TRIUMF

University of Victoria

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

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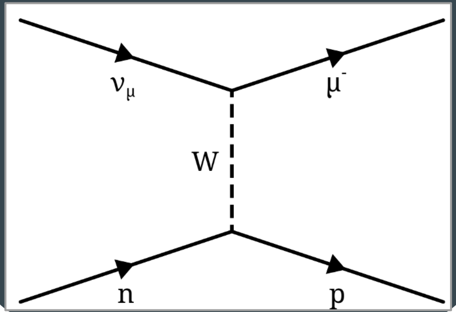
Outline

- Experiment
- Purpose of these measurements
- Results
- Next steps
- Conclusion

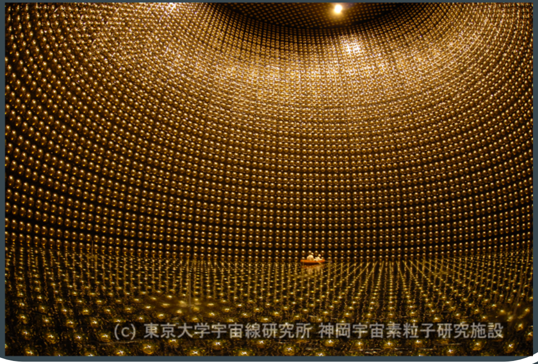
Super-Kamiokande experiment

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

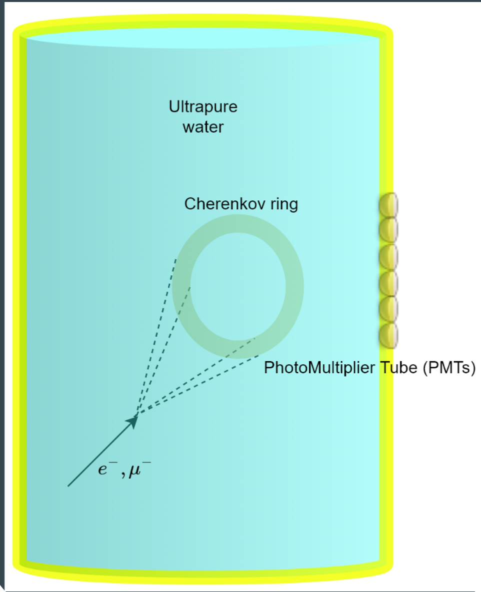
Neutrino interaction



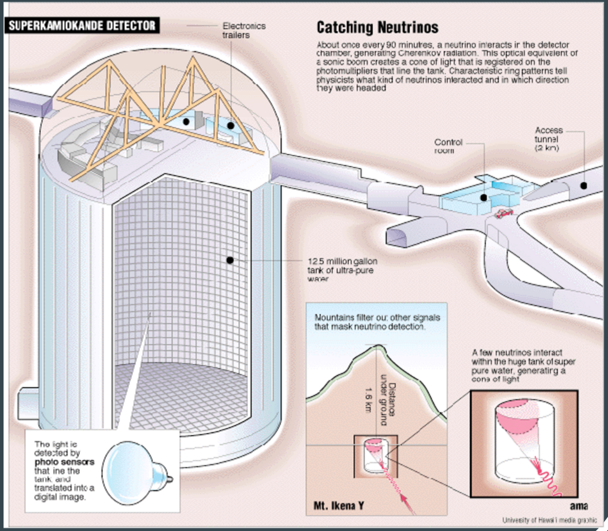
~11,000 photo-multiplier tube (PMT)



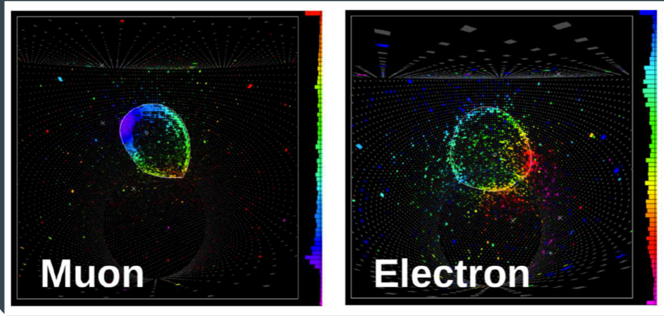
Neutrino events creating cherenkov radiation



Super-Kamiokande



Neutrino events

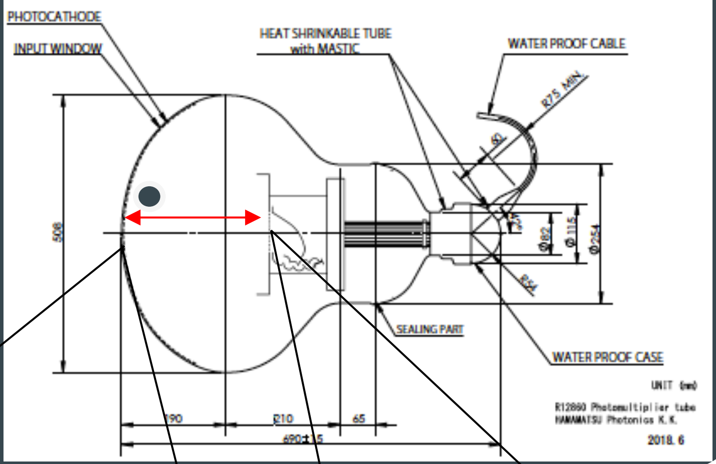


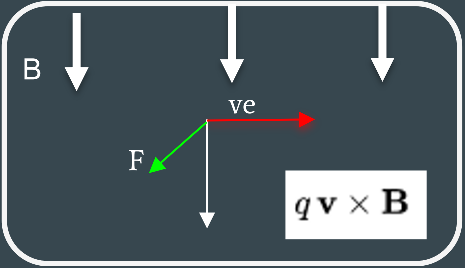
Context :What is a PMT

General idea: Detect photons

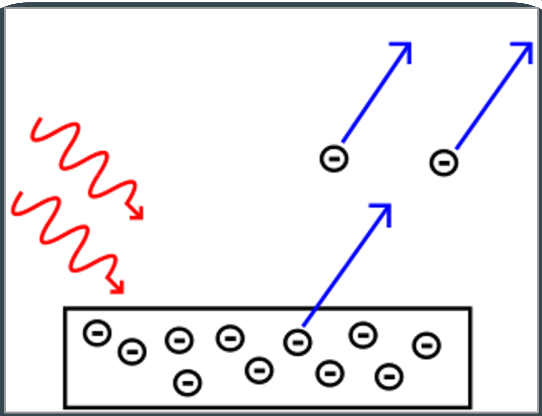
- Path can be influence by the magnetic field

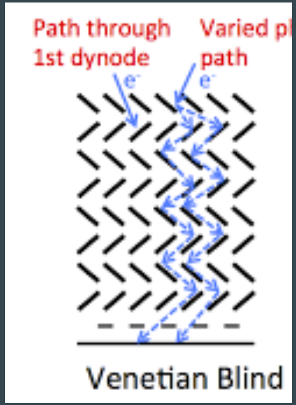
N photons





Photoelectric effect





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

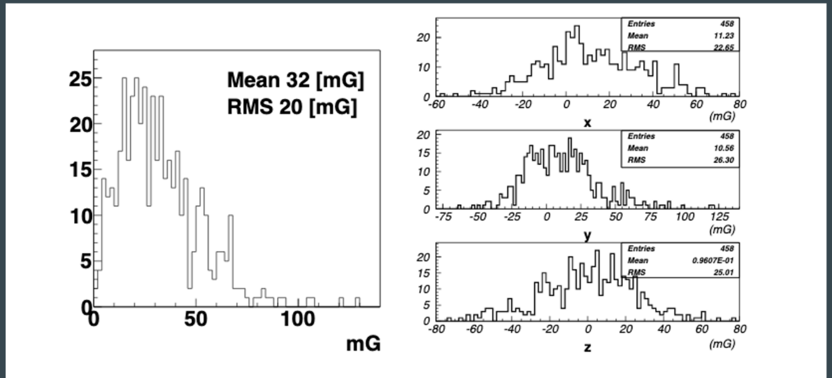
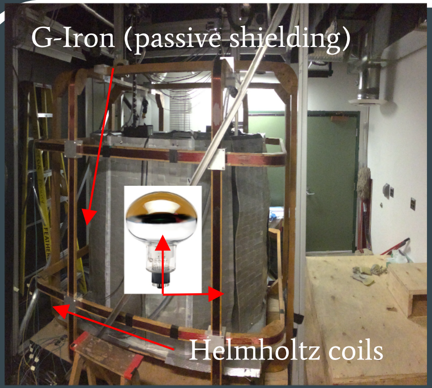
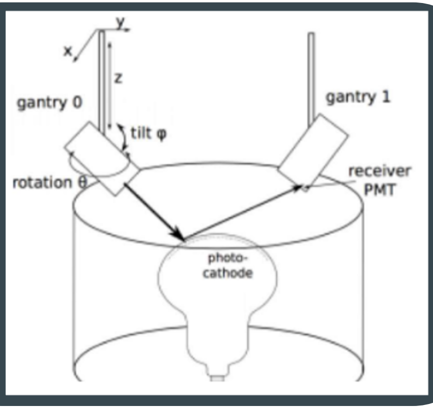


