CHIBA UNIVERSITY

ICECUBE NEUTRINO OBSERVATORY

Performance Evaluation of New Type of PMT Aimed for High Quantum Efficiency for High Energy Neutrino Experiment

高エネルギーニュートリノ実験のための、高量子効率化を目指した新型PMTの性能評価

Feb 14, 2025

Seno Zenta

IceCube

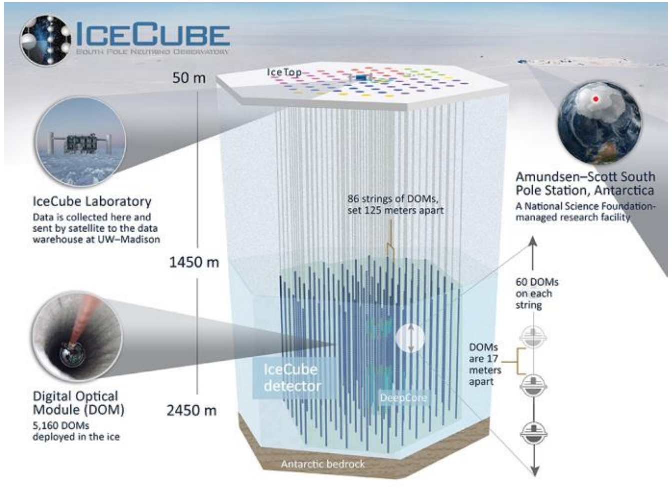
IceCube

・Install 5,160 detectors in an area of about 1km^3 in Antarctica, and Observe Cherenkov Light.
・Charged particles are produced by interactions between neutrinos and nucleons in ice.
→Cherenkov Light is produced when charged particles traverse the ice.
・Neutrinos are detected by observing Cherenkov light.

High Energy Neutrino

・High energy neutrinos have energies above TeV.

・Neutrinos are emitted from astronomical phenomena.
・Neutrinos have no electric charge, and no deflection by ambient magnetic fields.→ Directly arrives at the Earth
→Suitable for searching for high-energy phenomena.



IceCube-Gen2

IceCube-Gen2

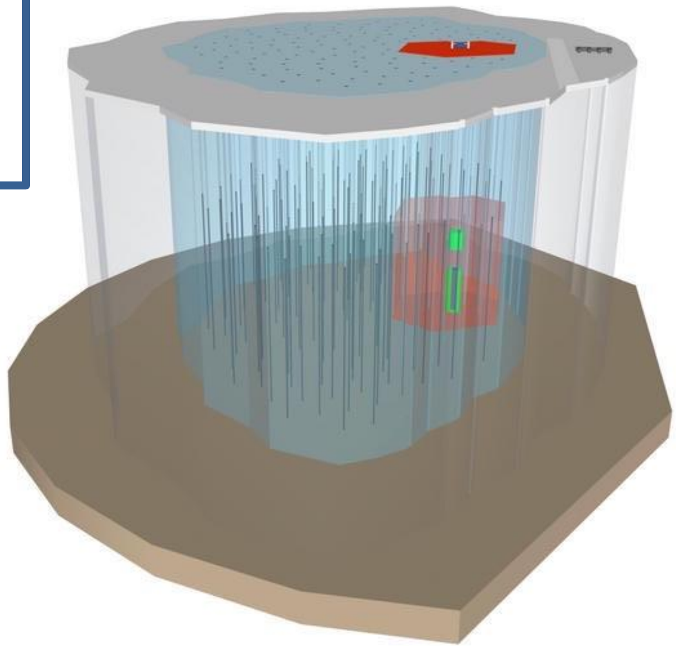
・Approximately 10,000 detectors will be buried at with twice the spacing of the IceCube experiment.
・The detection volume ⇒ ×8

⇩

・The sparser geometry degrades the detection capability of relatively low energy neutrinos.

⇩

Need detectors with higher detection performance



Gen2-DOM

・Eighteen 4 inch−PMTs are installed inside.

・The detectable area is about 4 times larger

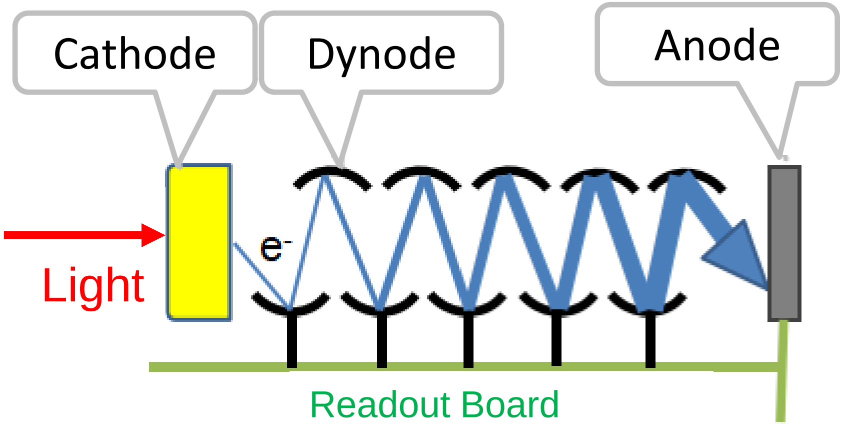
・Improving the performance of the PMT is directly related to improving the light collection performance of the detector.

Gen2-DOM

Towards Higher Quantum Efficiency

Photomultiplier Tube; PMT

・Amplify number of photons produced by the photoelectric effect.
・Amplification : $10^6 \sim 10^7$.
・Capability of a single photon counting



High-QE

・QE : A probability to produce a photo-electron from a photon
Recently, prototype of 「High-QE PMT」 becomes available.
Quantum efficiency is expected to be about 1.3 times higher than conventional PMT.

Flow of my research

Objective : Evaluate the performance of photon detections

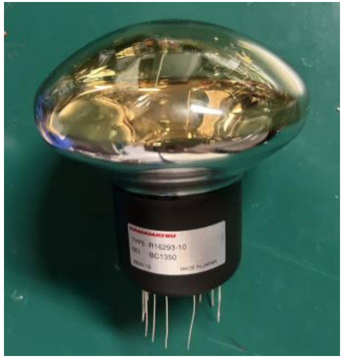
- Measured samples
  : 2 old type PMT(N-QE1, 2) and 2 new type PMT (H-QE1, 2).

- Gain calibration
  Gain : Multiplication factor of photo-electrons amplified by PMT.
  Set the same Gains to various PMTs.

- Measurement of dark rate
  Dark rate : Frequency of signal detected by PMTs even in dark.

- Evaluation of QE
  Compare photon yields.

