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

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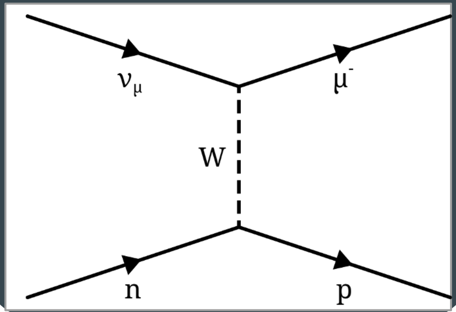
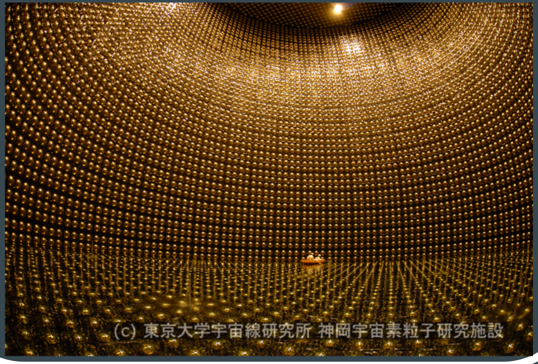
Super-Kamiokande experiment

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

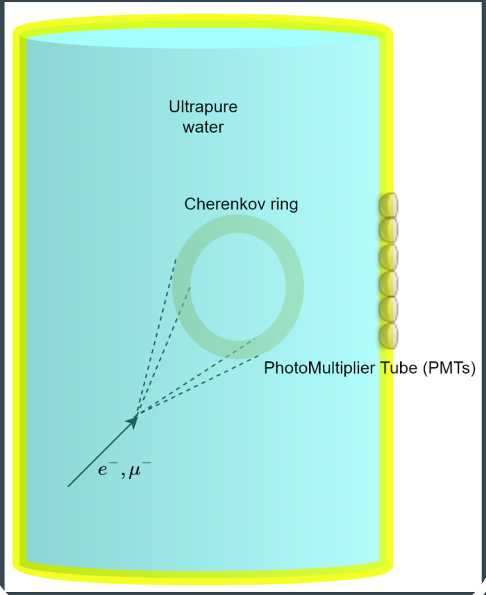
Neutrino interaction



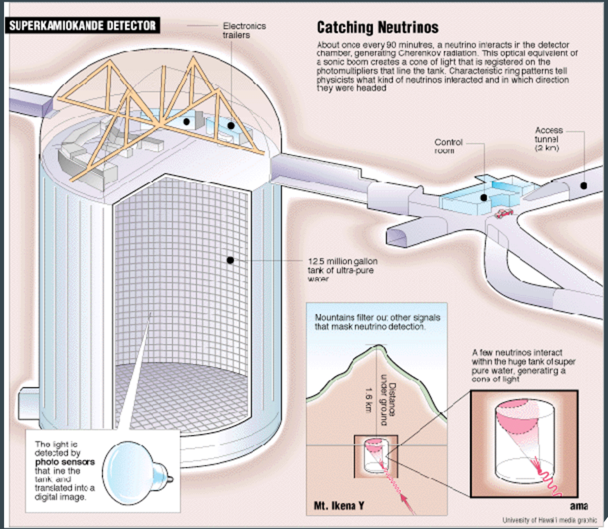
~11,000 photo-multiplier tube (PMT)



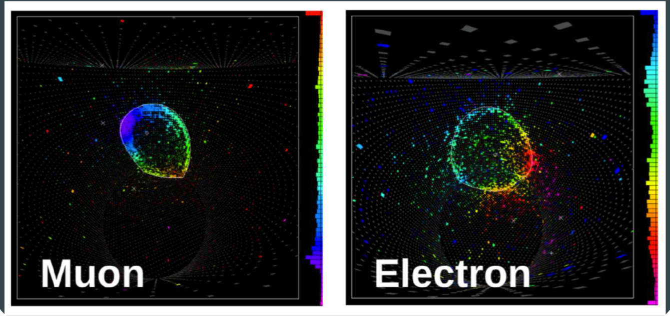
Neutrino events creating cherenkov radiation



Super-Kamiokande



Neutrino events



The magnetic field in Kamioka

- Earth field 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 has an impact ?
YES!

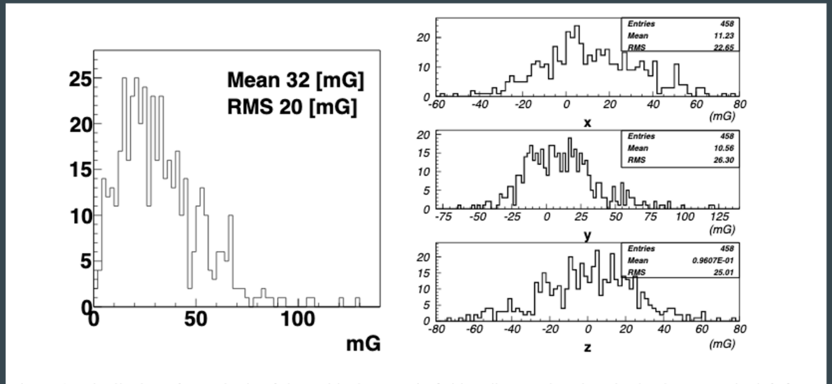
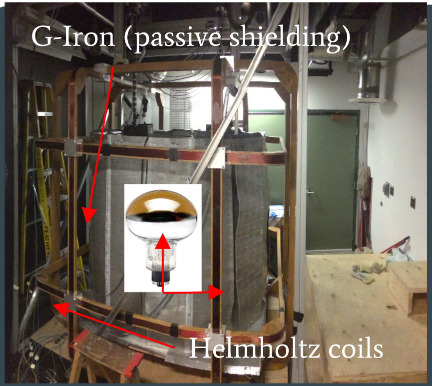
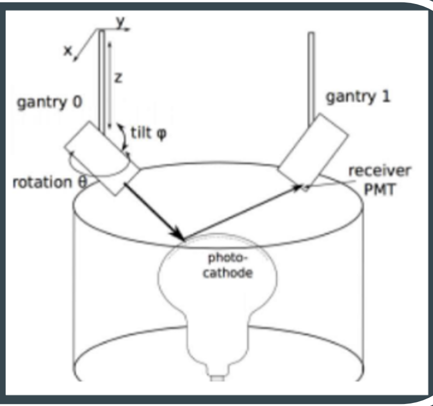