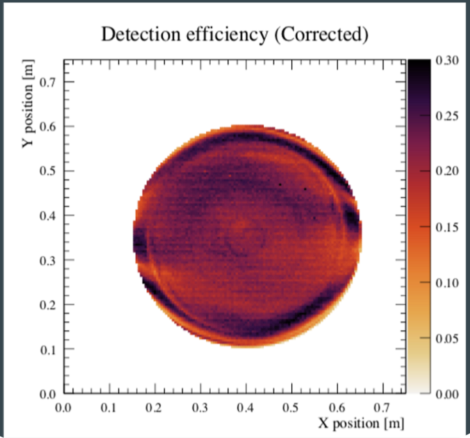
Figure 1: Distribution of magnitude of the residual magnetic field at different locations in the detector. The left figure shows the magnitude; the right figures show the value along the usual SK coordinate system axes.

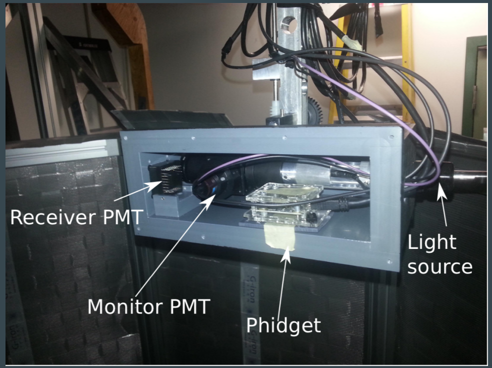
The Photosensor Test facility (PTF) at TRIUMF

- 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









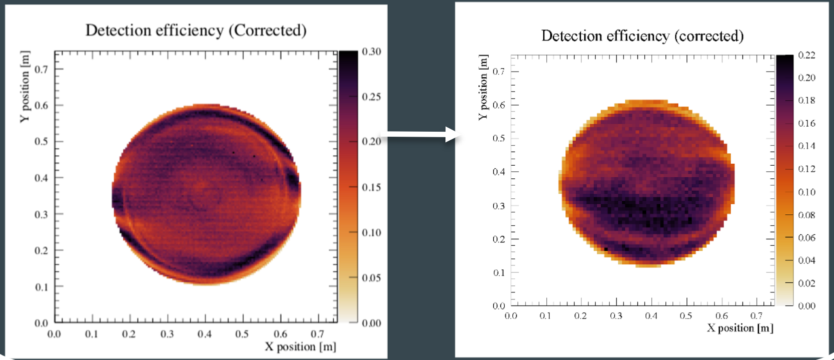
Goals of PTF

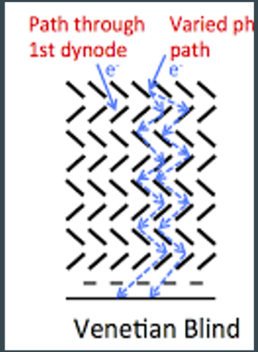
- General idea: Build a semi-empirical model that would predict the magnetic field effect on a PMT
  - Want to find precisely the effect on
    - Transit time
    - Detection efficiency
    - Gain

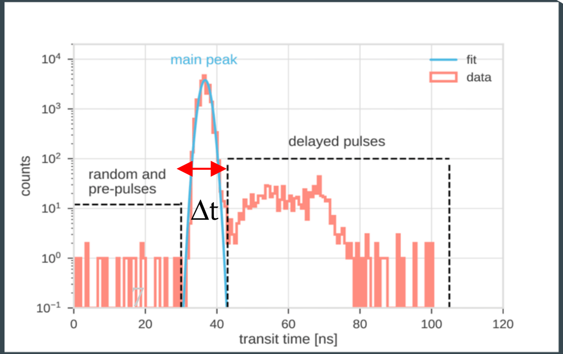
-> Goal : Implement the magnetic field effect/2D characterization in the SK simulation.

0 mG

-100 mG







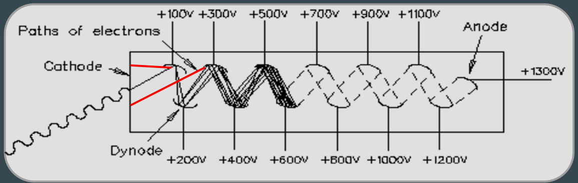
Count of photoelectron pulse

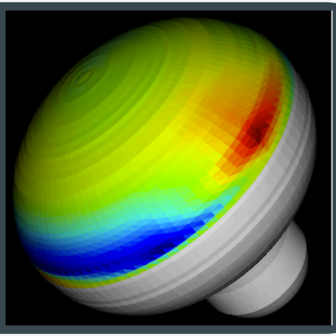
The number of pulse

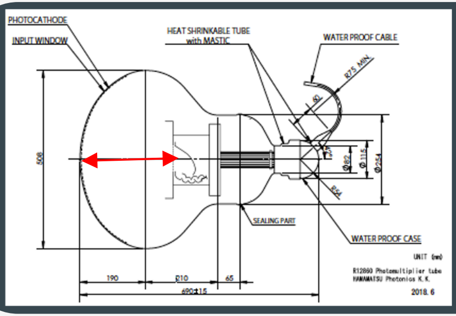
Hypothesis

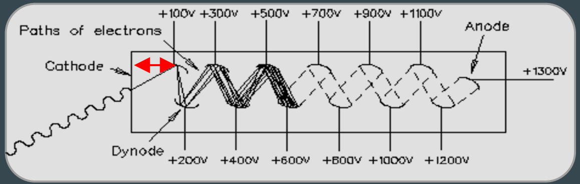
<u>How does the magnetic field affects:</u>