N-QE

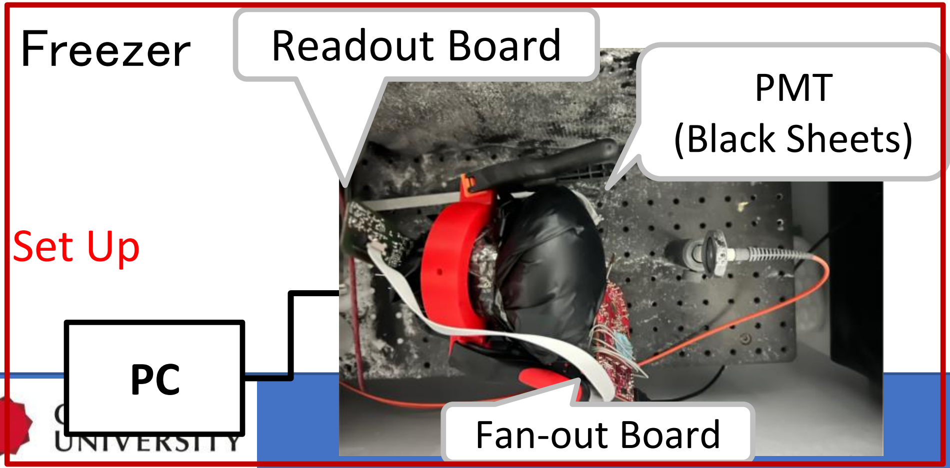


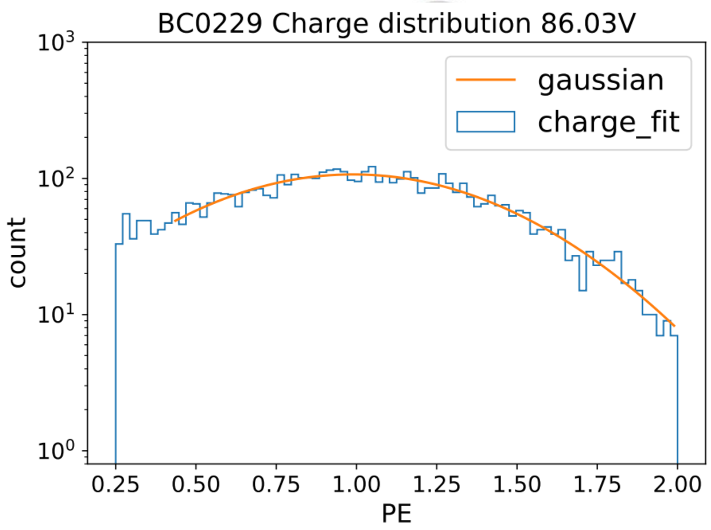
H-QE

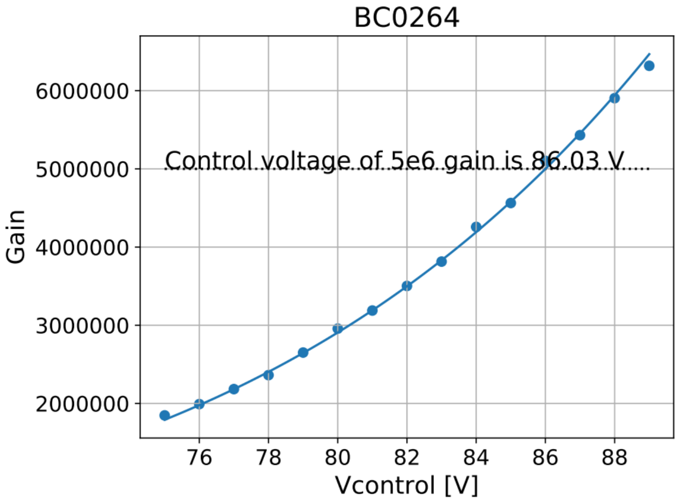
Gain calibration

Procedure

・Measurement at room and low temperature.
・Apply various voltages to PMTs, and calculate Gain with the charge distribution.
・Plot graphs, and calculate the voltage when Gain: 5.0×10^6.
(This voltage : Control Voltage)







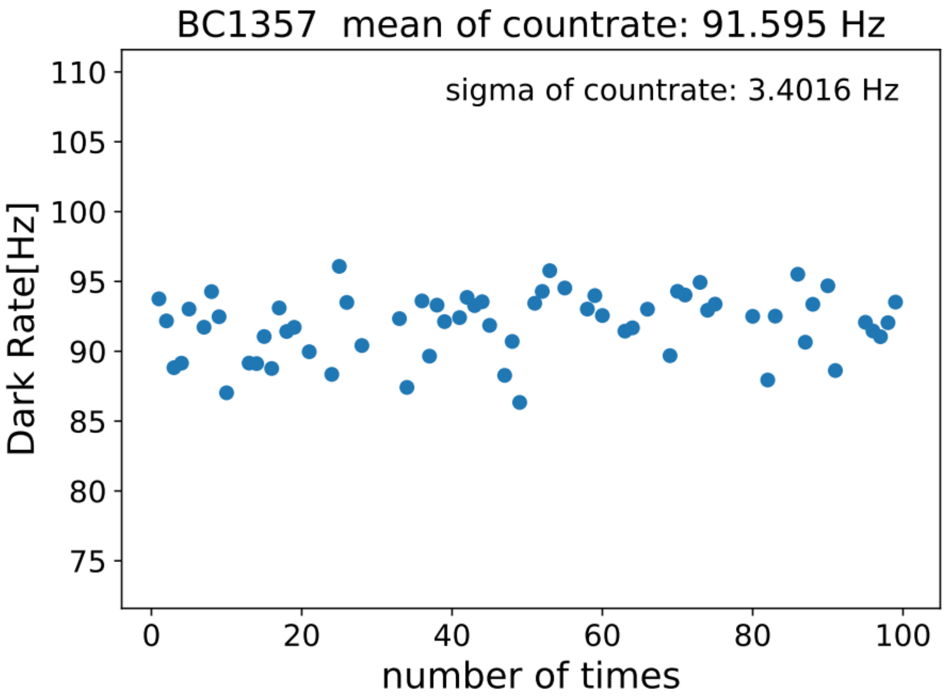
Measurement of Darkrate

Procedure

Set up : The same as for Gain calibration.

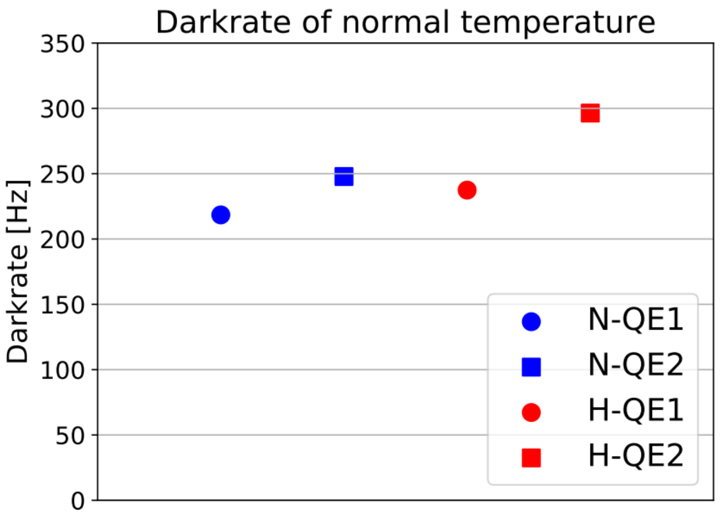
Take 100 measurements for 300 sec.

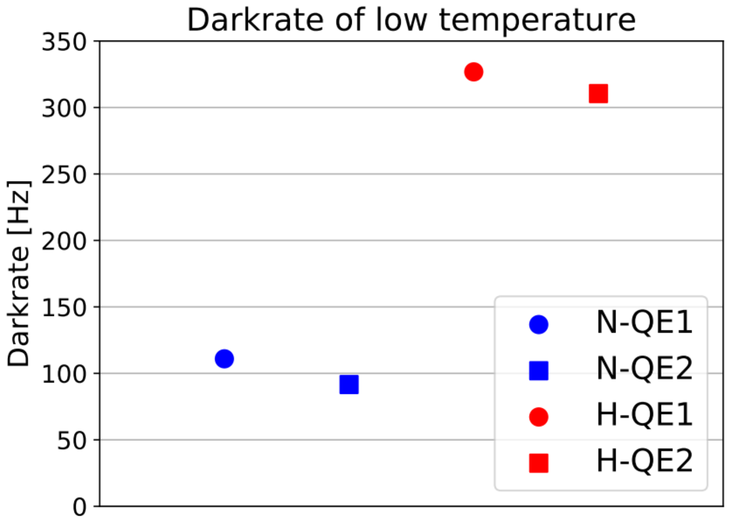
Evaluate the average over time.



Measurement of dark rate

Result





- N-QE : Dark rate decreases at low.
- H-QE : Dark rate increases at low.

Possible cause : Effect of Scintillation Light

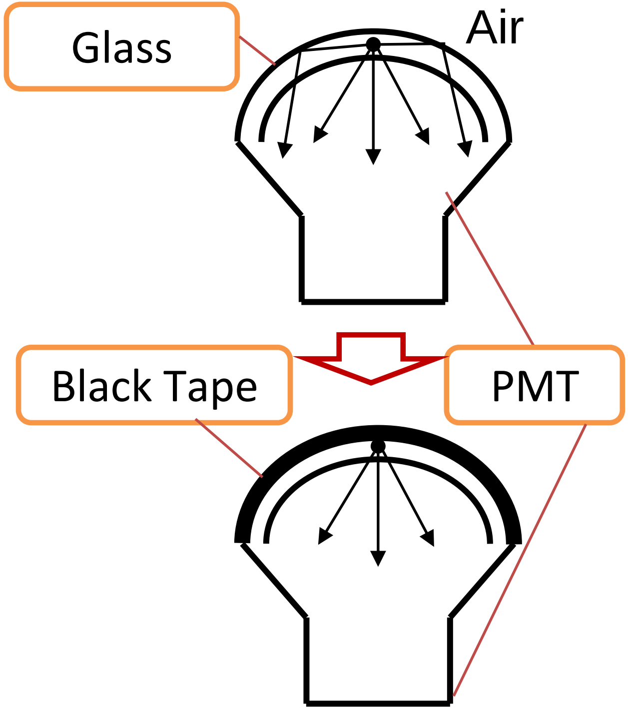
Cause of High Dark rate at Low Temperature

Sources of Dark rate

・Thermal excitation

・Scintillation light from charged particles produced by radioactive decay inside the glass.

Measure Darkrate by covering black tape to the glass to suppress the reflection of Scintillation Light.