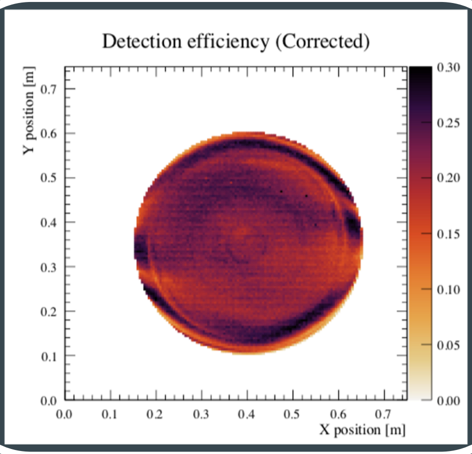
Figure 1: Distribution of magnitude of the residual magnetic field at different locations in the detector. The left figure shows the magnitude; the right figures show the value along the usual SK coordinate system axes.

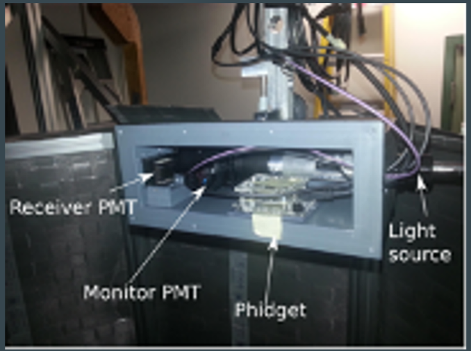
The Photosensor Test facility (PTF) at TRIUMF

- 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

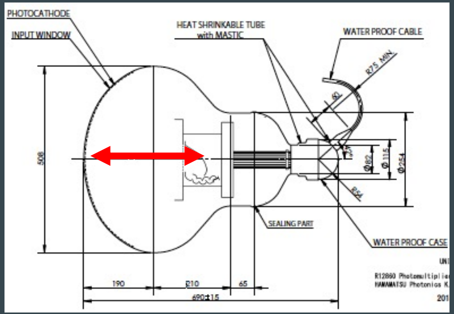




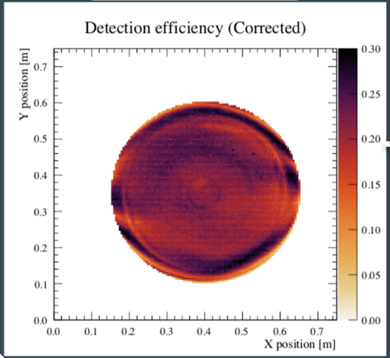




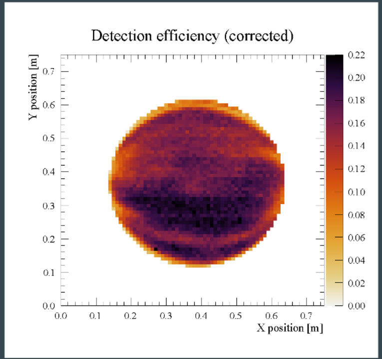
Goals of PTF



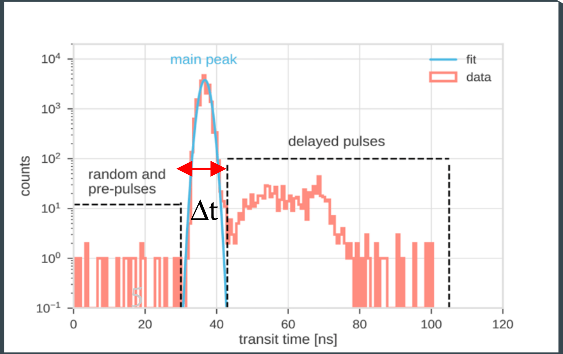
0 mG



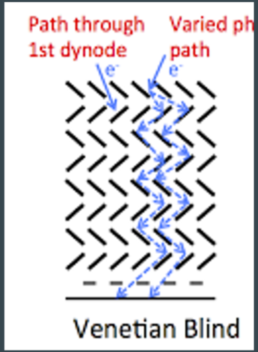
-100 mG



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



-> Goal : Implement these effects in the Super-K large simulations and evaluate the physics impact