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



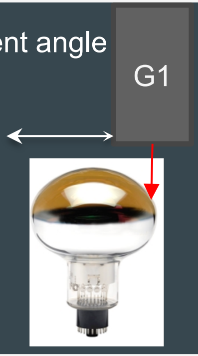




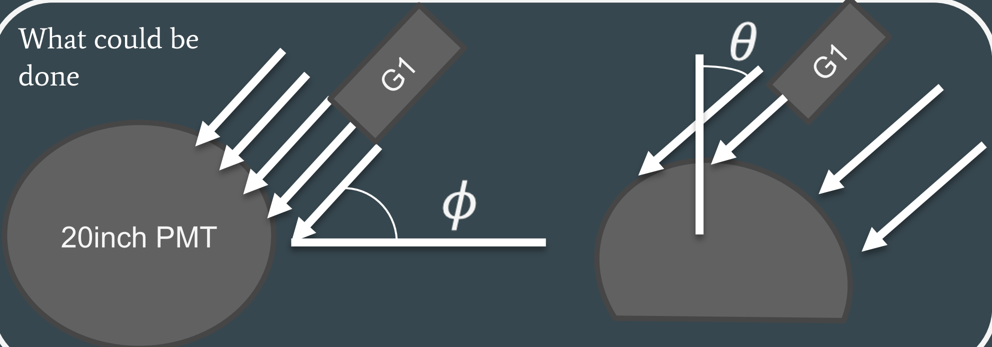


SK simulations

Incident angle scan

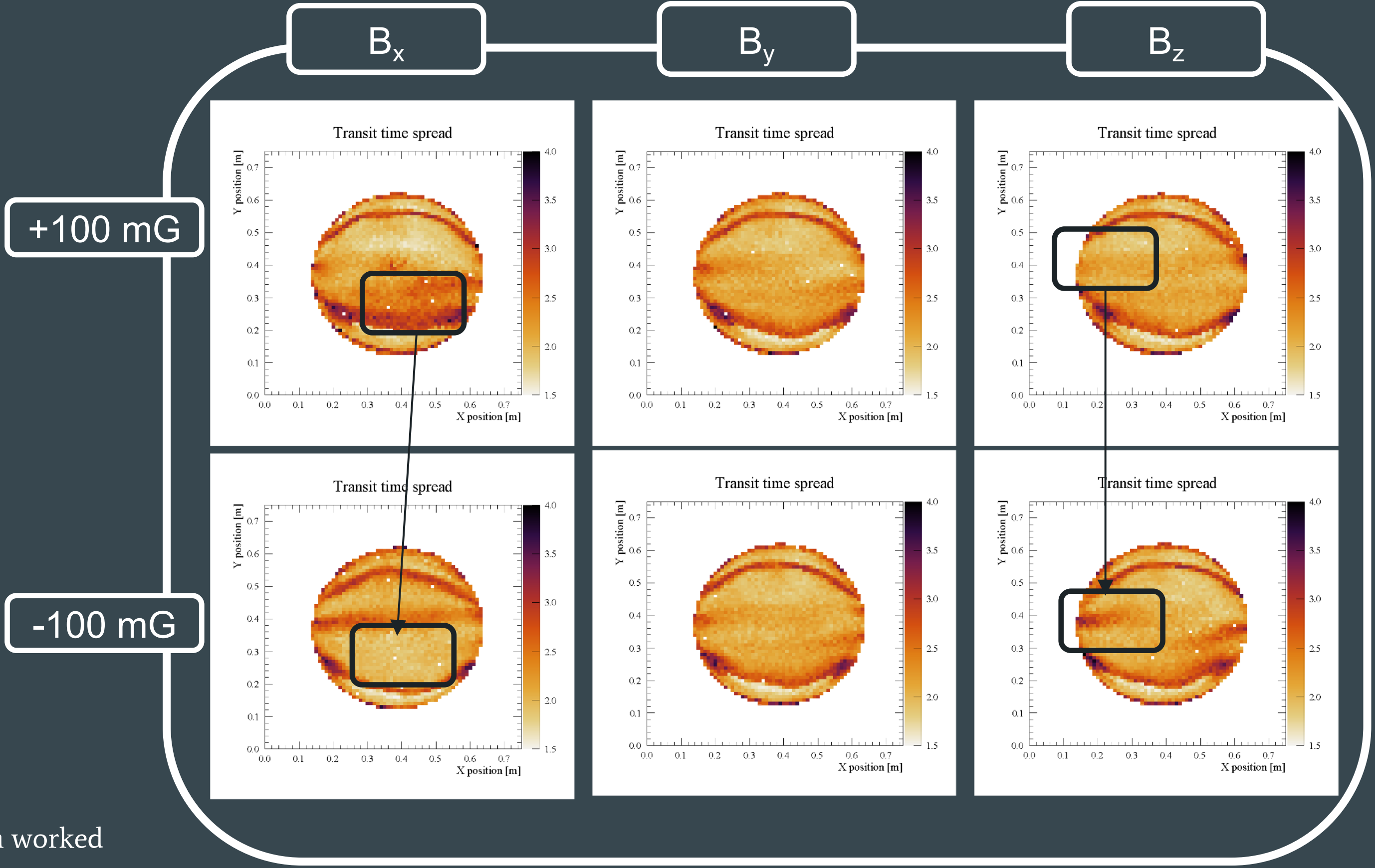


What could be done



Measurements : Transit time spread

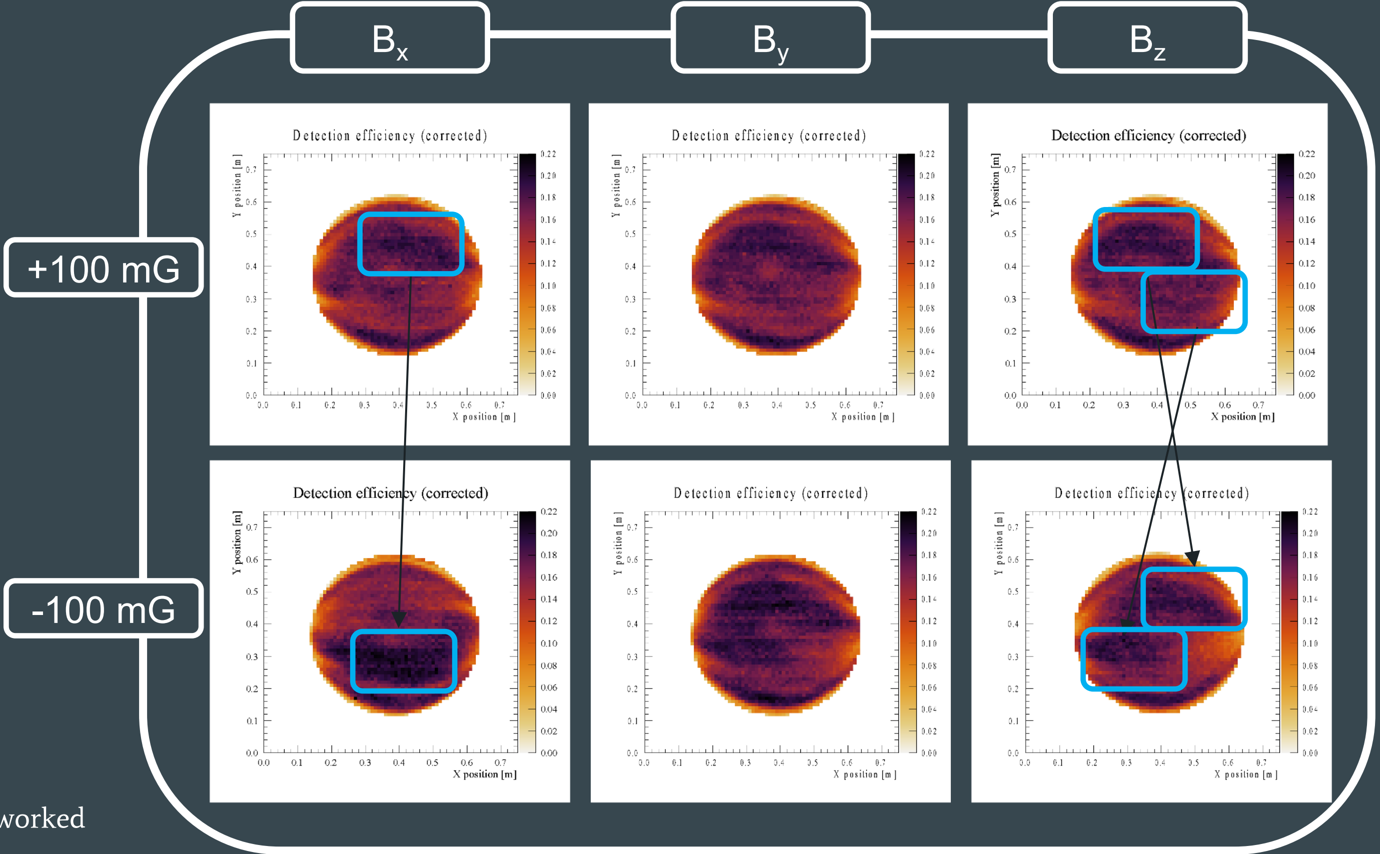
- Hard to modelize theoretically this change
- As expected local variations



Credit : John Walker and Blair Jamieson worked

Measurements of the detection efficiency

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



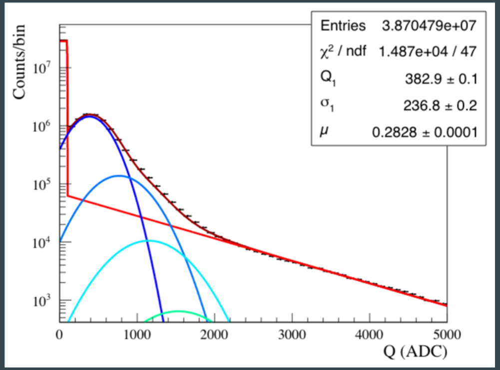
-> More data needed to build a simple empirical model