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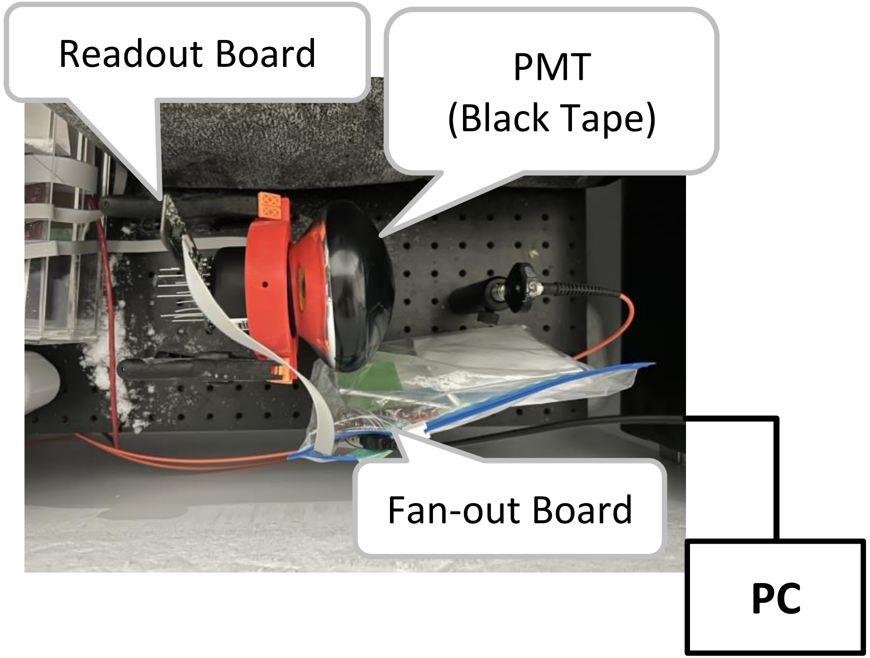
Effects of Scintillation Light

Procedure

・Cover PMT with black tape.

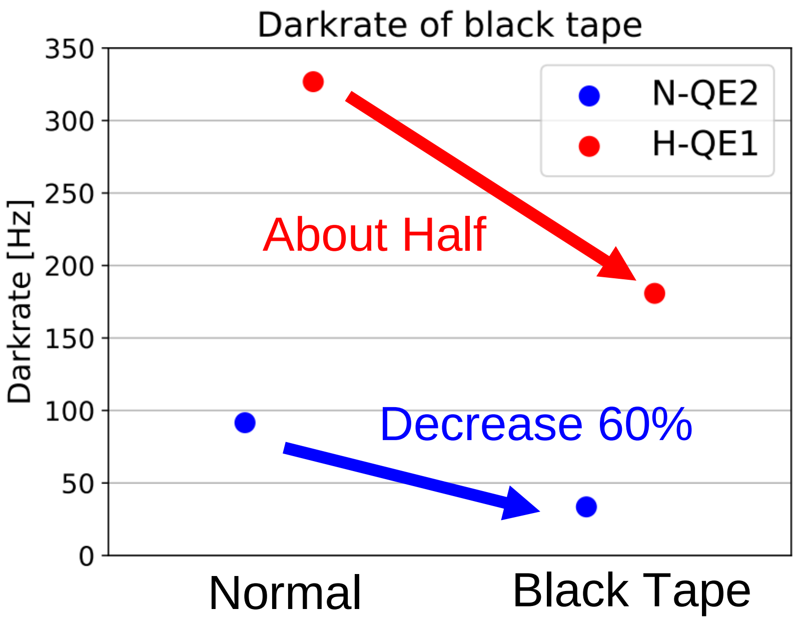
・Compare dark rates between the normal QE and the high QE



Set Up

Effects of Scintillation Light

Result



・Even suppressing the Scintillation Light contribution, the dark rate of H-QE1 is still high,180Hz.

・Dark rate in N-QE decreased more than in H-QE.

・H-QE may be significantly affected by Scintillation light compared to N-QE.

・Radioactive materials could be included in the glass during the production process of H-QE.

・This ×6 higher dark rate is much beyond possible enhancement of QE(×1.3).

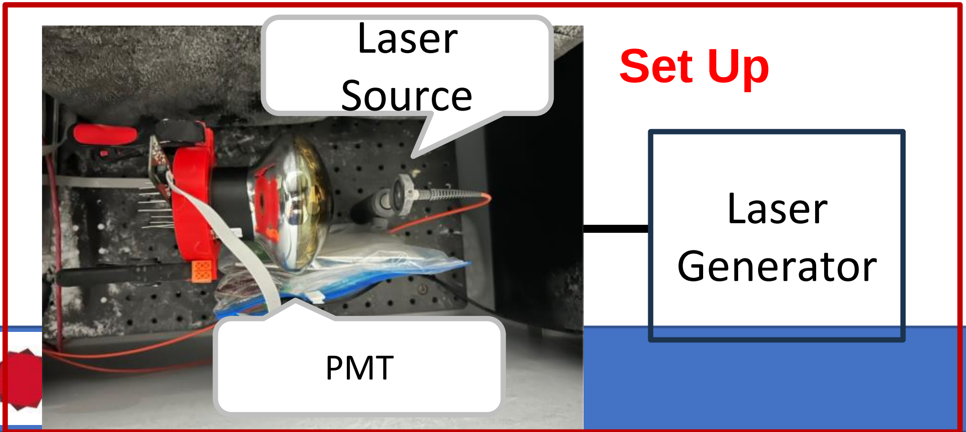
Evaluation of QE

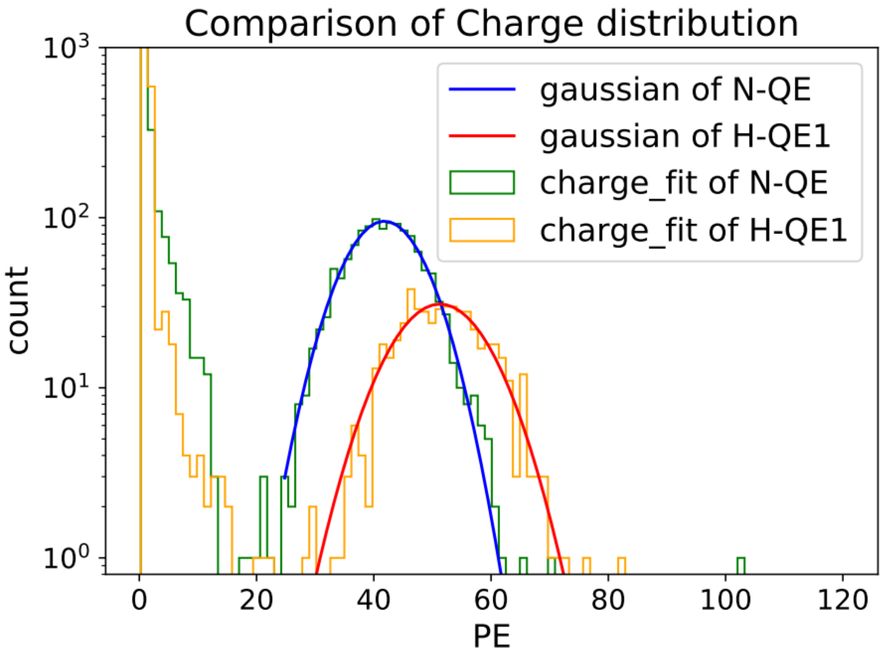
Procedure

・PMT to be in the same position.

・Take four repetitions for N-QE, H-QE1, and H-QE2 (To check reproducibility).

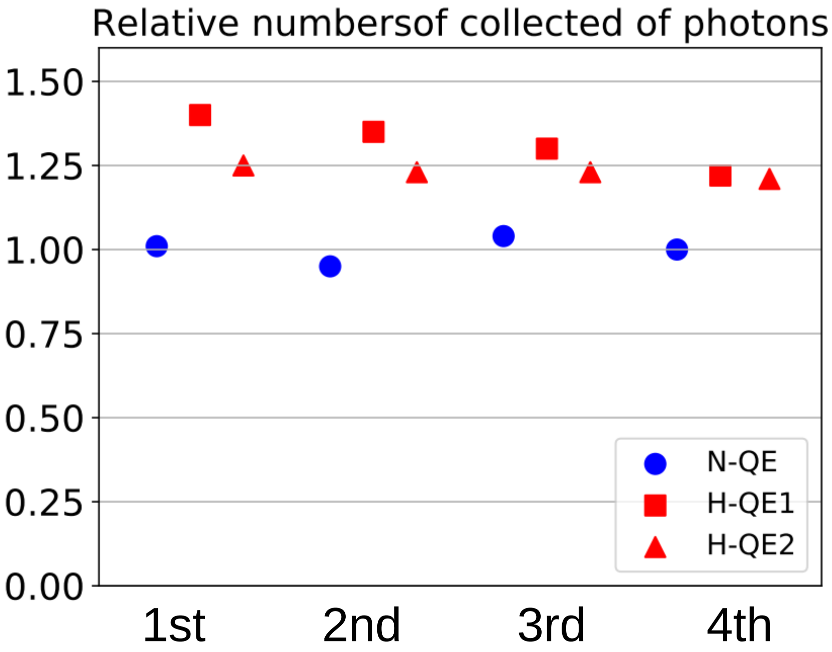
・Inject the same intensity laser to all the PMTs, and compare the collected charge distribution.