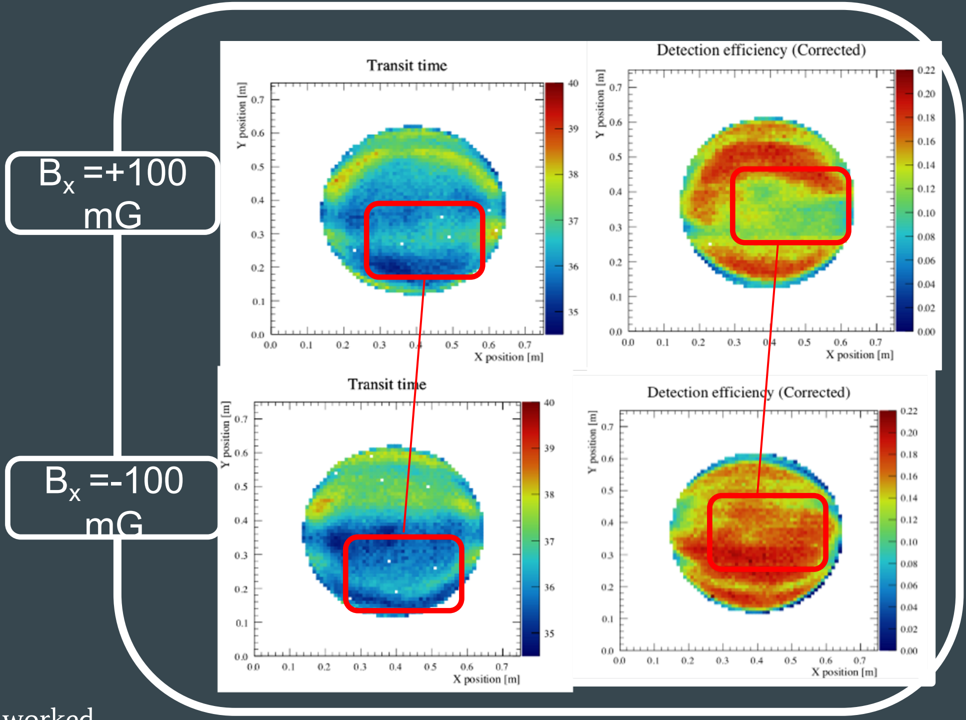
Count of photoelectron pulse

The number of pulse

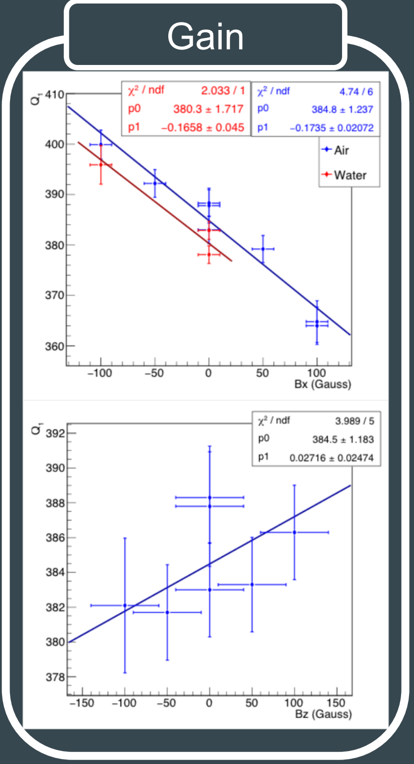
Measurements done in PTF

- Strong position dependance
  - Local variations of time and efficiency
- Shift of high region under the magnetic field
- Only the beginning
  - Want to test much more parameters in the future (wavelength, polarisation, incident angle)
  - PTF is undergoing major hardware upgrades

PMT parameters under a magnetic field variation



Gain

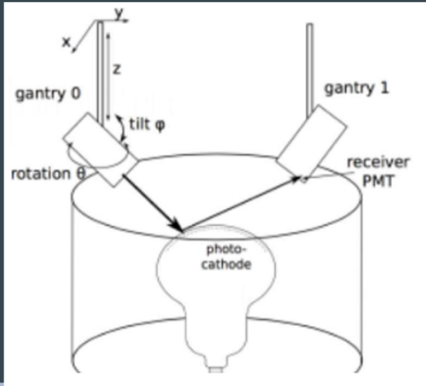


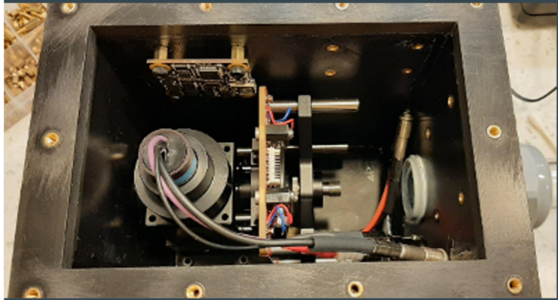
Credit : John Walker and Blair Jamieson worked