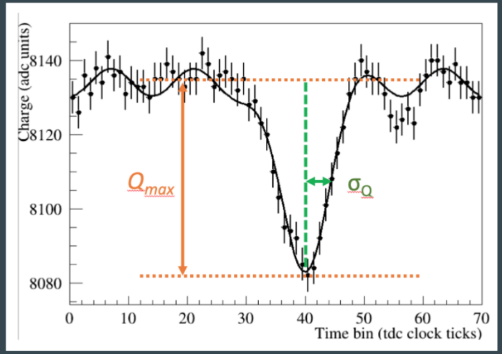
Credit : John Walker and Blair Jamieson worked

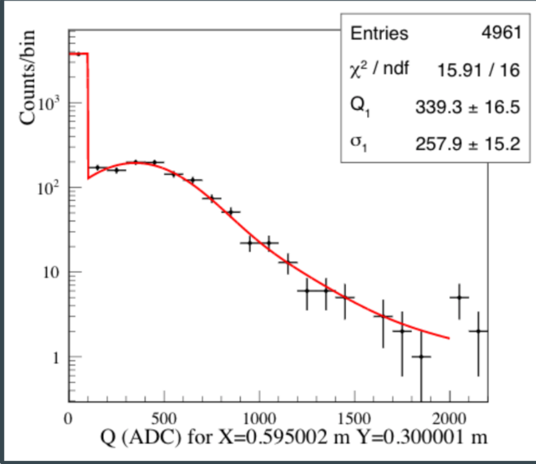
Gain measurements

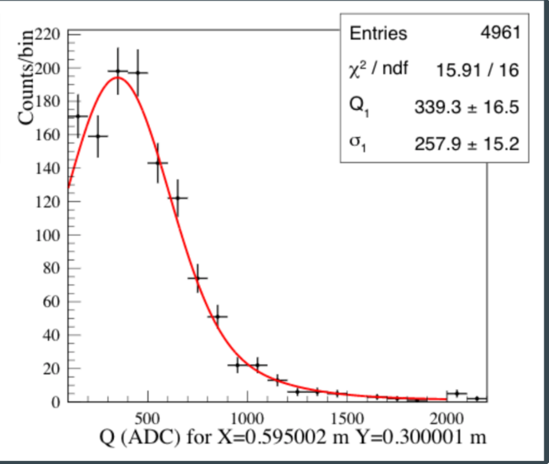
Gain = multiplication factor for a single photoelectron arriving at dynode.

- Model: sum of Gaussian, parameters:
  - Q :gain of SPE
  - σ_1 : Width of SPE
  - w: Weight of exponential background w
  - **α**: exponential constant
  - μ: avg number of photoelectrons collected
- Only Q_1, σ_1, μ allowed to vary.







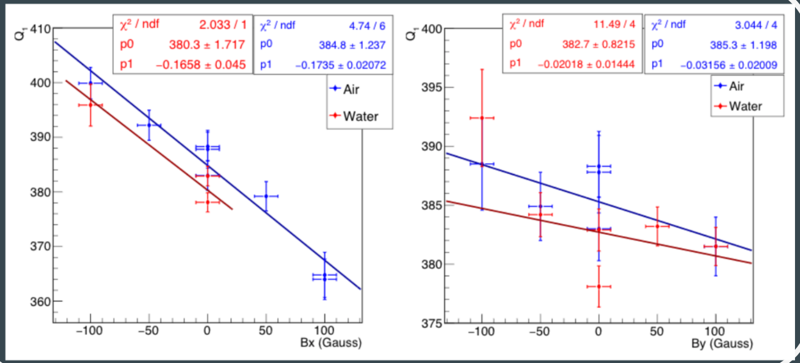


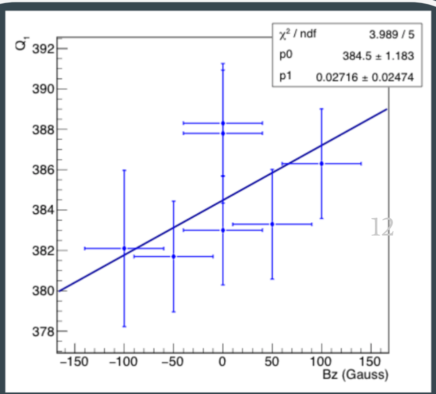
->Good agreement between fit parameter and data

Credit : John Walker and Blair Jamieson worked

Gain measurements

- 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





-> More data needed to build a simple empirical model

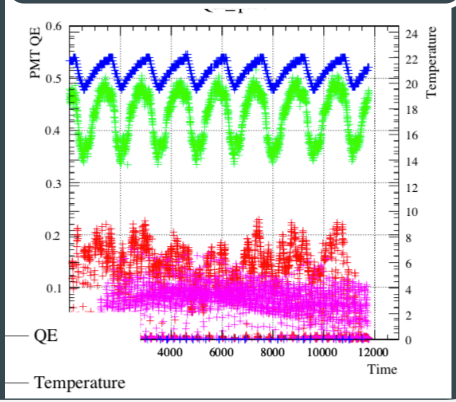
Credit : John Walker and Blair Jamieson worked

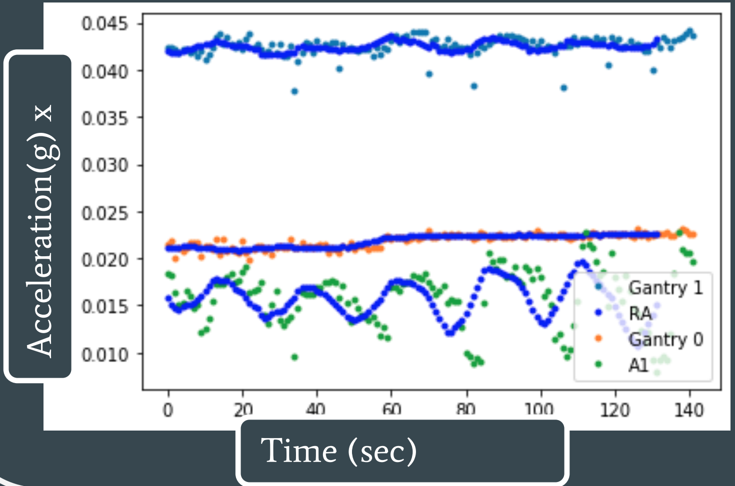
Ongoing work

- 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

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

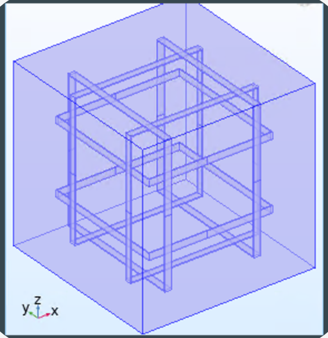
Temperature and QE as a function of time

