Status and Performance of the Multi-anode MCP-PMT for the Belle II TOP counter

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Micro-Channel Plate Based Detectors, Argonne, Dec. 2, 2014

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- Performance of the MCP-PMTs
- Lifetime of the MCP-PMT photocathode
- Summary

Mass production of the MCP-PMT

- The MCP-PMT for the TOP counter is a newly developed photon sensor in collaboration with HAMAMATSU.
- First time for the mass production of 512+α MCP-PMTs.

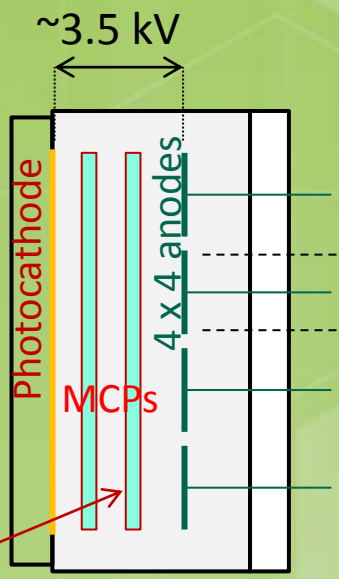
⇩

- Production by HAMAMATSU and performance check at Nagoya are like the two wheels of a cart.
  - Feedback of our measurement is essential to successful production of MCP-PMT of good quality.

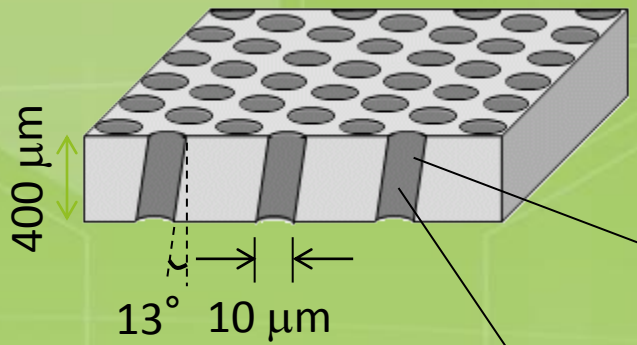
MCP-PMT specification

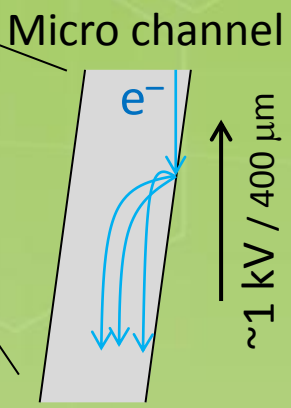
MCP-PMT

Square shape to maximize the photo-coverage



Micro Channel Plate (MCP)





Short distance to multiply the photoelectron

→ Small transit time spread

Use 32 PMTs per TOP module, 512 PMTs in total.

Requirements for the MCP-PMT

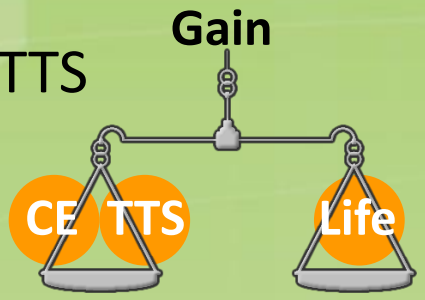
- QE (Quantum Efficiency)
  - at least 24% at peak wavelength (λ)
  - 28% on average of 512 PMTs at peak λ
  - longer lifetime than 3 C/cm^2
- CE (Collection Efficiency) in 1.5 T
  - about 55%
- TTS (Transit Time Spread) in 1.5 T
  - less than 50 ps for single photons
- Gain in 1.5 T
  - as low as possible for QE life
  - higher gain is preferable for CE and TTS