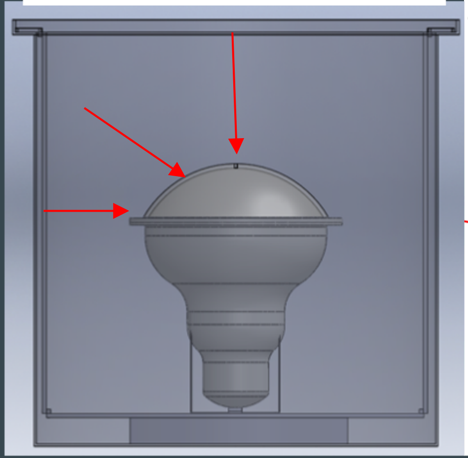
PTF hardware upgrades and relocation

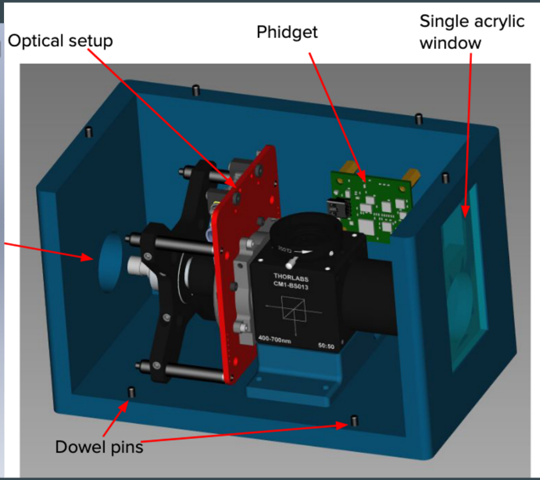
S.Wingfelder Pos-C14

- Improve measurements, reliability and efficiency of measurements
  - Redesign of the optical box
    - Rotator to allow study of polarization
    - Allow high angle measurements
  - Reduction of the ambient magnetic field (relation of PTF further from the cyclotron)
    - Magnetic field survey
  - Temperature sensors
  - Improvement of the collision avoidance software to allow reflection measurements
  - And much more !



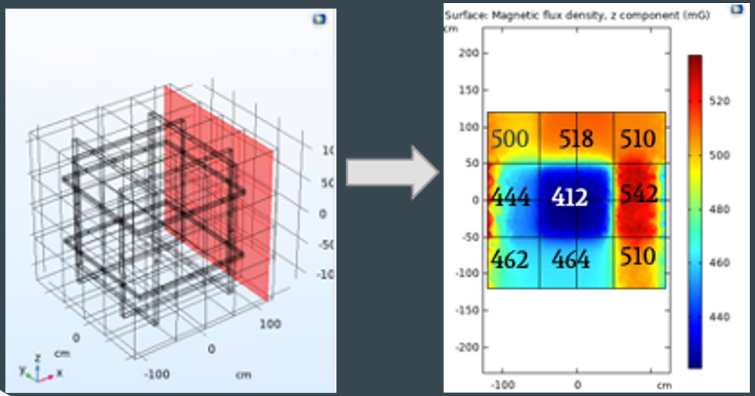




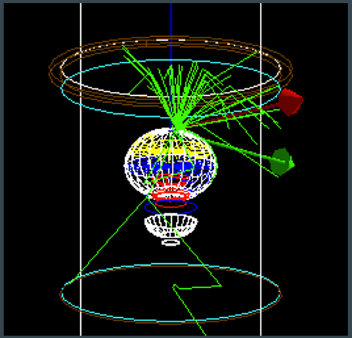


On-going work

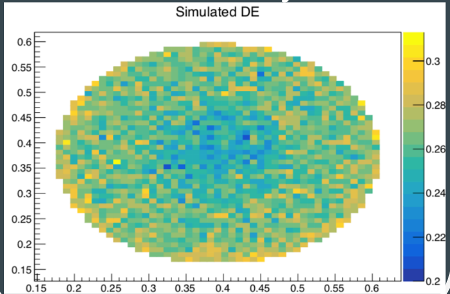
- Building Monte-Carlo simulations of PTF
  - Understand reflections/refractions of photons (Geant4)
    - Separate this effect from the inner process that will use PTF data
  - Long term idea is to add PTF measurements
- Building magnetic field simulations of PTF
  - Help understand the magnetic field in the new room
  - Input measurements that were done and study non-uniformity

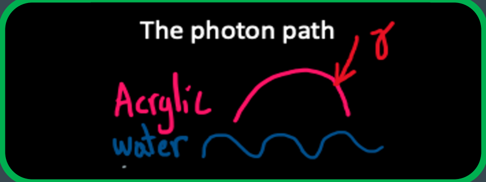


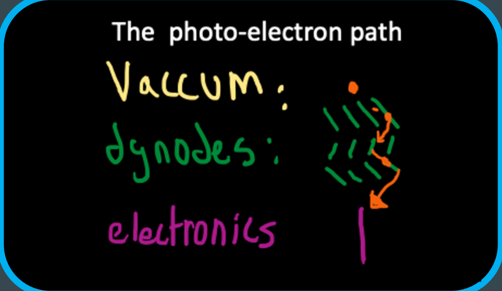
Build PTF geometry



Simulate detection efficiency







Magnetic field measurements

2	500.2692	518.4977	510.3909
1	444.4239	412.9745	542.1148
0	462.6183	464.0317	854.6711
	0	1	2

Conclusion

- Did some measurements of the effect of the magnetic field on the 20inch PMT
  - Important effect on the gain, the transit time and the detection efficiency
  - Will include more parameters
- PTF is undergoing hardware upgrades
- Monte-Carlo simulations work on the PTF is being done
  - First step towards building the semi-empirical model
- Magnetic field simulations are done
  - Allow a better understanding of the measured field

Thank you

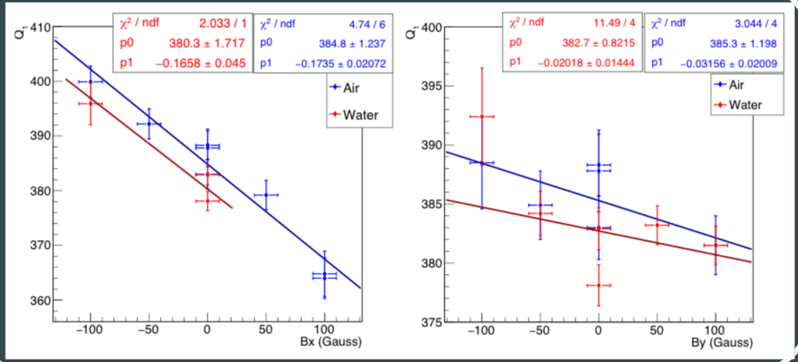
Back-up

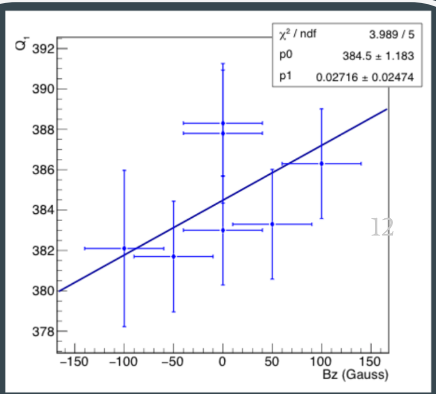
Gain measurements

- 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
->Need accurate angular response



