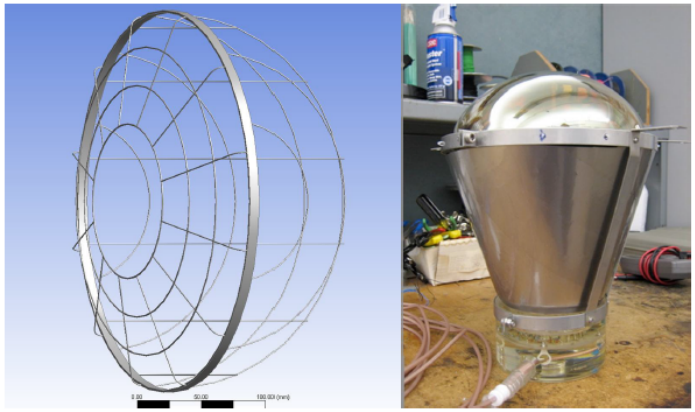
- New sensors are expected to have better anti-magnetic field performance
  - 20” PMTs with box&line dynodes : <10% CE drop under 200mG
  - HPDs : higher V + symmetric shape
  - 12” HQE PMTs (evaluated in the U.S.)

→ may be easier to find a feasible coil config.



# Passive magnetic shielding

- Used in many experiments
  - Double Chooz, Daya Bay,
  - Kamiokande, …
- Studies also in LBNE-WC



Other than cost considerations there are no clear advantages to the active compensation coil approach over the passive shield approach, while there are several clear disadvantages. The only potential advantage of compensation coils is the possibility of lowering the field to 50 mG for the great majority of PMTs. This does not appear necessary — as stated above.

(from the LBNE-WC CDR)

- Need to check
  - Performance degeneration (detection efficiency / acceptance)
  - Cost
  - And more… (anti-corrosion, production period/stability, …)

# Summary and plan

- Still trying to find a coil configuration for better magnetic field compensation
  - Target for use of current 20” PMTs : $B_{total}$<100mG
  - Need to estimate possible detector asymmetry
- New sensors are expected to have better anti-magnetic field performance
  - Measurement of prototype 20” sensors in 0.5-1 years
- Passive shielding options are worth considering
- The magnetic field at OD sensor positions must be checked
- I will try to make some conclusion (on coil options) by the next open meeting

# Supplement

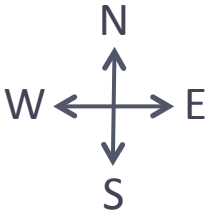
# Introduction

- The PMTs (or HPDs) used in Hyper-K have large drift distances from the photocathode to the first multiplication stage.
  - Sensitive to magnetic fields on the order of 1 Gauss or less.
- The Earth's magnetic field can cause significant loss of efficiency.
- We have to lower the magnetic field inside the PMTs.

# Geomagnetic field at a HK candidate site

Can access the database for the Geomagnetic survey
by GSI (Geospatial Information Authority of Japan, 国土地理院)