Evaluation of QE

Result



・The reproducibility is good.

・ H−QE1 is 1.32 times, H-QE2 is 1.23 times, compared to the average of QE of N-QE.

Confirmed the improvement of QE

Summary and Next Step

Evaluation of QE

・We experimentally confirmed the improvement of QE factors of 1.32 and 1.23.

Dark rate, QE

・At low temperature, dark rate of H-QE is about 6 times higher than normal QE.
・H-QE could have a contribution from radioactive decay than N-QE, this is expected from the production.

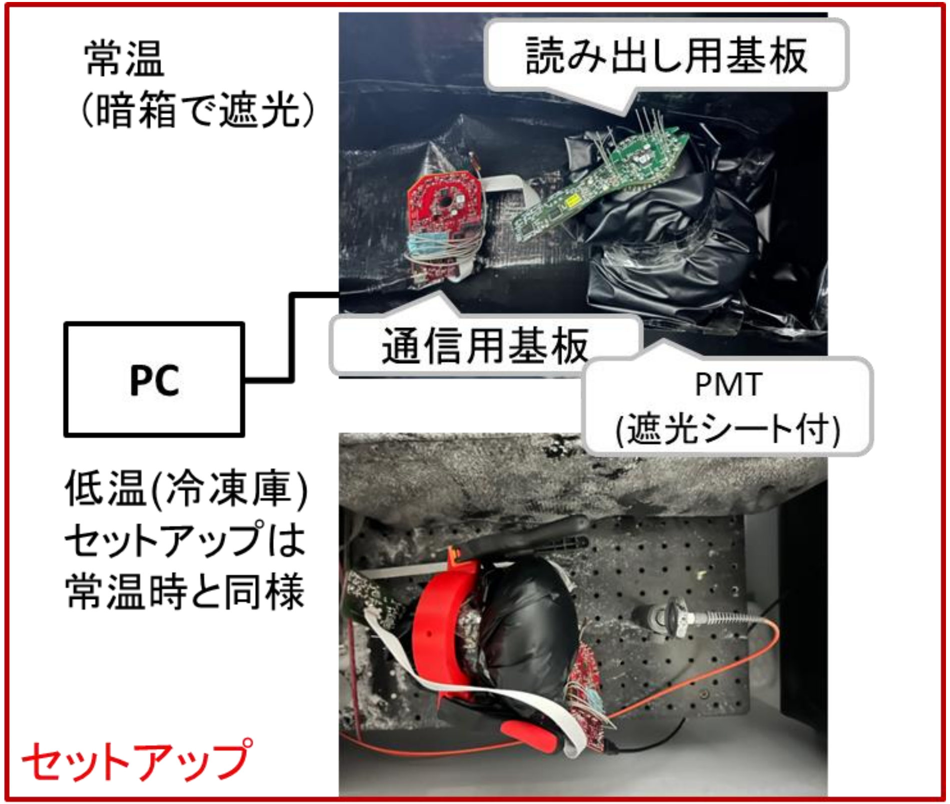
dark rate is bigger than × 1.3 higher QE
⇒Need a future improvement

Next Step

Share information with the manufacturers and explore room for improvement at dark rate.

Back Up

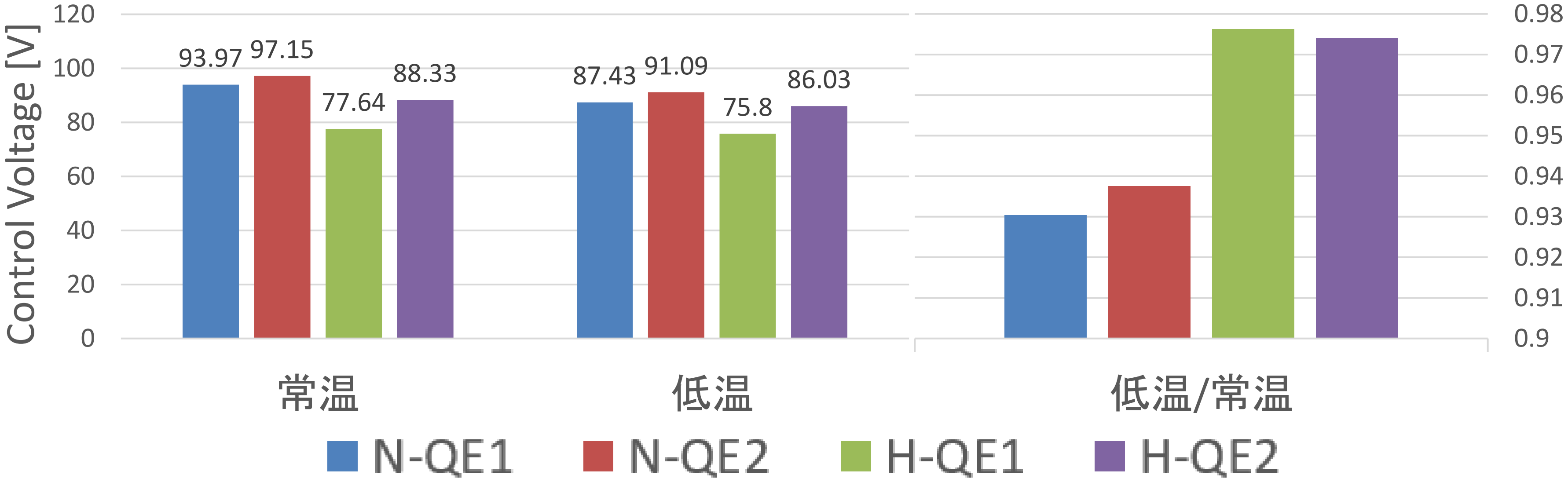
Gainの較正


常温
(暗箱で遮光)
読み出し用基板
PC
通信用基板
PMT
(遮光シート付)
低温(冷凍庫)
セットアップは
常温時と同様
セットアップ

Gainの較正

実験結果

グラフ１: 各PMTのControl Voltage の推移

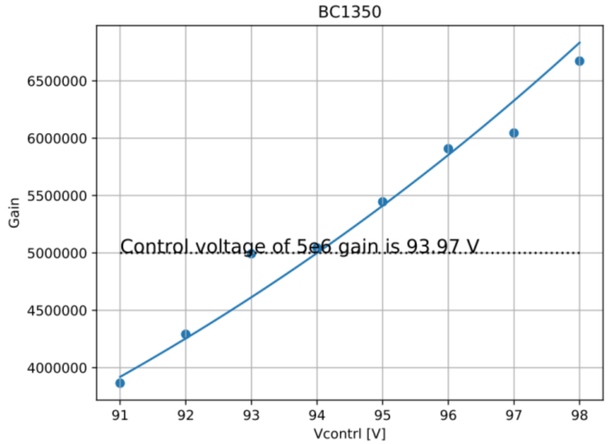


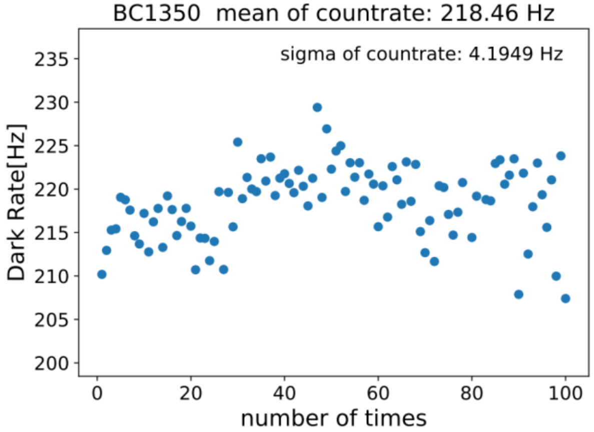
Gain測定

表１：PMTごとのControl Voltage

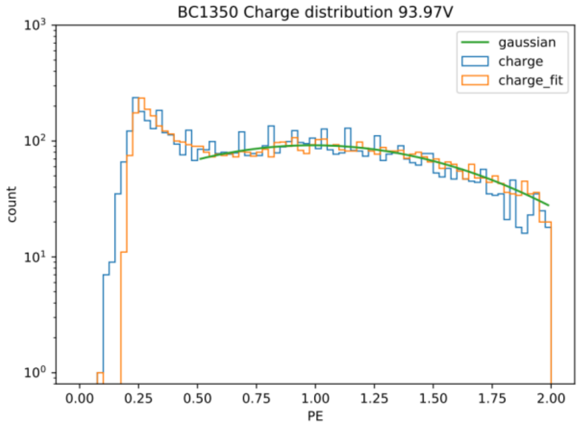
	常温[V]	低温[V]	低温/常温
N-QE1(BC1350)	93.97	87.43	0.93
N-QE2(BC1357)	97.15	91.09	0.94
H-QE1(BC0229)	77.64	75.80	0.98
H-QE2(BC0264)	88.33	86.03	0.97