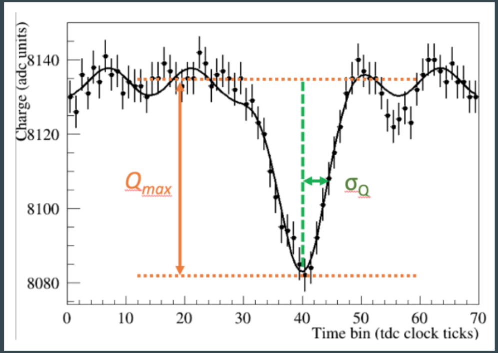


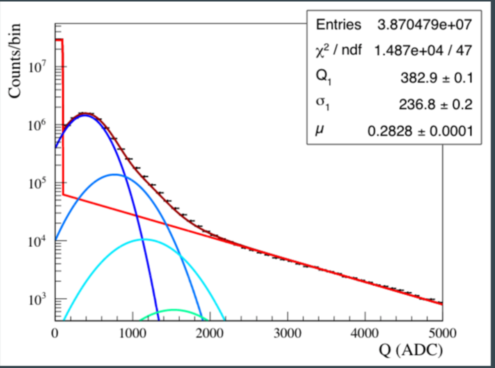
Credit : John Walker and Blair Jamieson worked