  → target operational gain: 5 x 10^5

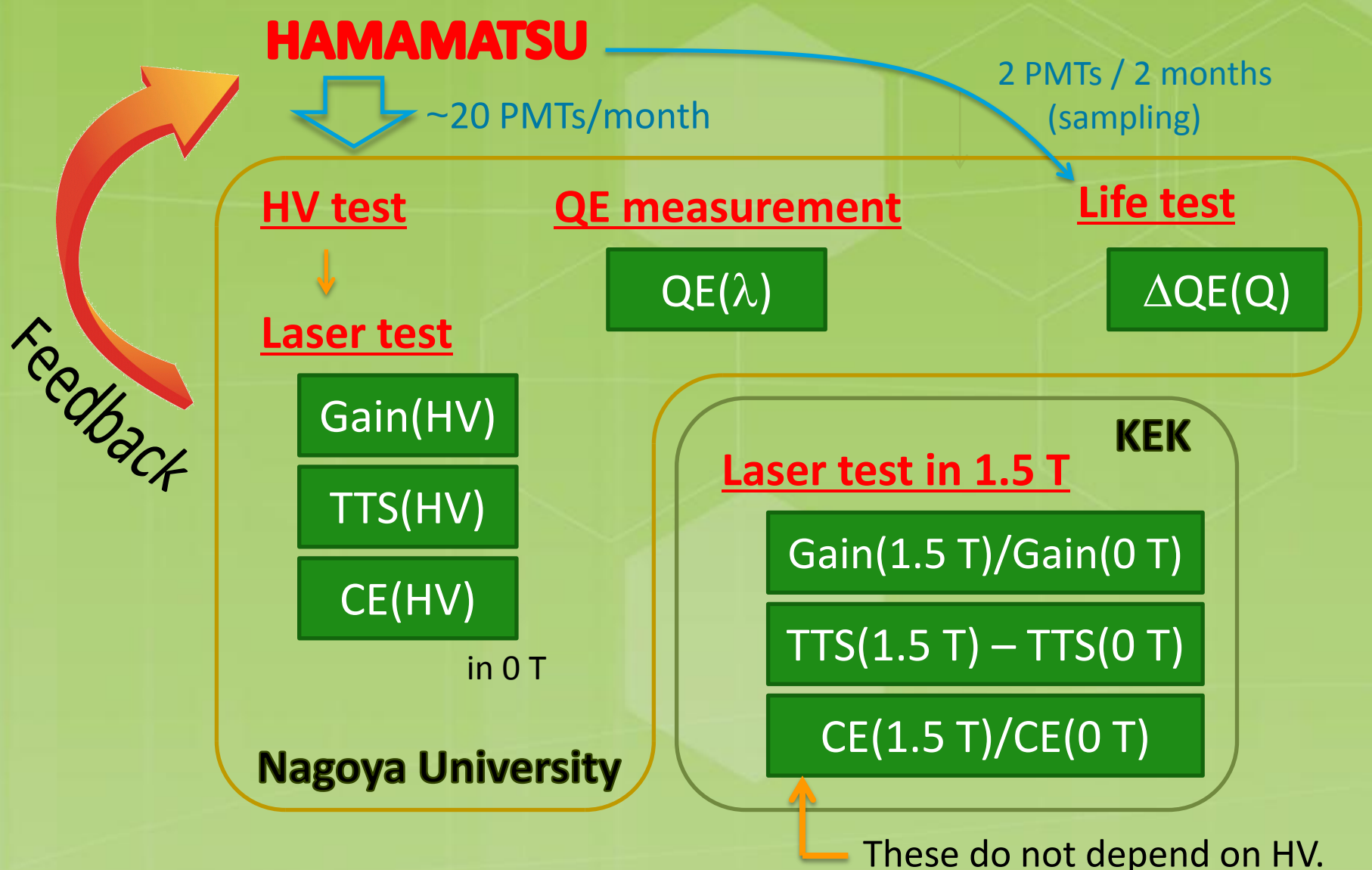
Need to be measuredc

- QE(λ)
- ΔQE(Q)
- CE(HV)
- TTS(HV)
- Gain(HV)