http://vldb.gsi.go.jp/sokuchi/geomag/menu_04/index-e.html

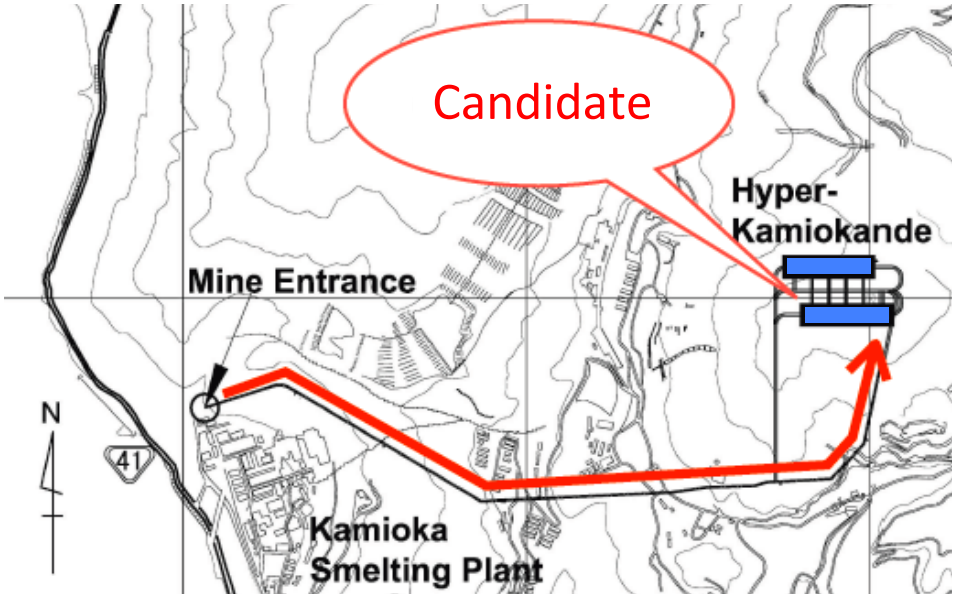



[Input value]

| | |
|---|---|
| Latitude | 36 ° 21 ' 9" |
| Longitude | 137 ° 18 ' 50" |

[Result]

| | | |
|---|---|---|
| Declination | 7 ° 35 ' (W+) | |
| Inclination | 50 ° 23 ' | |
| Total force | 47520 nT | **475 mG** |
| Horizontal intensity | 30305 nT | **303 mG** |
| Vertical intensity | 36602 nT | **366 mG** |

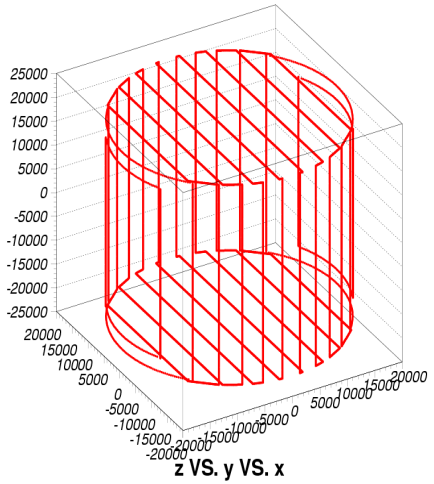



In the current design, the tank direction is along West-East.
(may change by the rock condition)

# Magnetic compensation coils

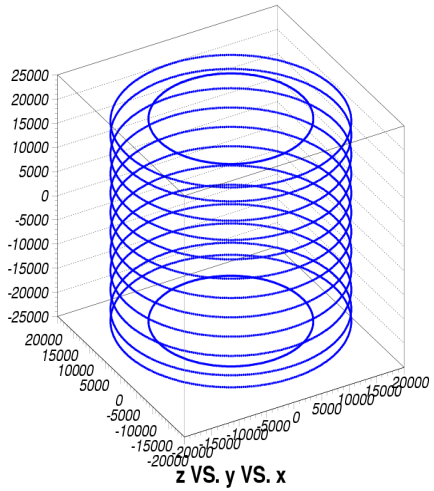
- Magnetic compensation by sets of direct-current powered coils.
- Used in the Super-K detector