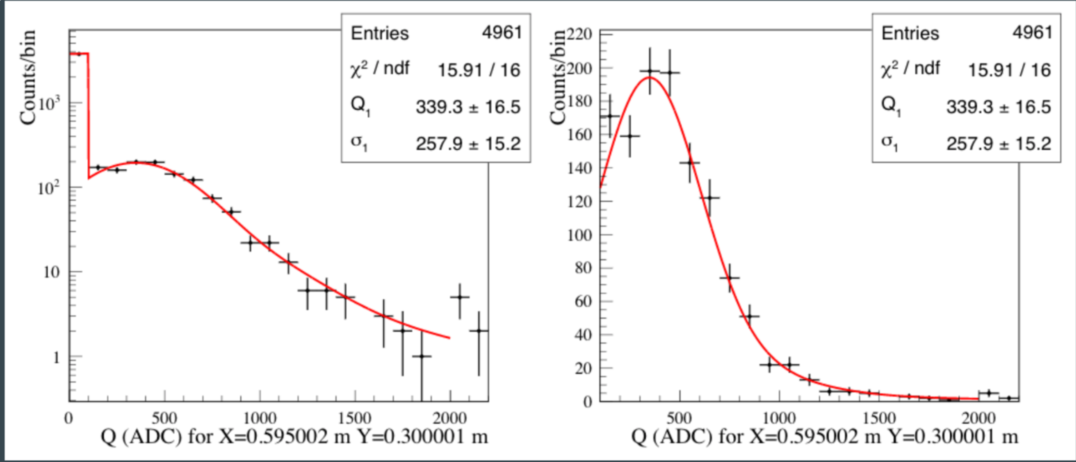
Gain measurements

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

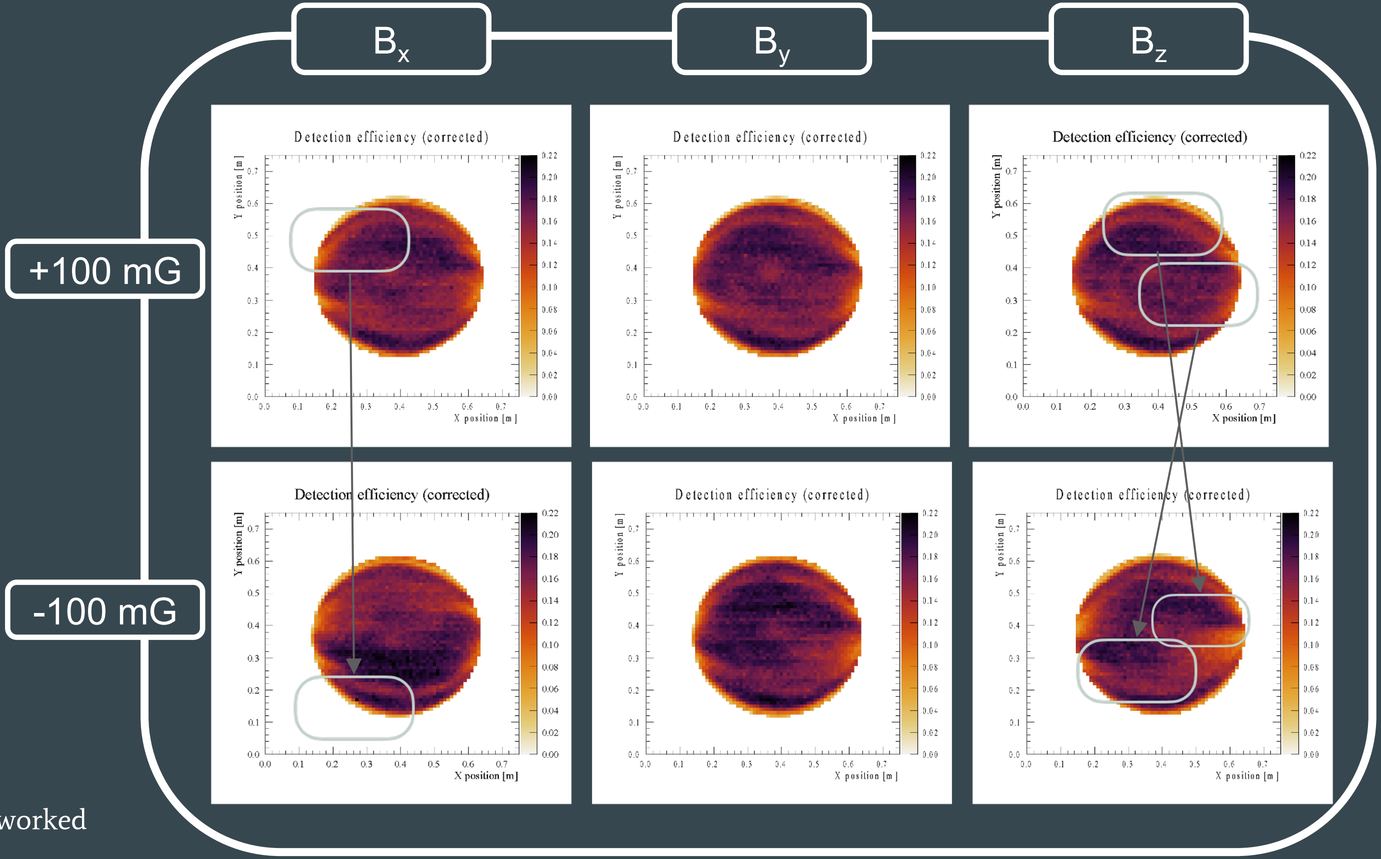
Credit : John Walker and Blair Jamieson worked

Measurements of the detection efficiency

- Same as previously :

-> More data needed to build a simple empirical model

->Need accurate angular response

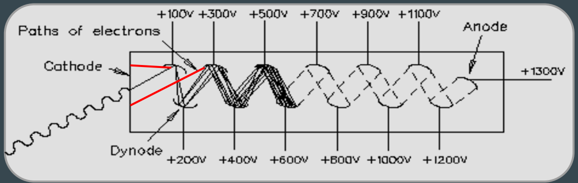


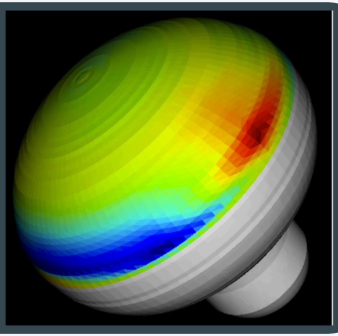
Credit : John Walker and Blair Jamieson worked

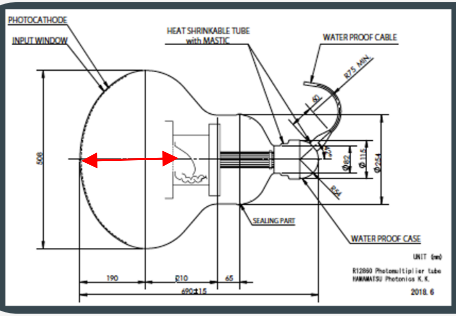
Hypothesis (1)

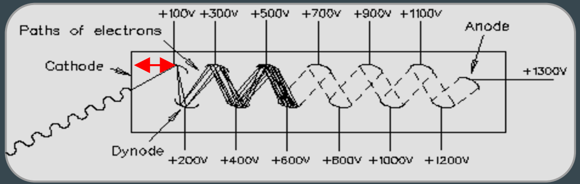
<u>How does the magnetic field affects:</u>