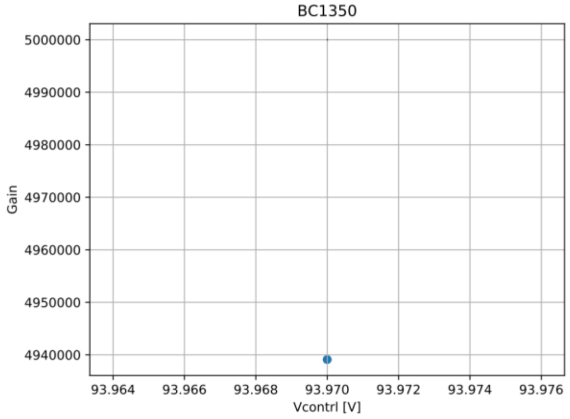
BC1350(常温)



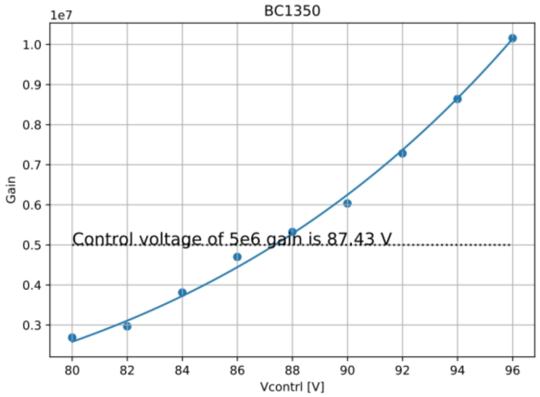


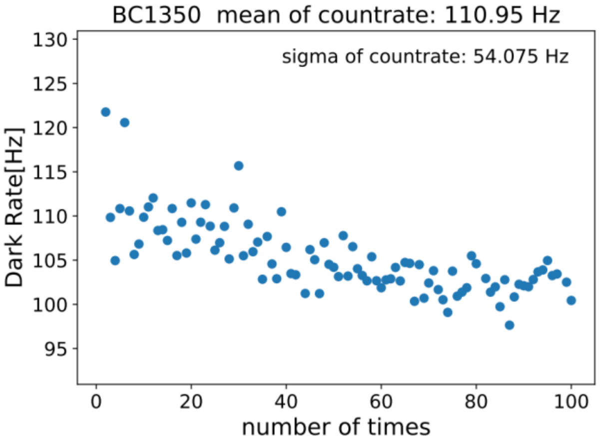
Control Voltage:93.97V
CVでのGainの誤差約1.2%
Darkrate：218.46Hz



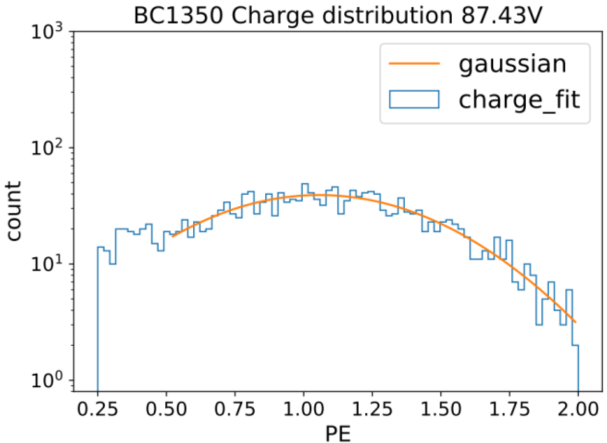


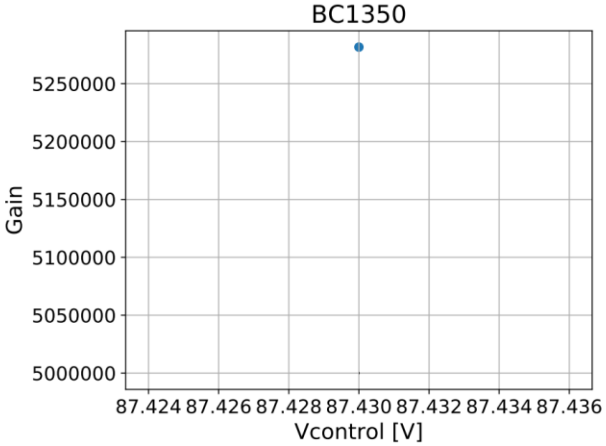
BC1350(低温)



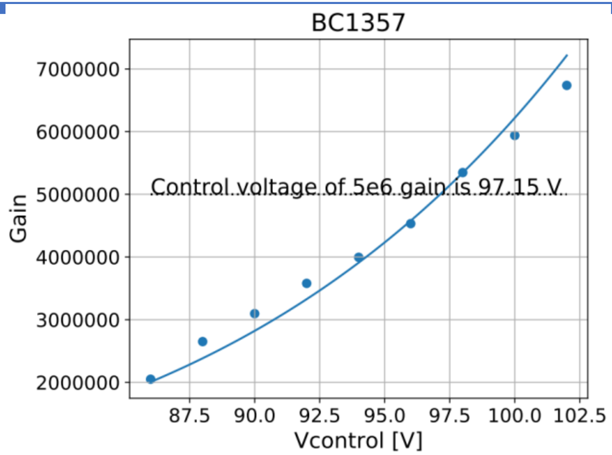


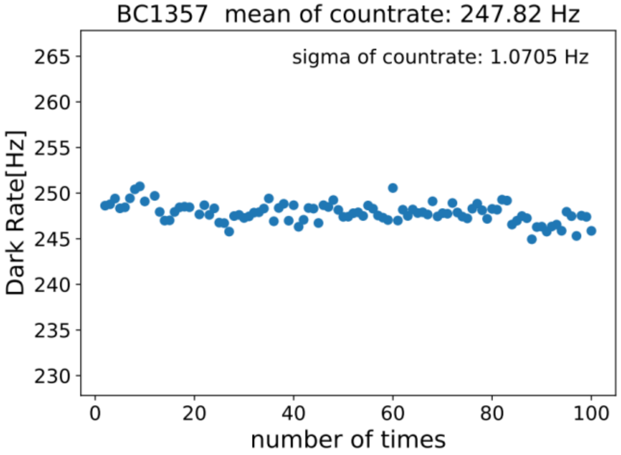
Control Voltage:87.43V
CVでのGainの誤差約4.6%
Darkrate:110.95Hz



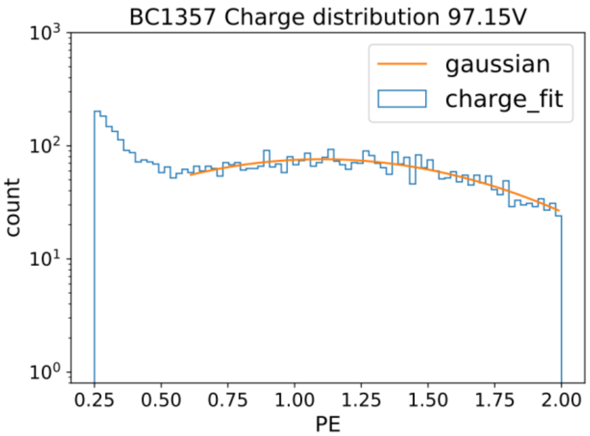


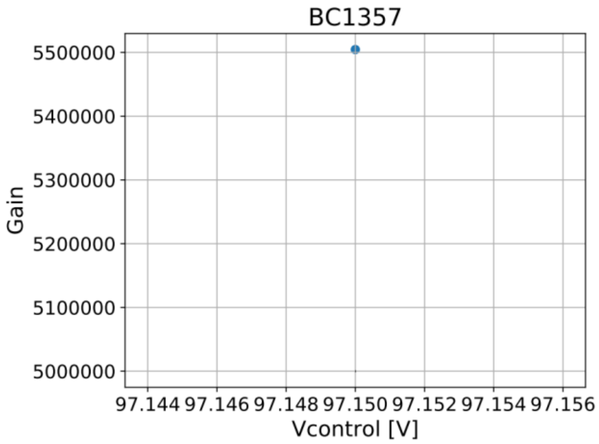
BC1357(常温)