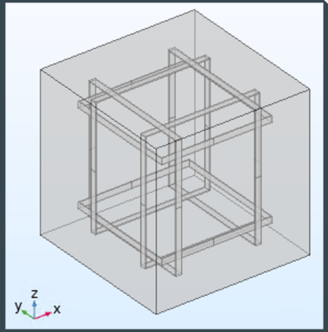


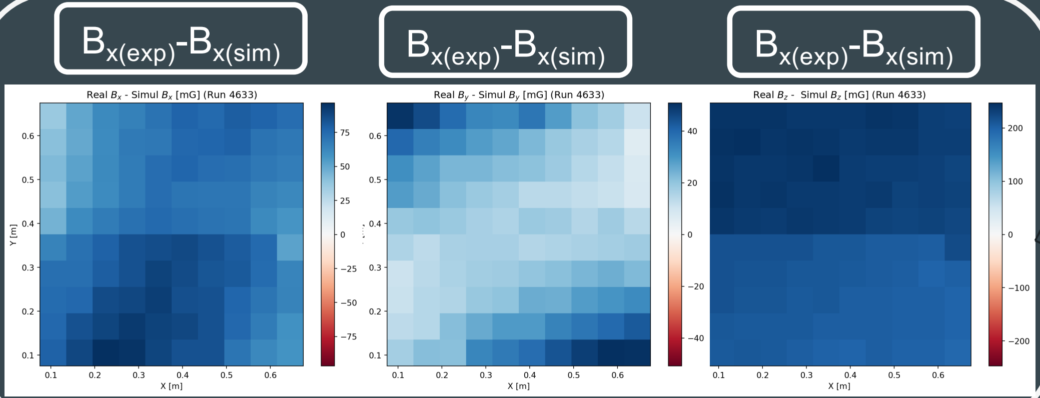


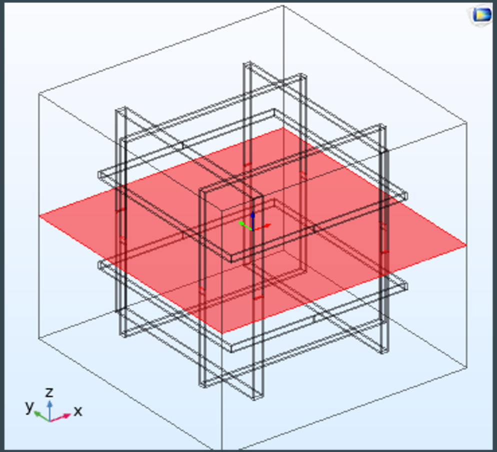
COMSOL simulation of PTF

- 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





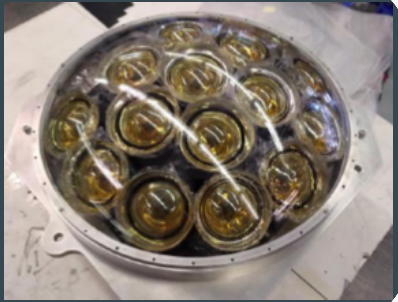


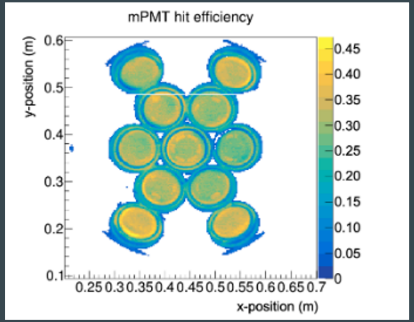


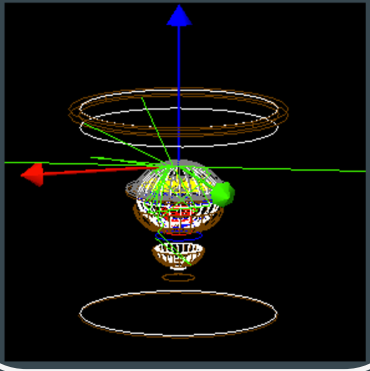
The next steps

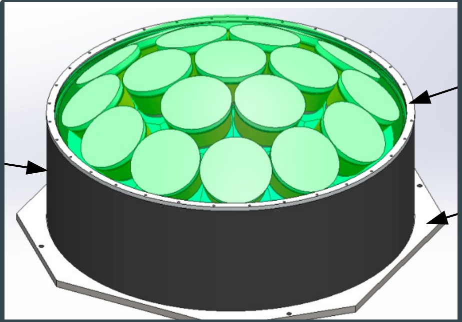
- Preparing PTF for characterizing as well the mPMT module
  - Dark rate measurements
  - Gain,transit time, detection efficiency
  - Angular response comparaison
  - Etc.

- 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

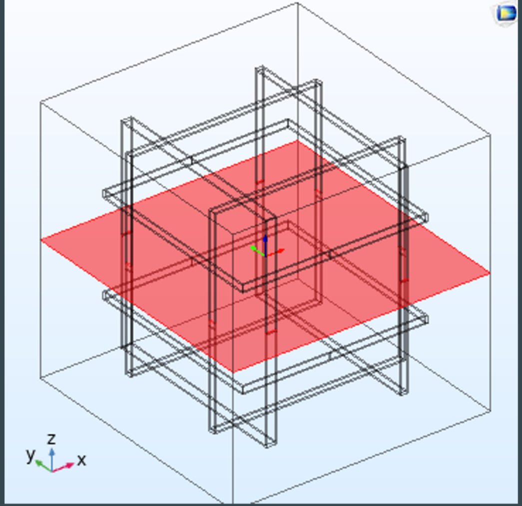
- PTF is undergoing hardware upgrades

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

Back-up

Compensating the magnetic field

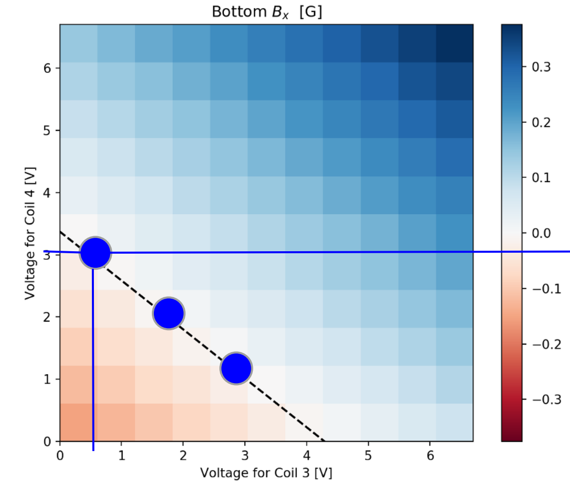
- Degauss procedure for a series of voltages
- 3X Obtain relation between the 2 coils for 1 direction

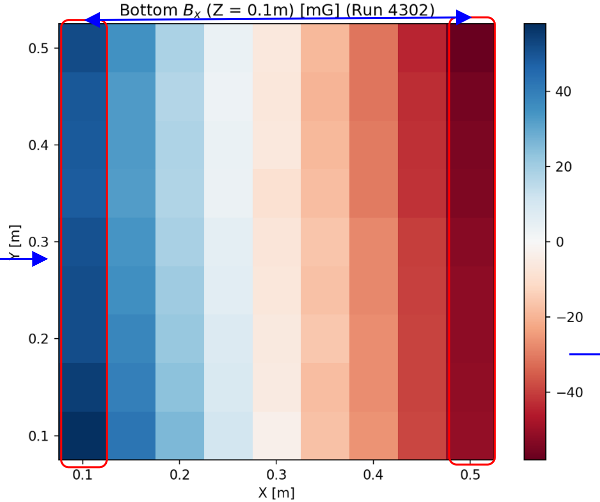


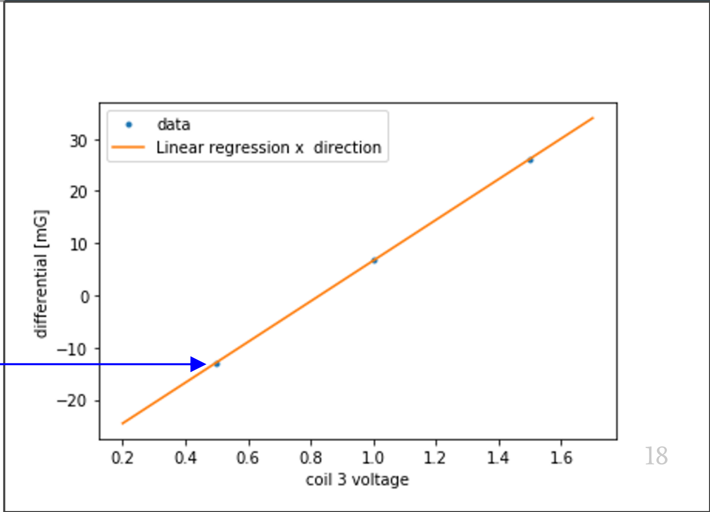
1-Voltage scan

2-Spatial scan :