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



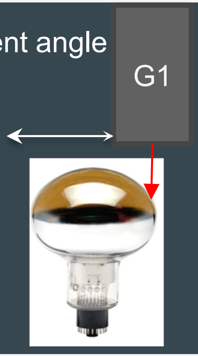




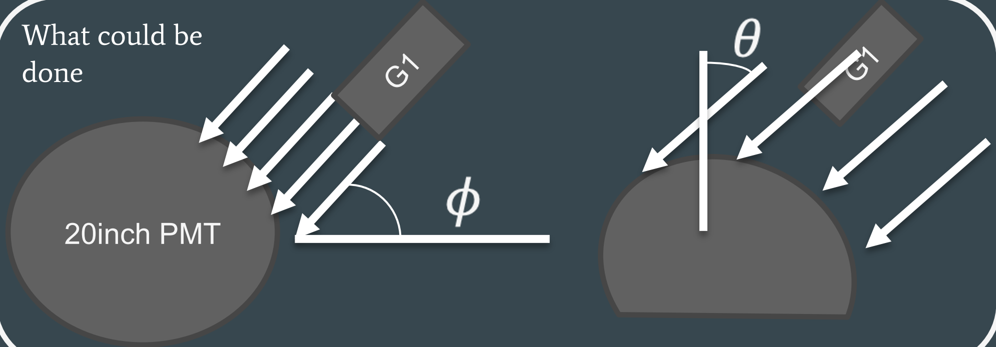


SK simulations

Incident angle scan

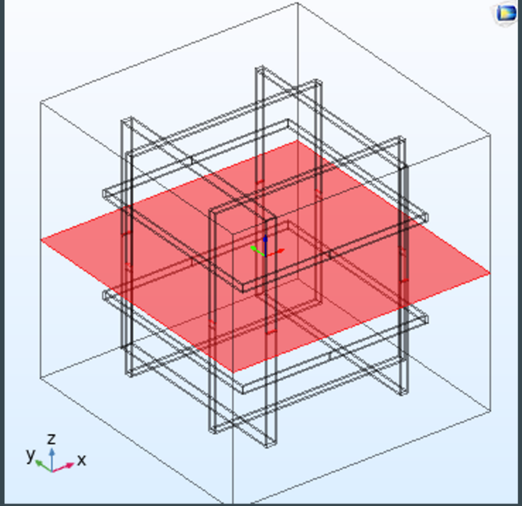


What could be done

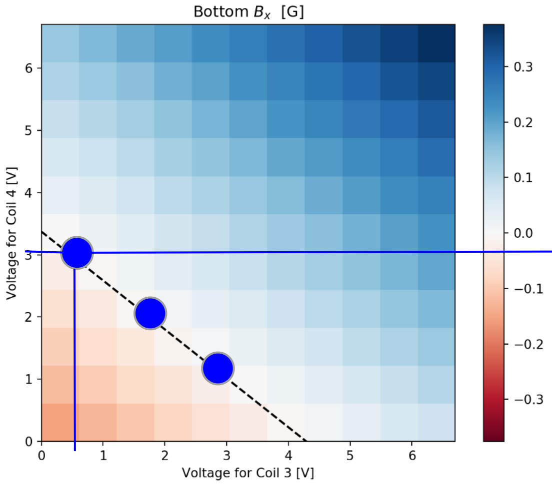


Compensating the magnetic field

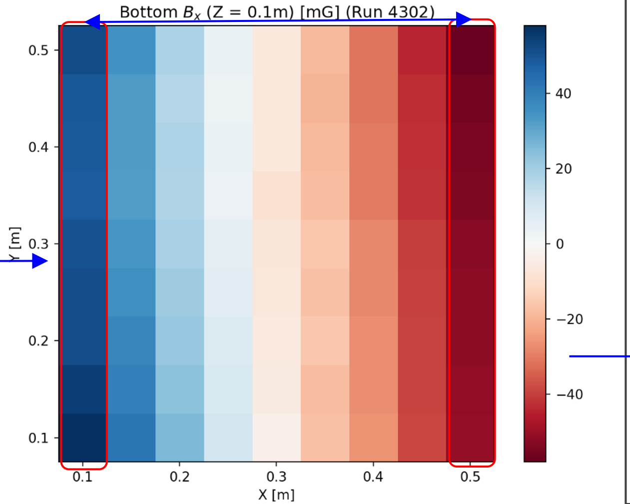
- Degauss procedure for a series of voltages
- 3X Obtain relation between the 2 coils for 1 direction



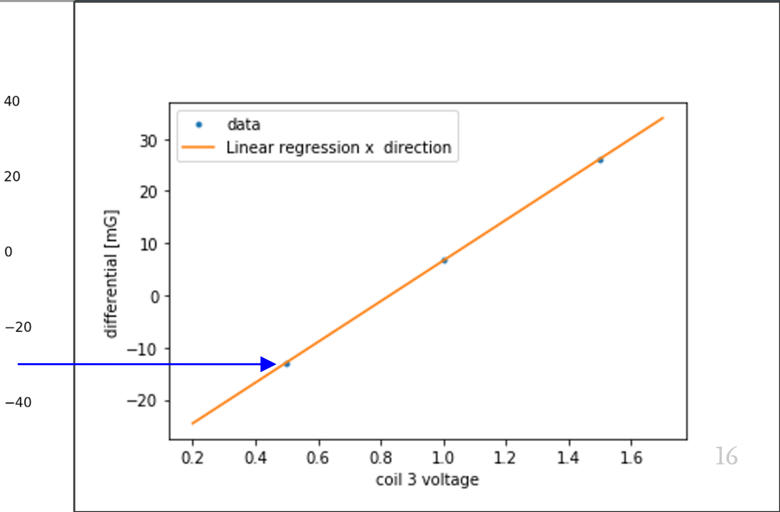
1-Voltage scan



2-Spatial scan :