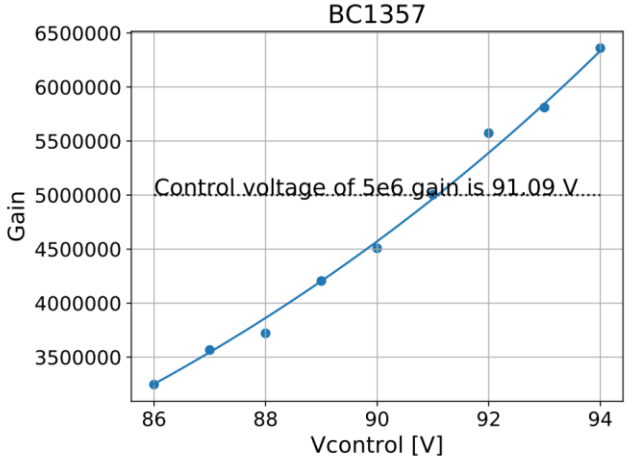


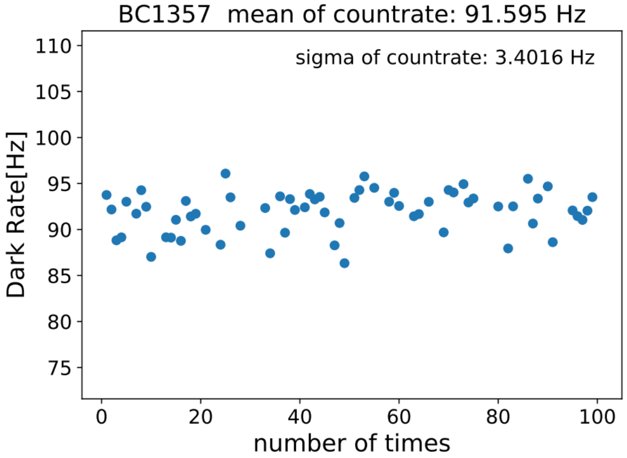
Control Voltage:97.15V
CVでのGainの誤差約8%
Darkrate:247.82Hz



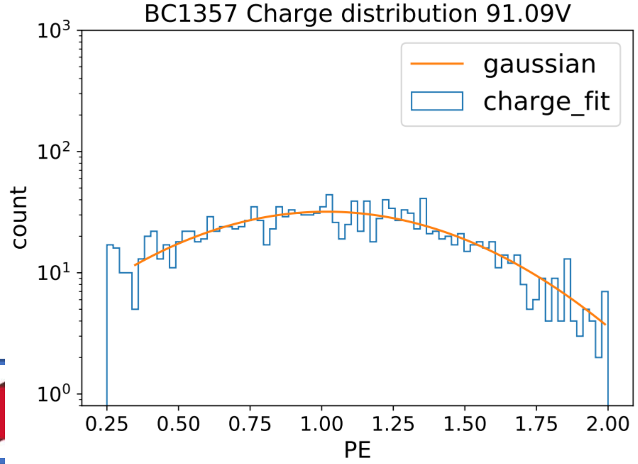


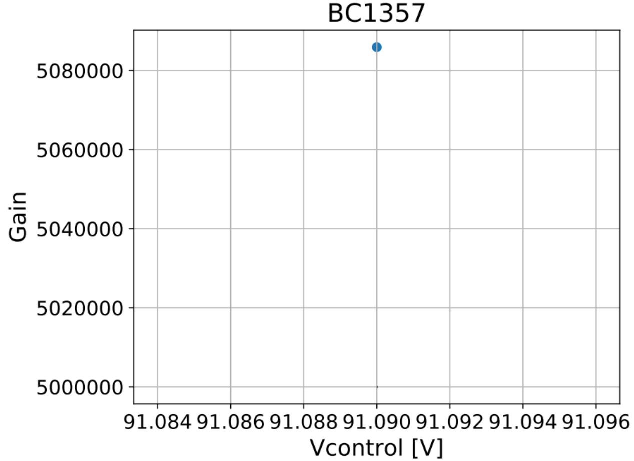
BC1357(低温)



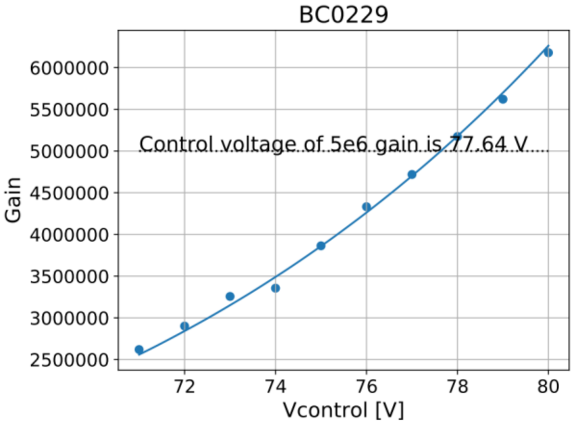


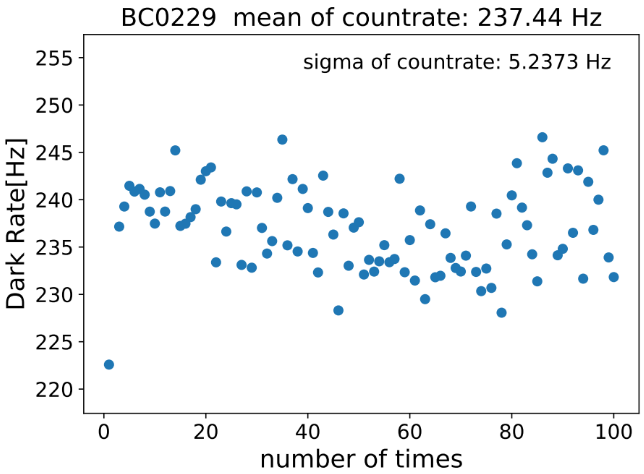
Control Voltage:91.09V
CVでのGainの誤差約1.7%
Darkrate:91.595Hz



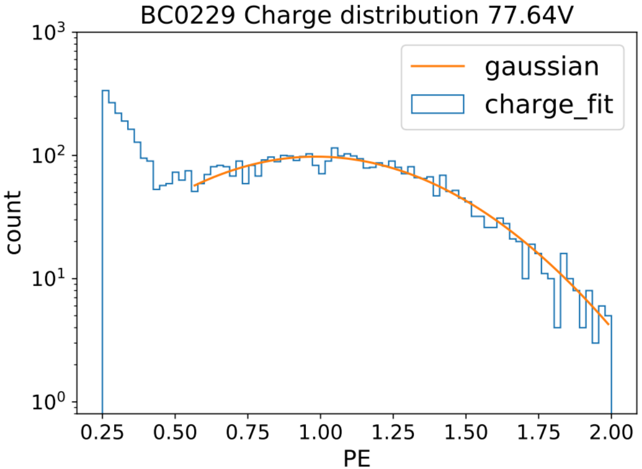


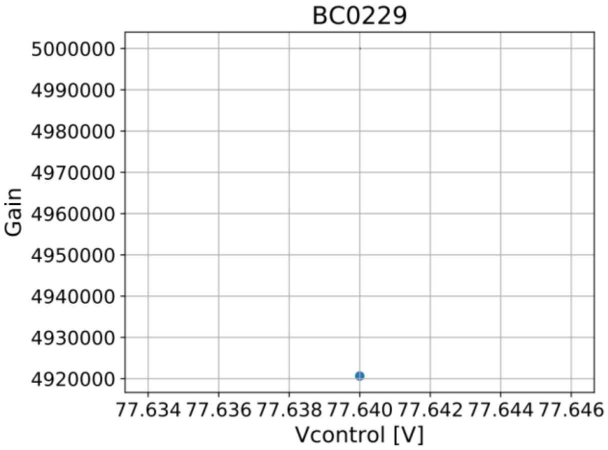
BC0229(常温)



