Super-Kamiokande PMTs Characterizations Using Artificial Magnetic Field and Robotic Laser-Equipped Arms

Vincent Gousy-Leblanc
Graduate student at UVIC
Supervised by Patrick de Perio, Akira Konaka, Dean Karlen

58th Winter Nuclear & Particle Physics Virtual Conference
February 9 - 12, 2021
Outline

- Experiment
- Purpose of these measurements
- Results
- Next steps
- Conclusion
Super-Kamiokande experiment

- Goal: Detect neutrino oscillations (Awarded Nobel Prize of 2015) and measure the mixing parameters

Neutrino interaction

- Neutrino events creating Cherenkov radiation

- Approximately 11,000 photomultiplier tube (PMT)

Neutrino events

- Muon
- Electron
Context: What is a PMT

General idea: Detect photons

- Path can be influenced by the magnetic field

\[ qv \times B \]
The magnetic field in Kamioka

- Earth magnetic field (~650mG) is compensated in Super-K
- Older measurements (2013)
  - Showed ± 80 mG in Z, ± 100 mG in Y and ± 80 mG in X
- Newer measurements
  - Showed ± 100 mG in 3 directions

Does it as an impact? -> Need to be measured
The Photosensor Test facility (PTF) at TRIUMF

- 3 pairs of Helmholtz coils (one in each direction)
  - Can control and monitor magnetic field

- 2 optical box (laser, phidget included to measure tilt, rotation angle and magnetic field)
  - Polarizable light
  - Chosen wavelength

- 2D Characterization of PMT (transit time, detection efficiency, gain)
  - PMT inside optical box to measure laser intensity

- Angular response and reflection measurements
Goals of PTF

- General idea: Build a semi-empirical model that would predict the magnetic field effect on a PMT
  - Want to find precisely the effect on
    - Transit time
    - Detection efficiency
    - Gain

-> Goal: Implement the magnetic field effect/2D characterization in the SK simulation.
Hypothesis

How does the magnetic field affects:

- Transit time
  - Incident angle
  - PMT model (20 inch vs mPMT)

SK simulations

Incident angle scan

20inch PMT Single value

What could be done

20inch PMT

θ

ϕ
Measurements: Transit time spread

- Hard to modelize theoretically this change
- As expected local variations

Credit: John Walker and Blair Jamieson worked
Measurements of the detection efficiency

- Y is unaffected by the change of field.
- High intensity region shift

-> More data needed to build a simple empirical model

Credit: John Walker and Blair Jamieson worked
Gain measurements

Gain = multiplication factor for a single photoelectron arriving at dynode.

- Model: sum of Gaussian, parameters:
  - $Q$: gain of SPE
  - $\sigma_1$: Width of SPE
  - $w$: Weight of exponential background $w$
  - $\alpha$: exponential constant
  - $\mu$: avg number of photoelectrons collected
- Only $Q_1$, $\sigma_1$, $\mu$ allowed to vary.

-> Good agreement between fit parameter and data

Credit: John Walker and Blair Jamieson worked
Gain measurements

- Data fit to straight line.
  - $p_0$ the intercept.
  - $p_1$ the slope

- Gain:
  - Decreases for increasing $B_x$.
  - Relatively constant for $B_y$ and $B_z$.
  - Effect similar in air and water.
  - Gain higher in air

--> More data needed to build a simple empirical model

Credit: John Walker and Blair Jamieson worked
Ongoing work

- Hardware upgrade of PTF are done during the relocation
  - Easier to compensate (further from TRIUMF cyclotron)
  - Overall improvements of the stability, precision of the measurements and control of the magnetic field
    - Temperature reading
    - Motion monitoring
  - COMSOL magnetic field simulations
    - Reduce time to compensate the field

Temperature and QE as a function of time

Red: QE_SK
Pink: QE_SK corrected
Green: QE_MN
Blue: Temperature reading

Temperature and Acceleration (g) x Time (sec)
COMSOL simulation of PTF

- Complete simulation of PTF are done
  - Can change the geometry easily for future modifications
  - Full compensation in the 3 directions is done
    - Compare measurements vs simulations in PTF

\[
B_x^{(exp)} - B_x^{(sim)}
\]
The next steps

- Preparing PTF for characterizing as well the mPMT module
  - Dark rate measurements
  - Gain, transit time, detection efficiency
  - Angular response comparison
  - Etc.

- Implementing magnetic field correction/non-uniformity to Geant4
  - Semi-empirical model that uses the PTF data
Conclusion

- Did some measurements of the effect of the magnetic field on the 20inch PMT
  - Important effect on the gain and the detection efficiency
  - Angular response scan still needs to be done to
    - Get a better idea of the non uniformity
    - Build a better model

- PTF is undergoing hardware upgrades

- Simulation work in Geant4 is in progress
  - First test to include the magnetic field in the simulation
Back-up
Compensating the magnetic field

- Degauss procedure for a series of voltages
- 3X Obtain relation between the 2 coils for 1 direction

1-Voltage scan

2-Spatial scan:

3-Differential plot
Ex-situ characterization plan for mPMTS

- Hardware upgrade of PTF are done during the relocation
  - Overall improvements of the stability and precision of the measurements and control of the magnetic field (for more details see X)
  - Possibility of doing angular scan

- Goal: characterization of the mPMT response to the magnetic field
  - Dark rate measurements
  - Reflectivity of the material (using 2 gantry scan)
  - Gain
  - Photon detection efficiency under different magnetic field
  - Timing and charge resolution
  - Include these effect into the detector simulation software
Hypothesis (2)

How does the magnetic field affects:

- Detection efficiency
  - Will depends on temperature (dark noise)
  - Add the dark counts?
  - Rate of after-pulse affected
  - Incident angle
Hypothesis (2)

How does the magnetic field affects:

- Gain
  - Depends on the dynode type (space between each dynodes)
  - Orientation of the PMT (more general)
  - Incident angle

->Results for 20inch PMT
Gain measurements (2)

- Light collected $\mu$ shows the same temperature effect as the detection efficiency measurements.
  - This effect is decoupled from the other parameters.
General idea
-Minimize the variation of the efficiency locally (in 2D).

Assumption: around one scan point, the variation should be really small

2-We want to minimize a quantity, a metric (will also help compare the method)

How the new correction methods works?

Apply hough transformation

Raw data
Fit calculated from metric

Detection efficiency

Torr using the rolling average of the difference from the average

Detection efficiency (Corrected), using Minuit
WCTE (water cherenkov test experiment)
IWCD experiment
Cover on/off ratio

- Air vs Water
- Detection efficiency higher (~20%) in water.
- No data for Bz variation in water taken.
- Systematic variation between measurements in water.
Transit time spread (2)

- Similar to the 2.2 ns quoted by Hamamatsu.
  - Hamamatsu do not consider the positional effect.
- Factor ~1.5 greater effect than RTT.
- Agreement between air and water measurements.
Gain measurements (2)

- Data fit to straight line.
  - p0 the intercept.
  - p1 the slope.

- Gain:
  - Decreases for increasing Bx.
  - Relatively constant for By and Bz.
  - Effect similar in air and water.
  - Gain higher in air.

- Gain-width $\sigma_1$:
  - Decreasing for increasing By.
  - Relatively constant for increasing Bx and Bz.
  - Close agreement between water and air.