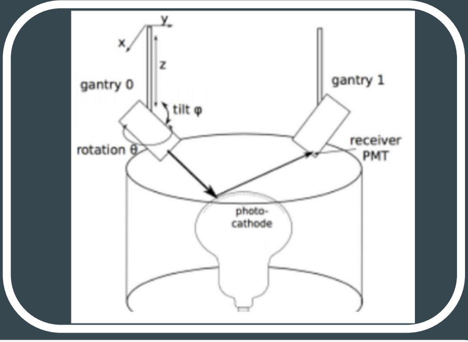
3-Differential plot

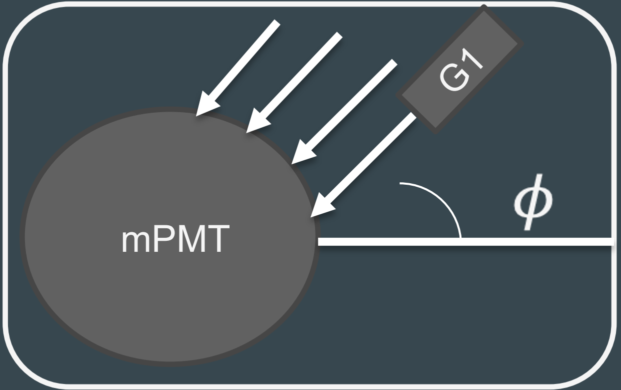


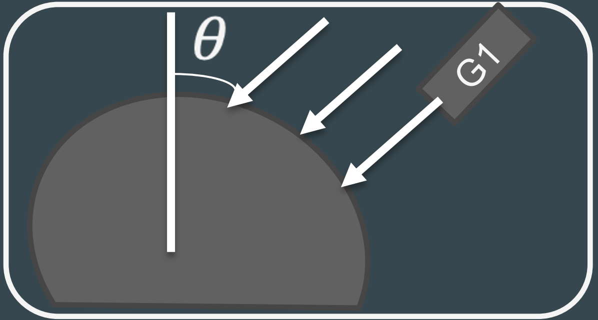
Ex-situ characterization plan for mPMTS

- 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



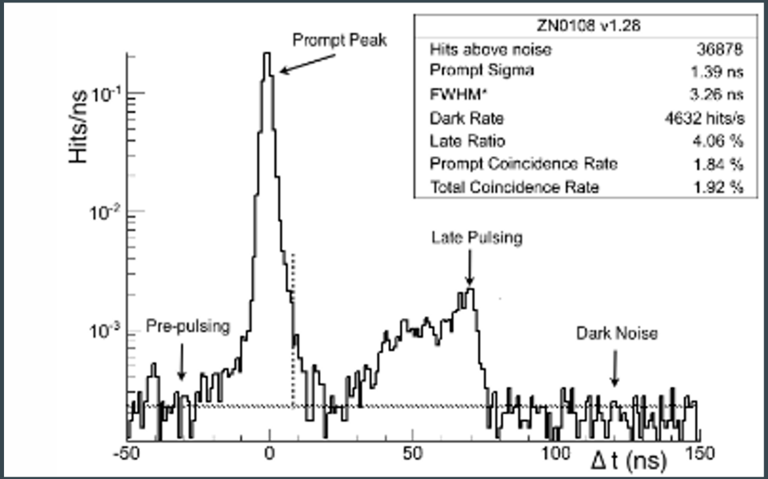




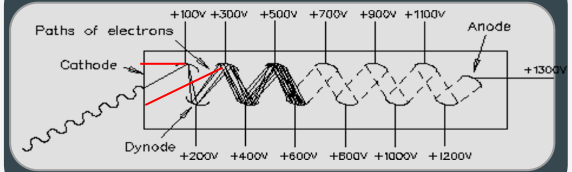
Hypothesis (2)

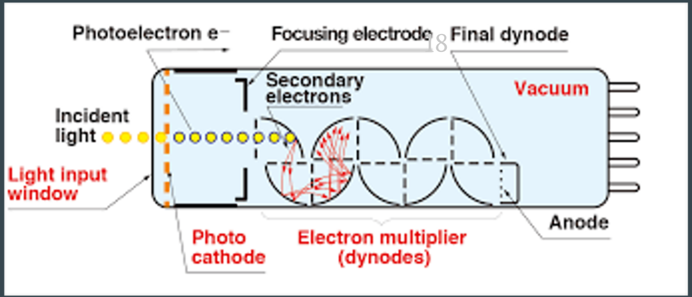
<u>How does the magnetic field affects:</u>

- 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





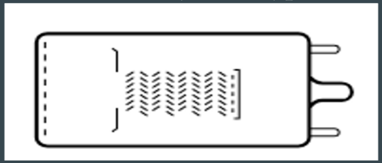
Hypothesis (2)

How does the magnetic field affects:

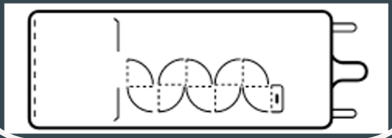
- Gain
  - Depends on the dynode type (space between each dynodes)
  - Orientation of the PMT (more general)
  - incident angle

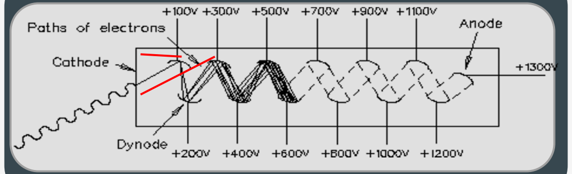
->Results for 20inch PMT

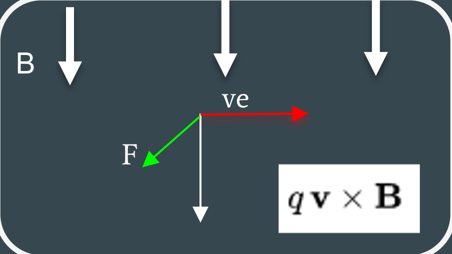
Venitian dynode type

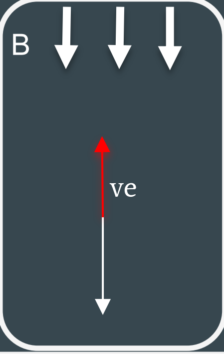


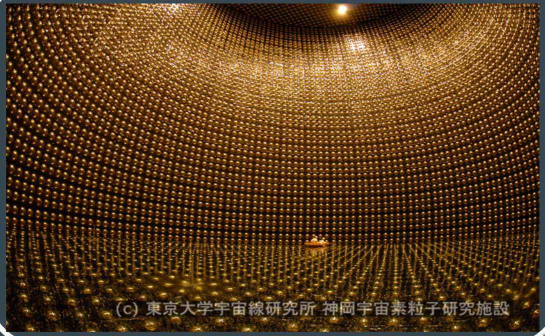
Box and grid type











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