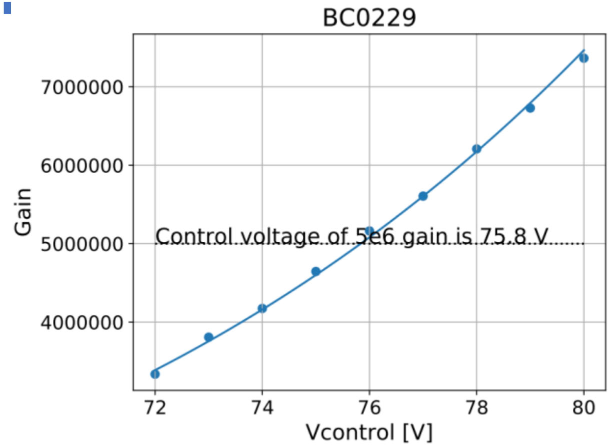


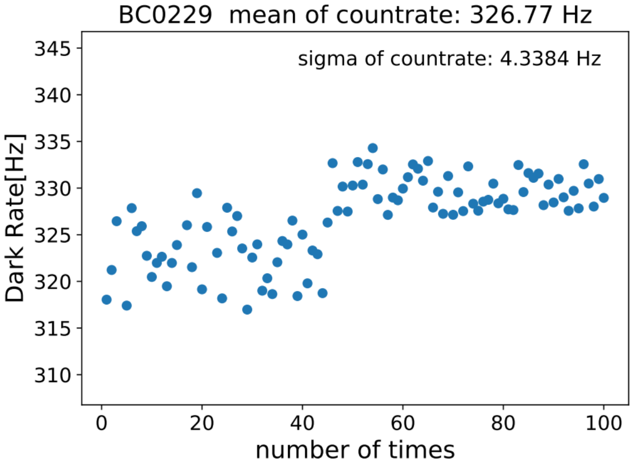
Control Voltage:77.64V
CVでのGainの誤差約2.0%
Darkrate:237.44Hz



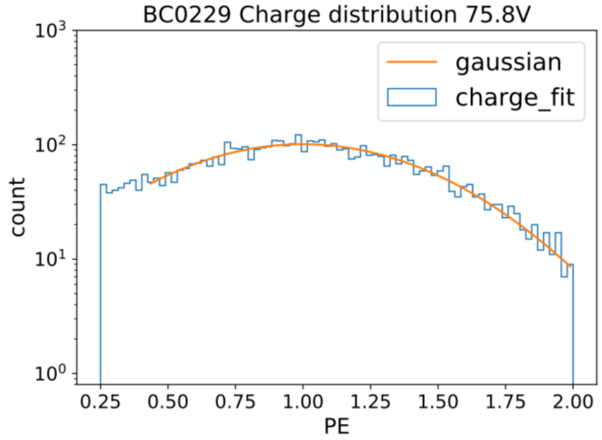


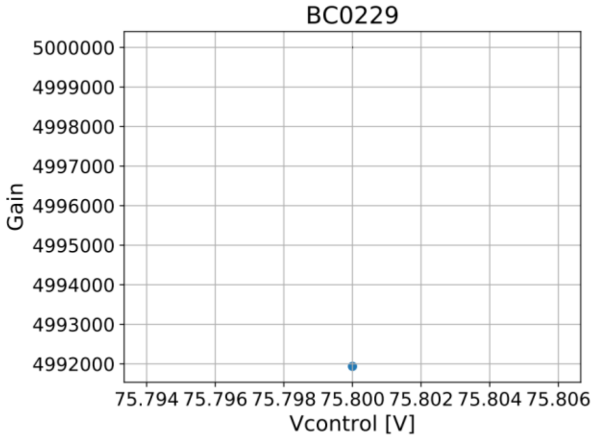
BC0229(低温)



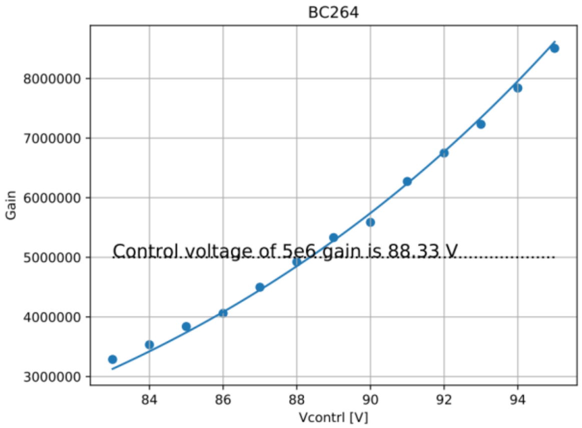


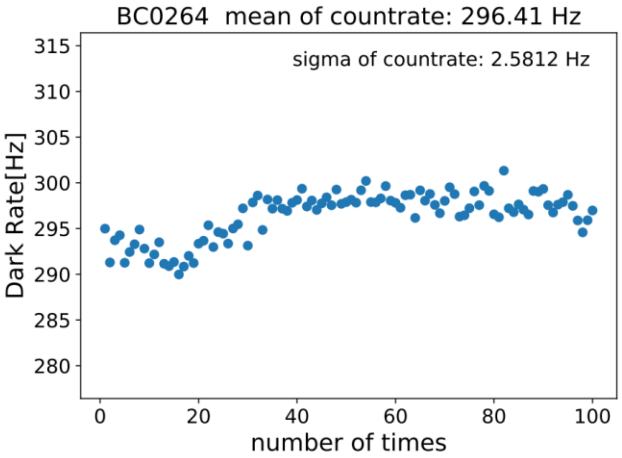
Control Voltage:75,80V
CVでのGainの誤差約1.0%
Darkrate:326.77Hz



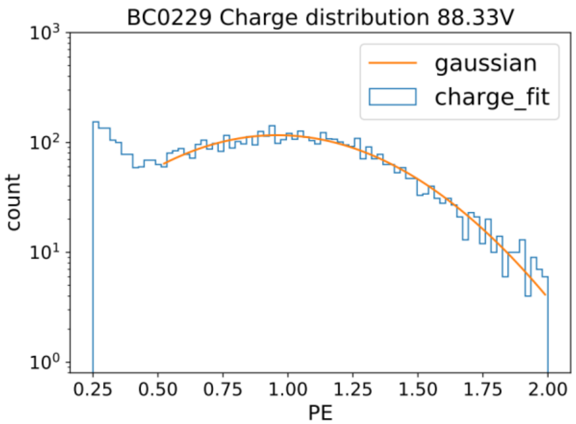


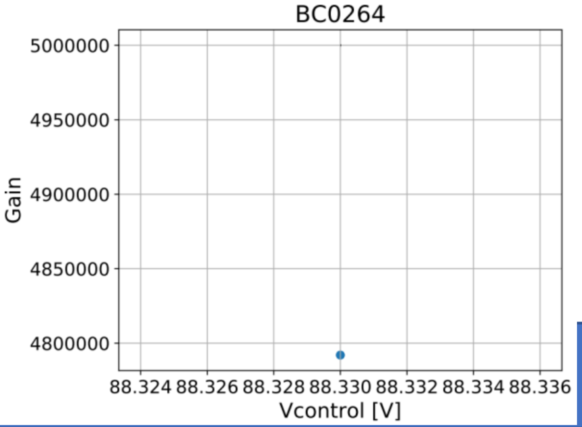
BC0264(常温)



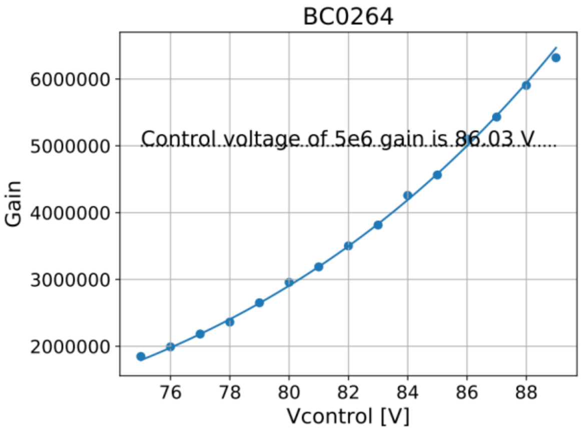


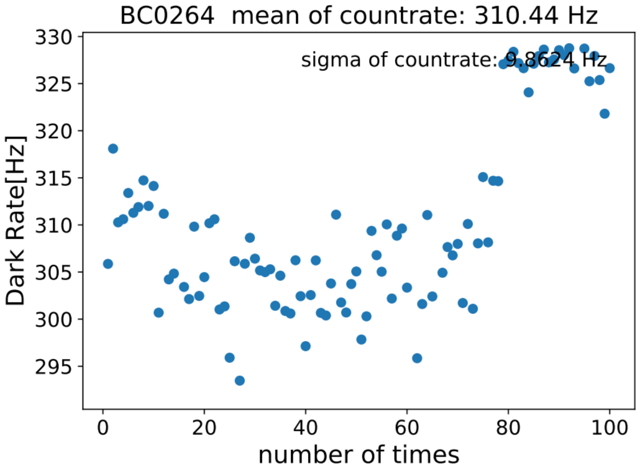
Control Voltage:88.33V
CVでのGainの誤差約5.2%
Darkrate:296.41Hz