in 1.5 T

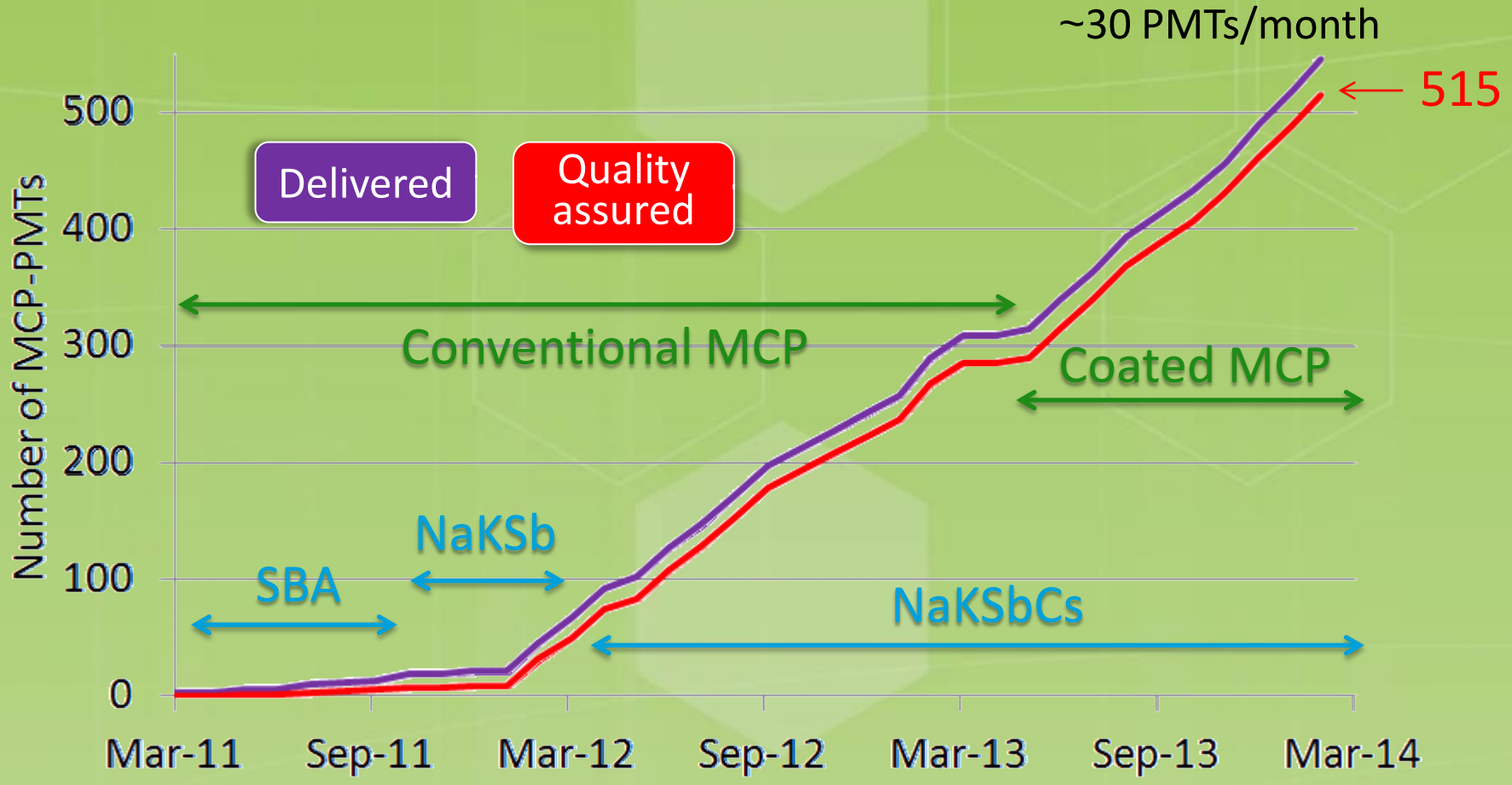


Strategy of the mass production



Progress of the mass production

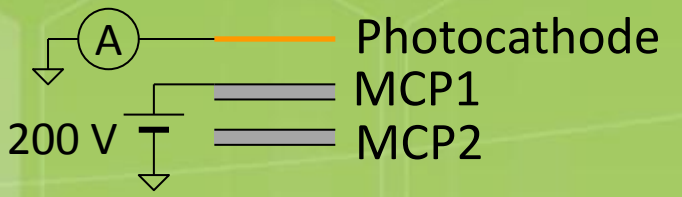
- Mass production started in March 2011 and finished in March 2014.