Vertical coils




+

Horizontal coils

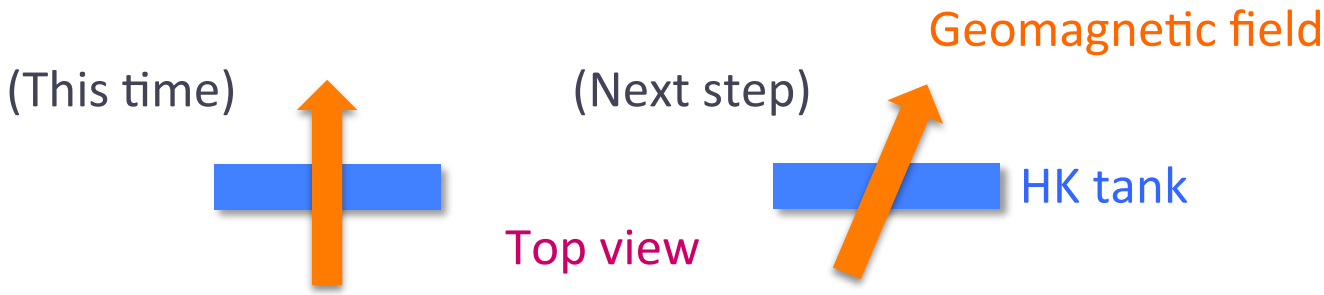



→ Consider the coil configuration for Hyper-K

# Disclaimer

- The detailed designing of the magnetic coils has not been done until recently.
  - No description on the magnetic compensation in the HK LOI.

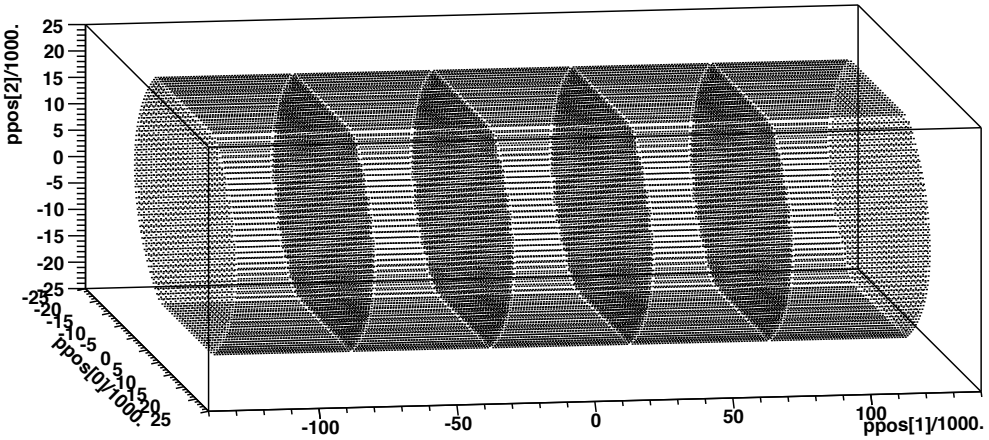
- As a first step :
  - Assume that the horizontal component of the Geomagnetic field is perpendicular to the tank axis.