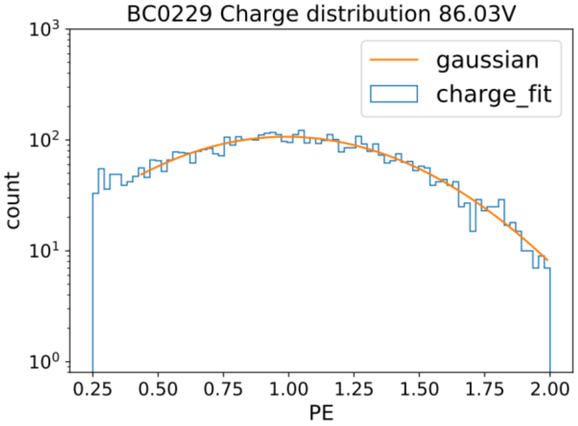


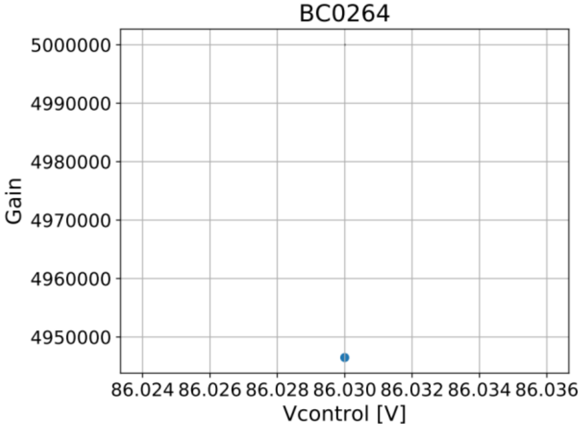
BC0264(低温)





Control Voltage:86.03V
CVでのGainの誤差約8%
Darkrate:310.44Hz





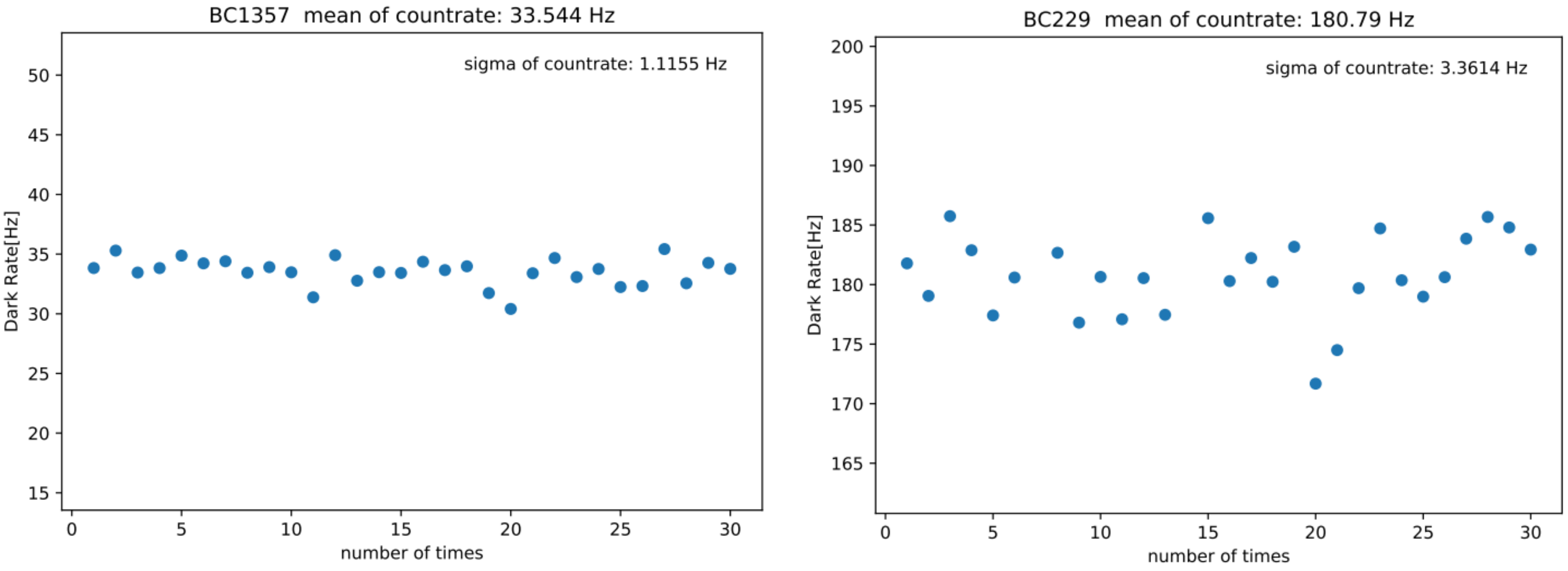
Darkrate

表2：PMTごとのDark Rate[Hz](標準偏差[Hz])

	常温	低温
N-QE(BC1350)	218.46(4.1949)	110.95(5.3314)
N-QE(BC1357)	247.82(1.0705)	91.595(3.4016)
H-QE(BC0229)	237.44(5.2373)	326.77(4.3384)
H-QE(BC0264)	296.41(2.5812)	310.44(9.8624)

シンチレーション光の反射

実験結果



シンチレーション光の反射の影響

実験結果

	通常[Hz]	黒テープ[Hz]
N-QE2	91.595	33.544
H-QE1	326.77	180.79

量子効率

実験結果

	N-QE(PE)	H-QE1(PE)	H-QE2(PE)
一回目	41.99	58.43	52.21
二回目	39.73	56.45	51.35

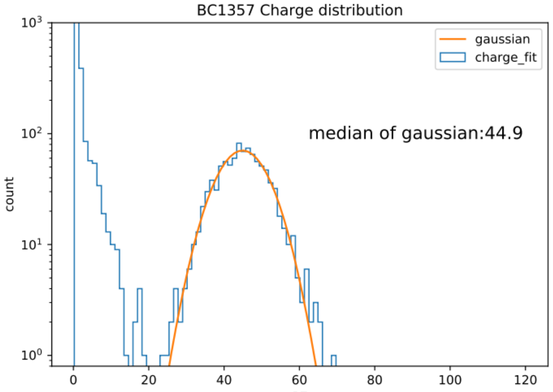
	N-QE(PE)	H-QE1(PE)	H-QE2(PE)
一回目	43.55	54.32	51.57
二回目	41.78	51.29	50.63

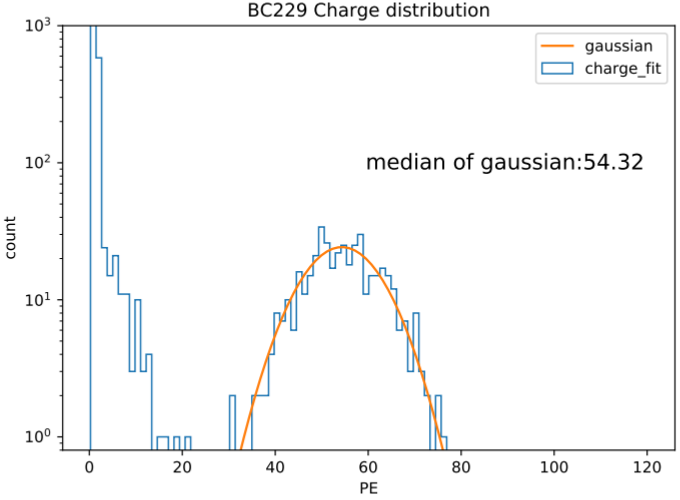
量子効率の測定結果

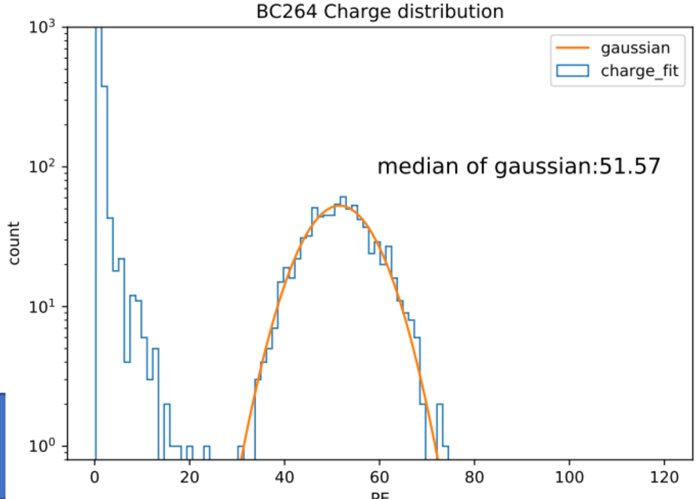
	N-qe(BC1357)	BC0229	BC0264
一回目	45.15	58.43	52.21
二回目	42.72	56.45	51.35

	N-qe	BC0229	BC0264
一回目	44.90	54.32	51.57
二回目	44.93	51.29	50.63

一回目(上がNormal。下二個がHigh)







二回目(上がNormal。下二個がHigh)