3-Differential plot



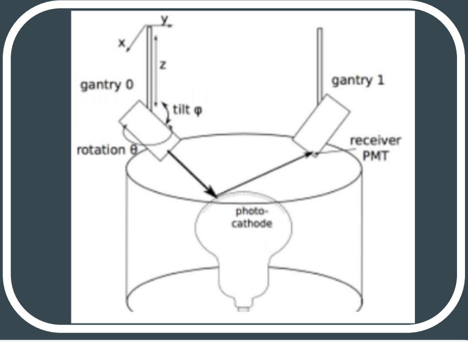


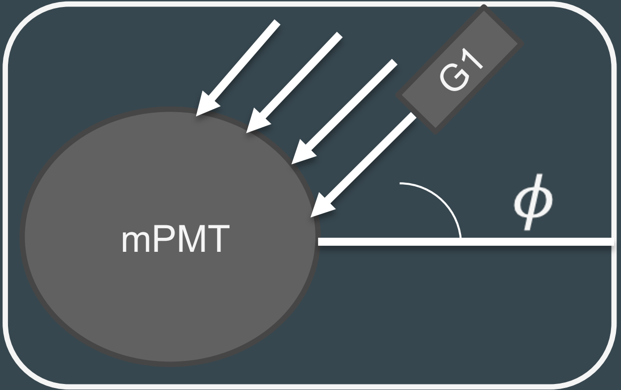


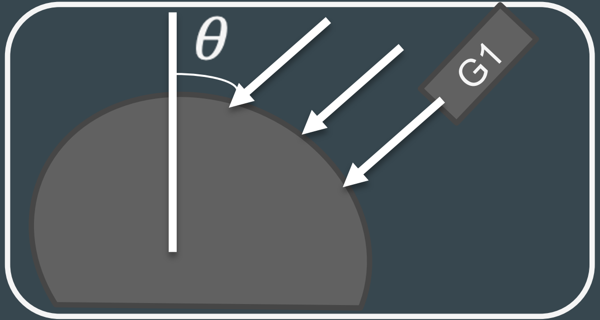
Ex-situ characterization plan for mPMTS

- 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



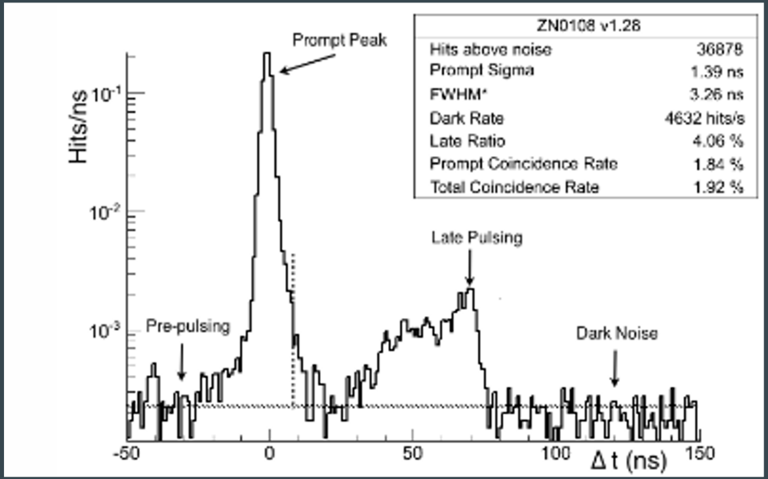




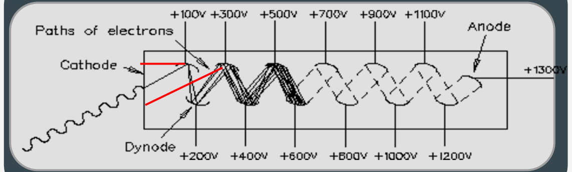
Hypothesis (2)

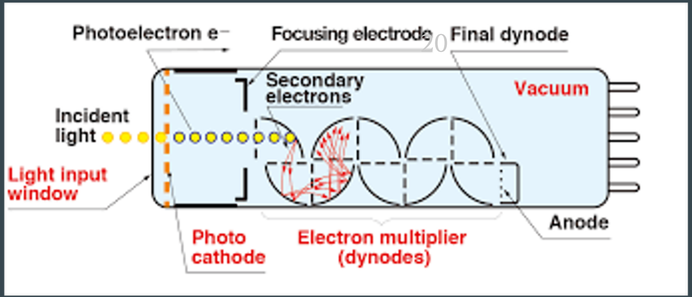
<u>How does the magnetic field affects:</u>

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



Ion feedback from the amplification process





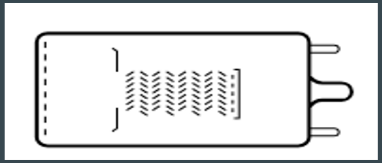
Hypothesis (2)

<u>How does the magnetic field affects:</u>

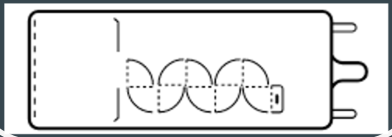
- Gain
  - Depends on the dynode type (space between each dynodes)
  - Orientation of the PMT (more general)
  - incident angle

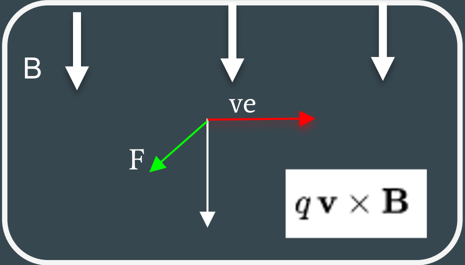
->Results for 20inch PMT

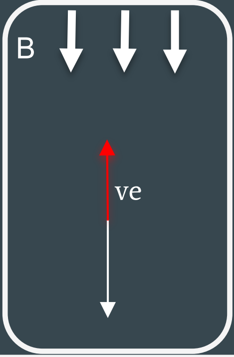
Venitian dynode type

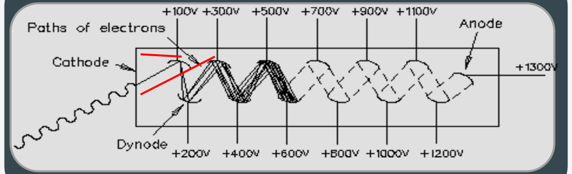


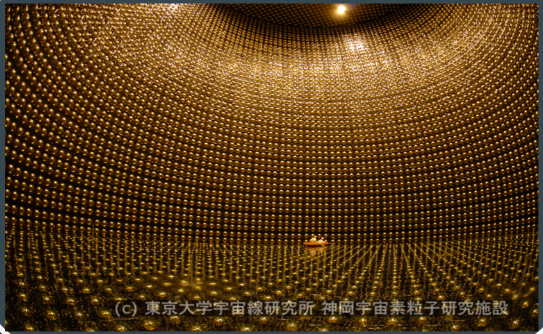
Box and grid type







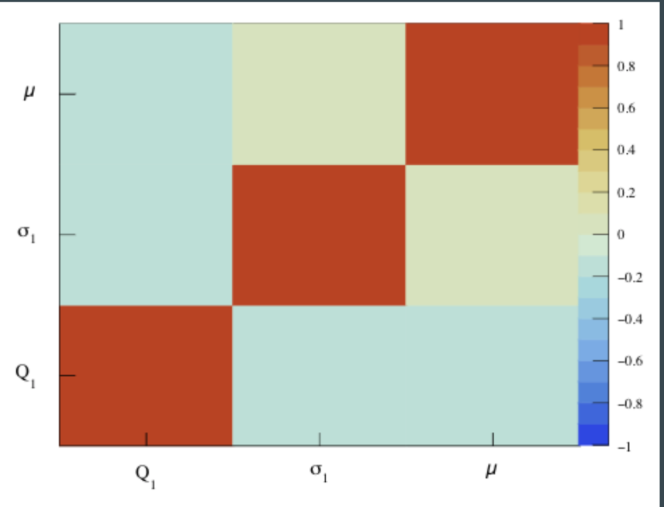


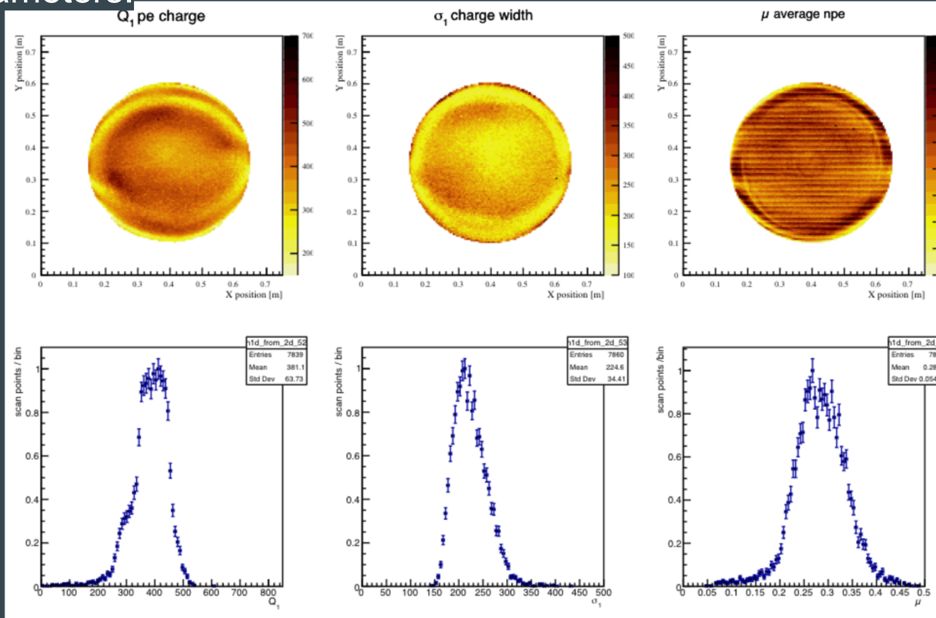


Gain measurements (2)