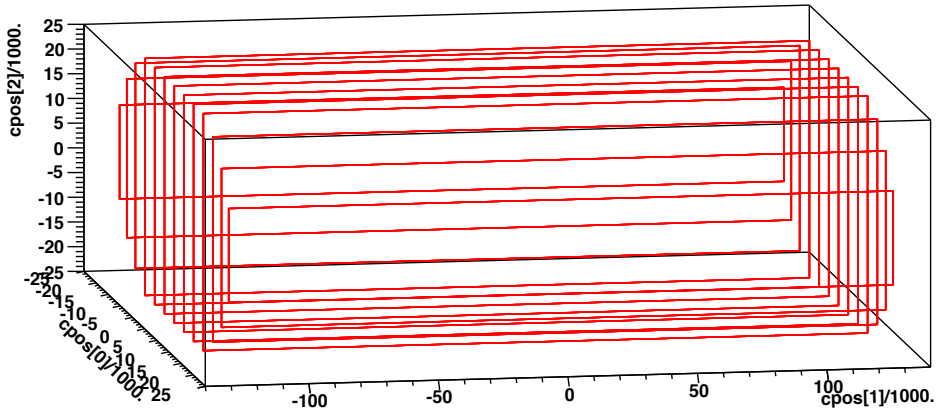


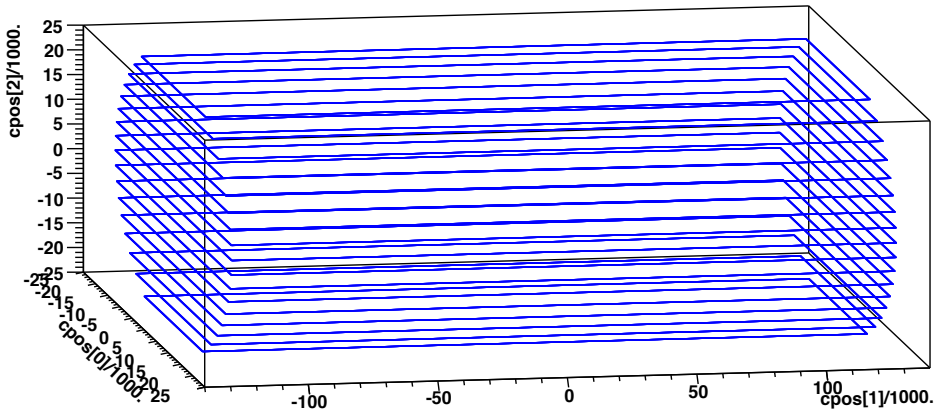

  - Consider the compensation at the inner detector PMT positions.
    - Compensation at the outer detector PMT positions → next step
      (The OD-PMTs are smaller and must be less affected by magnetic fields.)

# Developed a tool to calculate the magnetic field

- C++ code
- Calculate the magnetic field at each of the 99,000 ID-PMT positions
  - Contributions from each ~10 cm piece of a coil are calculated using the Biot-Savart law and are integrated over the whole coils.

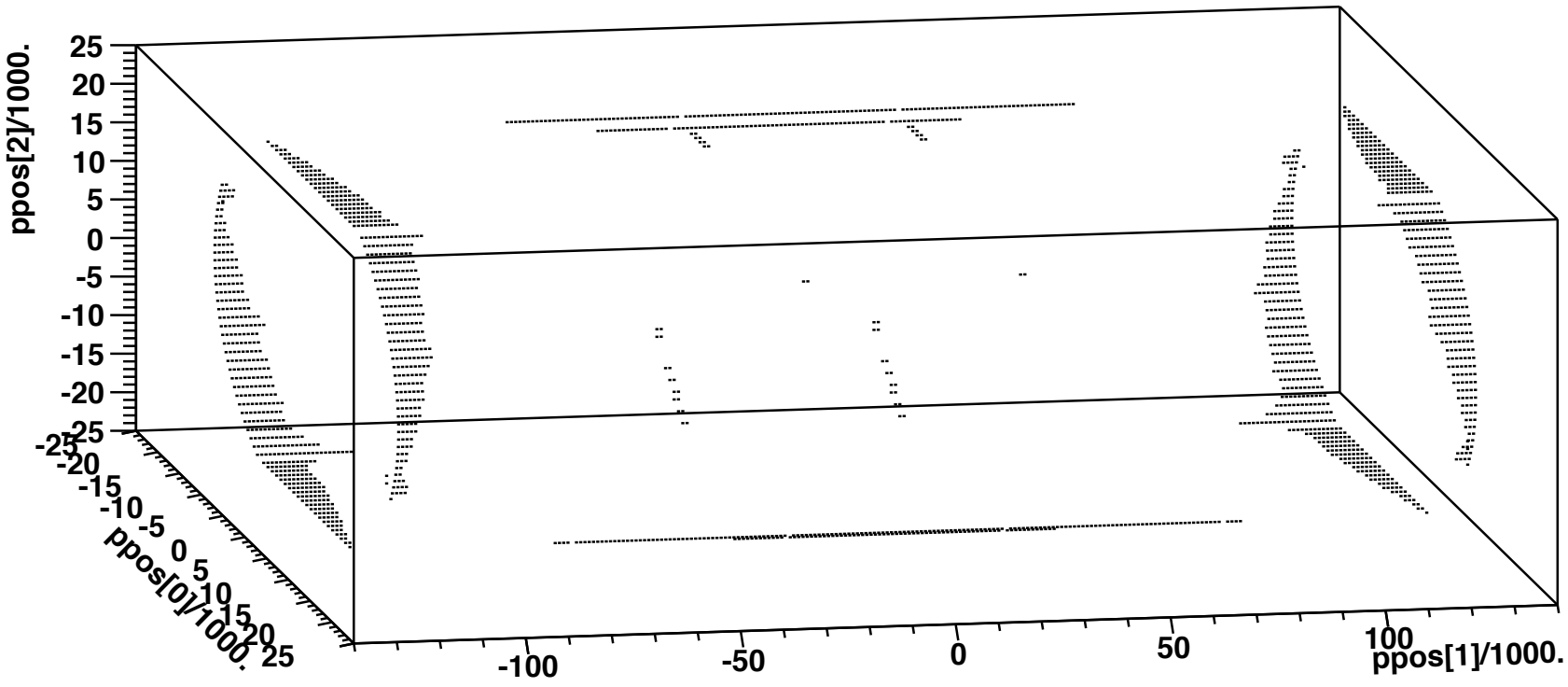


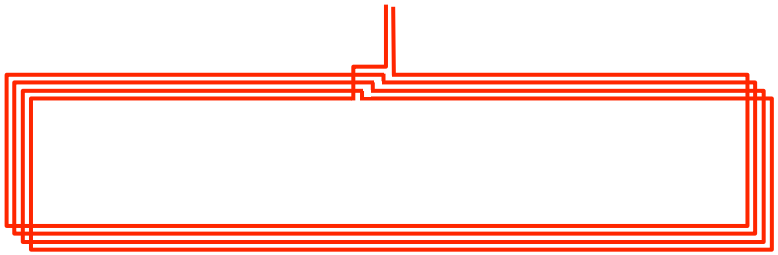
# PMT positions w/ >100mG magnetic fields

⊥ to the PMT facing direction



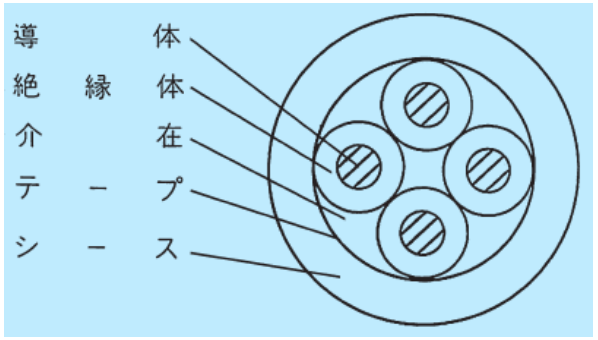

Need more optimizations

# Coil cables and heat load



- Each coil → 4-turn coils
- Use 4-conductor cables

- Total length of conductor for a typical vertical coil (red line) = ~2500 m




- If we use cables with 38mm$^2$ conductors (cable diameter = 28mm), the supply voltage for this coil is

  V = RI = 0.491 Ω/km x 2.5 km x 37.5 A = 46 V

- Total heat load for one tank is ~50kW (rough estimation).
  - should increase if the tank is not perpendicular to the geomagnetic field.