- Light collected μ shows the same temperature effect as the detection efficiency measurements.
  - This effect is decoupled from the other parameters.

Correlation matrix



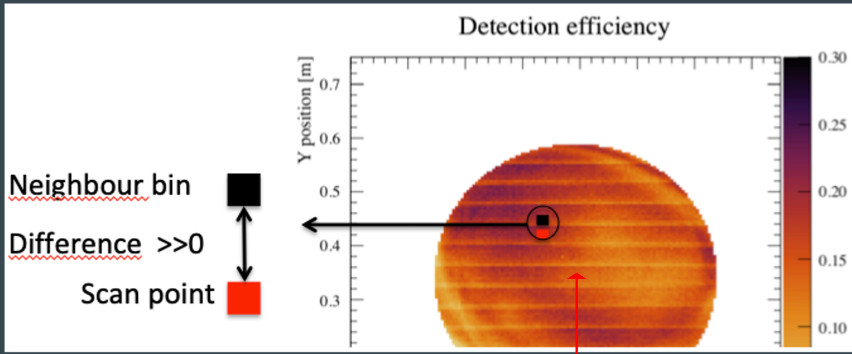


How the new correction methods works ?

<u>General idea</u>
-Minimize the variation of the efficiency locally (in 2D).

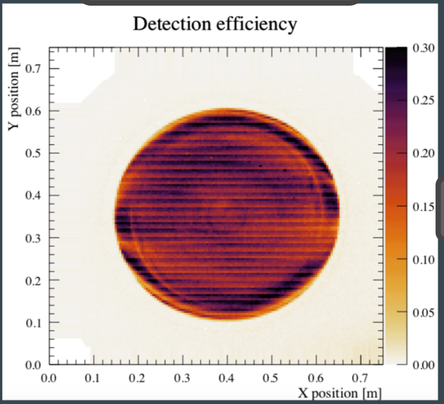
Assumption : around one scan point, the variation should be really small

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



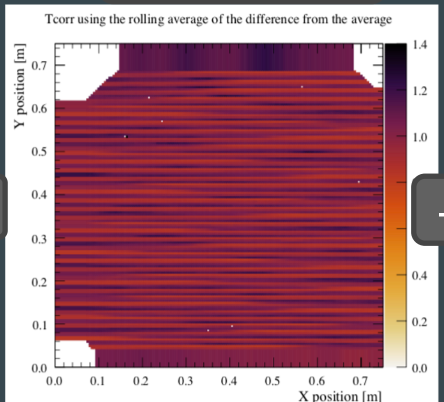
$$\sum_{1}^{Nbbins} (QE_{SKcorr}(y) - QE_{SKcorr}(y-1))^2$$

Raw data



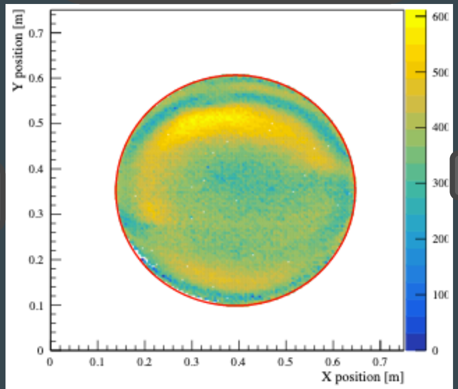
X

Fit calculated from metric



->

Apply hough transformation



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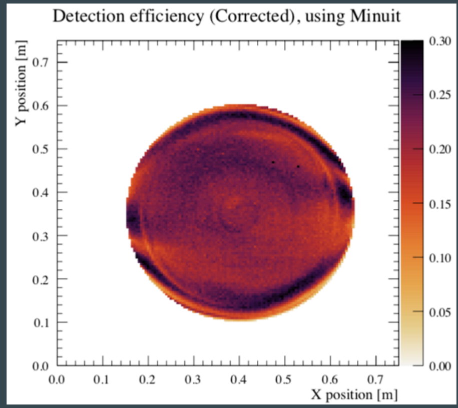
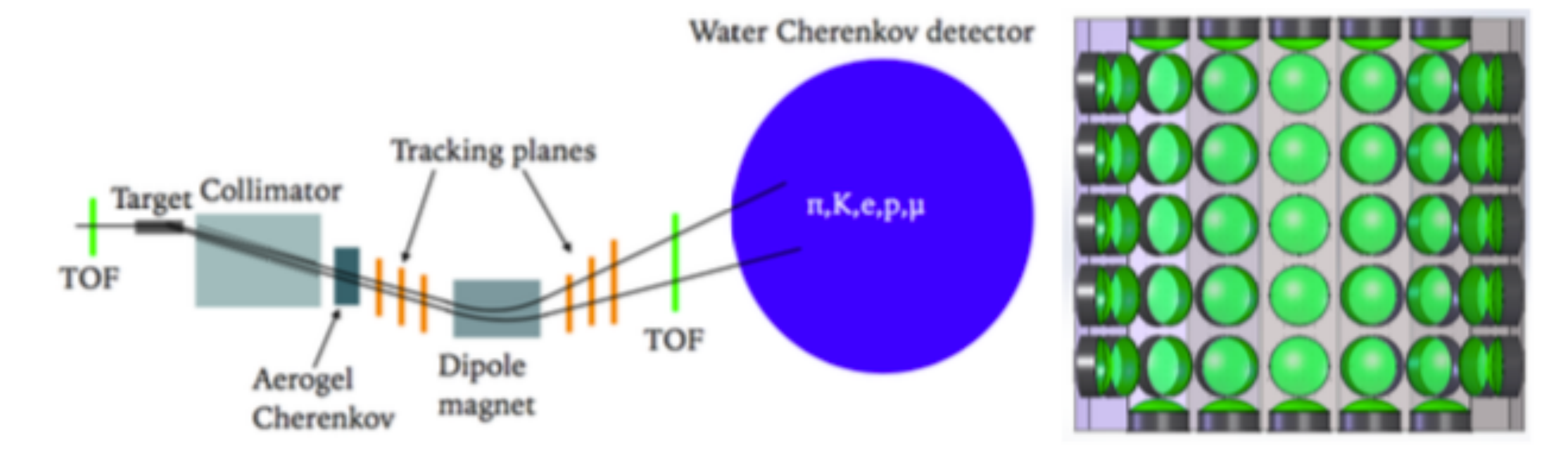
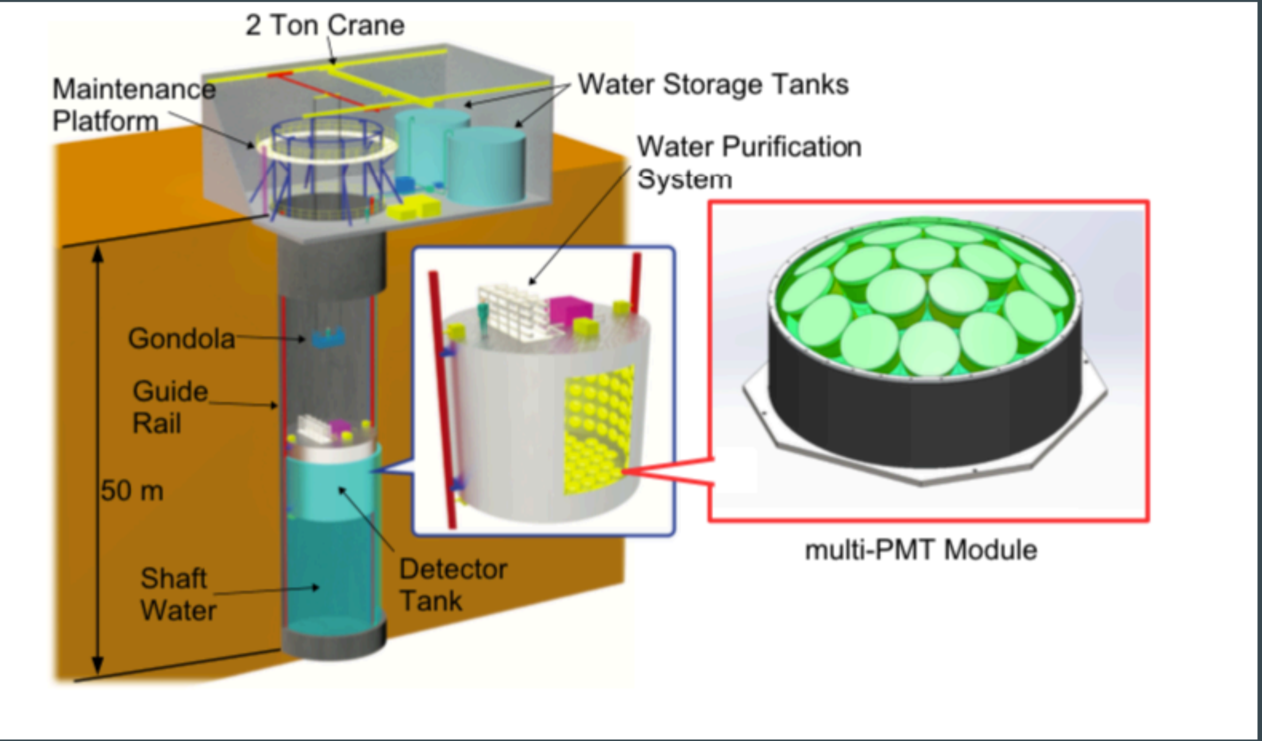