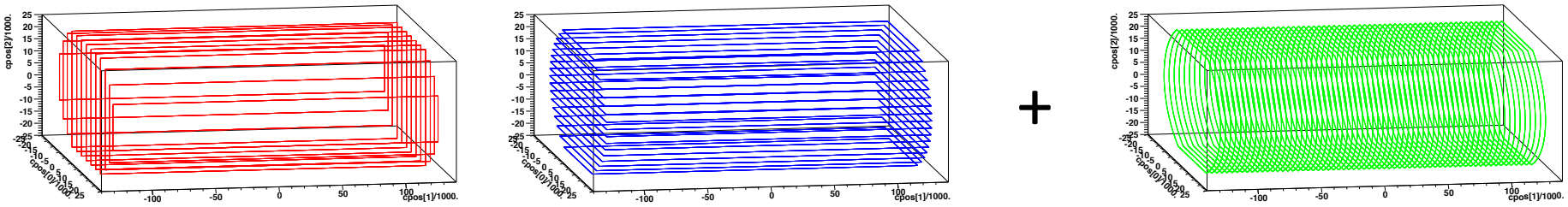
■4心

| 導体 | | | 絶縁体厚さ (mm) | シース厚さ (mm) | 仕上り外径 (約mm) | 最大導体抵抗(20℃) (Ω/km) | 試験電圧 (V) | 最小絶縁抵抗(20℃) (MΩ-km) | 概算質量 (kg/km) | 許容電流 周囲温度40℃ (1条)(A) |
|---|---|---|---|---|---|---|---|---|---|---|
| 公称断面積 ($mm^2$) | 素線数/素線径 (mm)または形状 | 外径 (mm) | | | | | | | | |
| 2.0 | 7/0.6 | 1.8 | 0.8 | 1.5 | 12.0 | 9.42 | 1,500 | 2,500 | 180 | 23 |
| 3.5 | 7/0.8 | 2.4 | 0.8 | 1.5 | 13.5 | 5.30 | 1,500 | 2,500 | 260 | 33 |
| 5.5 | 7/1.0 | 3.0 | 1.0 | 1.5 | 16.0 | 3.40 | 1,500 | 2,500 | 370 | 44 |
| 8 | 7/1.2 | 3.6 | 1.0 | 1.5 | 17.0 | 2.36 | 1,500 | 2,000 | 485 | 54 |
| 8 | 円形圧縮 | 3.4 | 1.0 | 1.5 | 16.5 | 2.34 | 1,500 | 2,000 | 460 | 54 |
| 14 | | 4.4 | 1.0 | 1.5 | 19.0 | 1.34 | 2,000 | 1,500 | 745 | 76 |
| 22 | | 5.5 | 1.2 | 1.6 | 23 | 0.849 | 2,000 | 1,500 | 1,120 | 100 |
| 38 | | 7.3 | 1.2 | 1.8 | 28 | 0.491 | 2,500 | 1,500 | 1,800 | 140 |
| 60 | | 9.3 | 1.5 | 2.0 | 35 | 0.311 | 2,500 | 1,500 | 2,800 | 190 |
| 100 | | 12.0 | 2.0 | 2.4 | 44 | 0.187 | 2,500 | 1,500 | 4,650 | 260 |
| 150 | | 14.7 | 2.0 | 2.6 | 51 | 0.124 | 3,000 | 1,000 | 6,760 | 340 |
| 200 | | 17.0 | 2.5 | 2.9 | 60 | 0.0933 | 3,000 | 1,500 | 9,060 | 410 |
| 250 | | 19.0 | 2.5 | 3.1 | 65 | 0.0754 | 3,000 | 1,000 | 11,300 | 470 |
| 325 | | 21.7 | 2.5 | 3.4 | 72 | 0.0579 | 3,000 | 900 | 14,400 | 555 |

※4心の許容電流は、4心のうち1心を中性線又は接地線として使用する場合に適用する。

# Next steps

- More optimization to reduce magnetic fields further
- Configurations in case that the HK detector tank direction is not perpendicular to the geomagnetic field




- Check magnetic fields at the outer detector PMT positions
- Studies on passive magnetic shielding options (?)
  - Such as mu-metal wire cages for PMTs, etc.

# Summary

- I have started a detailed designing of the magnetic compensation coils.
- I got a configuration which satisfies the remaining magnetic fields perpendicular to the PMT facing direction are below 100mG at >95% of the ID-PMT positions.
  - Need to reduce magnetic fields further.
- Your new ideas/studies are welcome.