WCTE (water cherenkov test experiment)

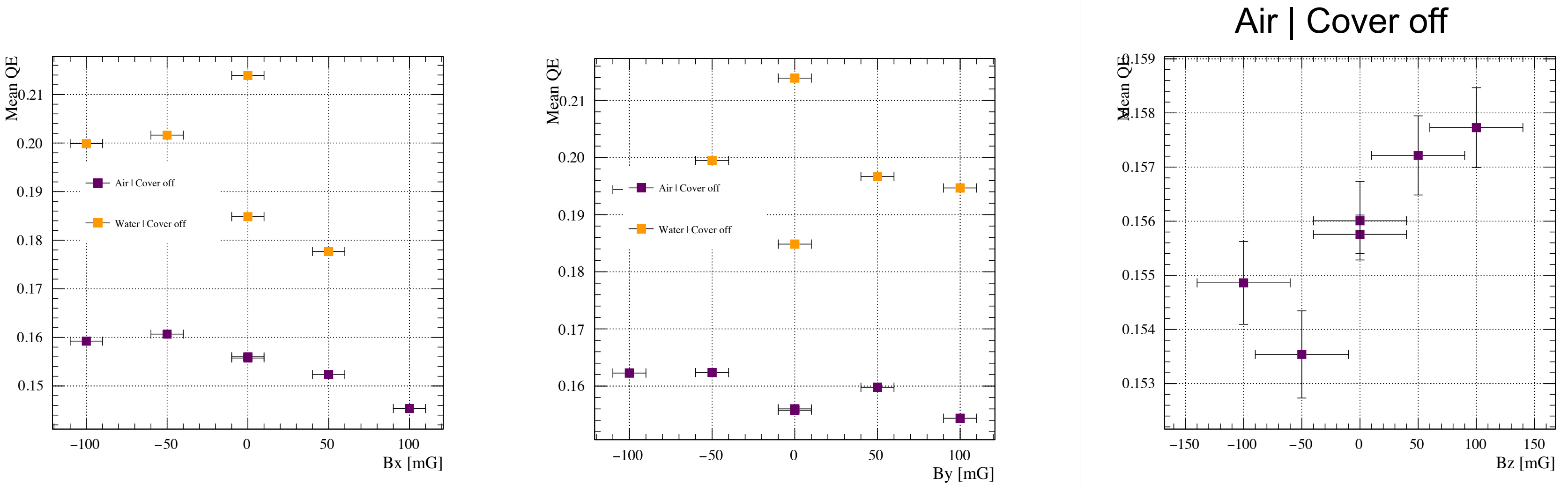


IWCD experiment



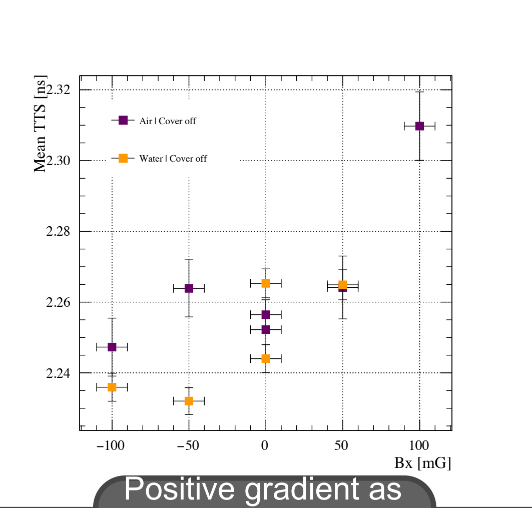
Cover on/off ratio

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

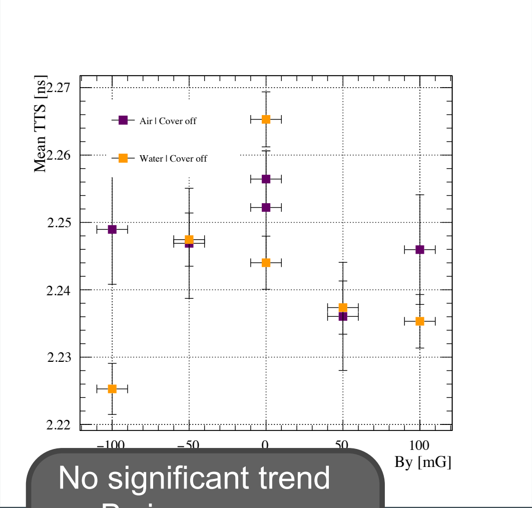


Transit time spread (2)

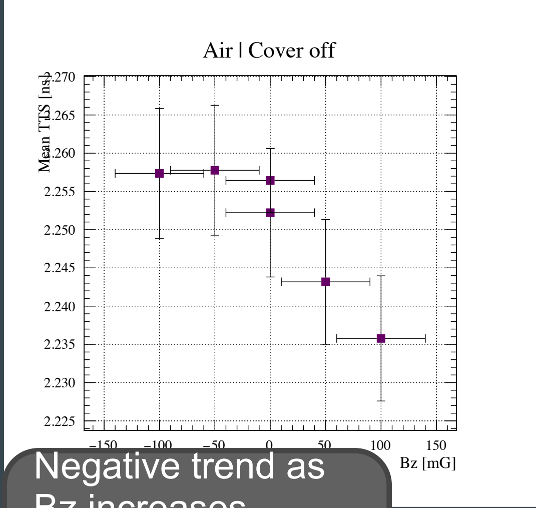
- Similar to the 2.2 ns quoted by Hamamatsu.
  - Hamamatsu do not consider the positional effect.
- Factor ~1.5 greater effect than RTT.
- Agreement between air and water measurements.



Positive gradient as Bx increases? ~2% effect over 200 mG.



No significant trend as By increases. Small differences between measurements.



Negative trend as Bz increases. ~1% effect over 200 mG.

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 σ_1:
  - Decreasing for increasing By.
  - Relatively constant for increasing Bx and Bz.
  - Close agreement between water and air.