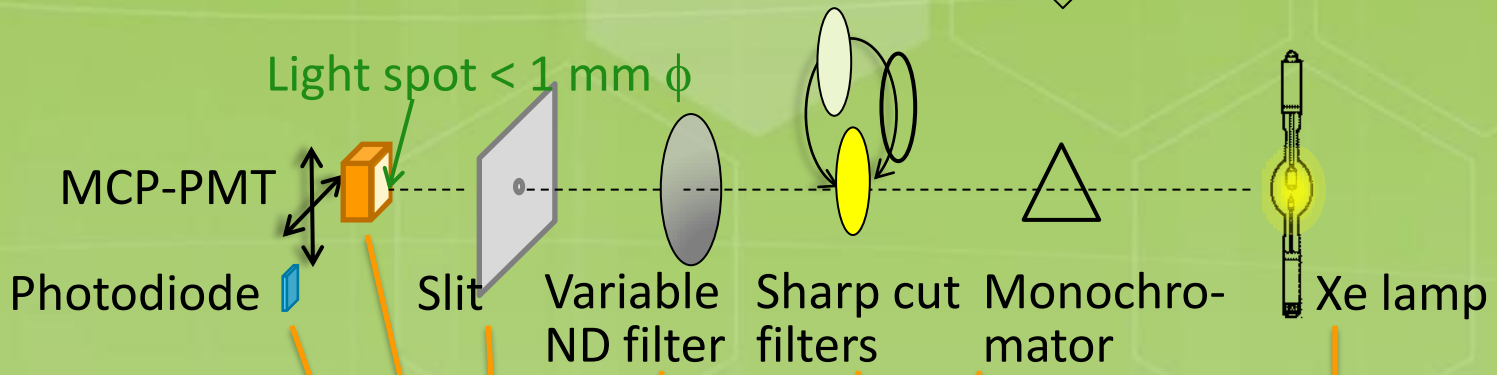


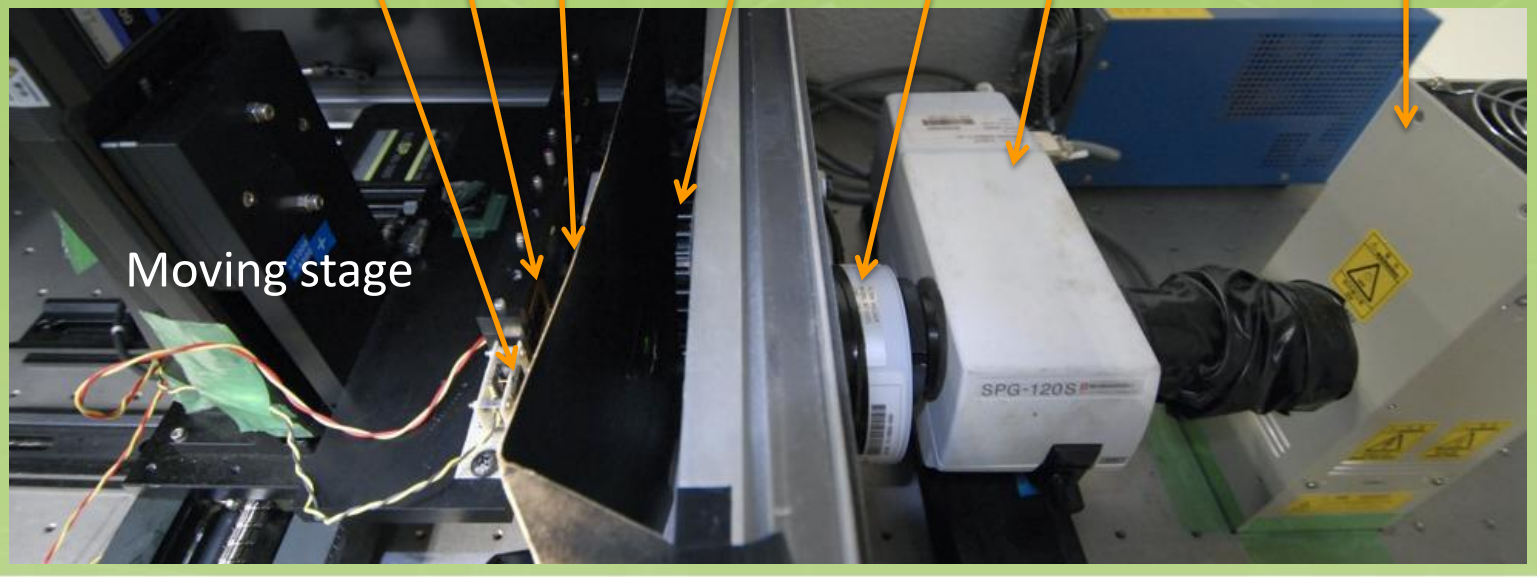
Performance of the MCP-PMTs

QE test setup

- Measure the photocathode current with a picoammeter:
  $QE_{MCP} = I_{MCP} / I_{PD} \times QE_{PD}$
- Automated (Just leave it for 4 h after click start button).

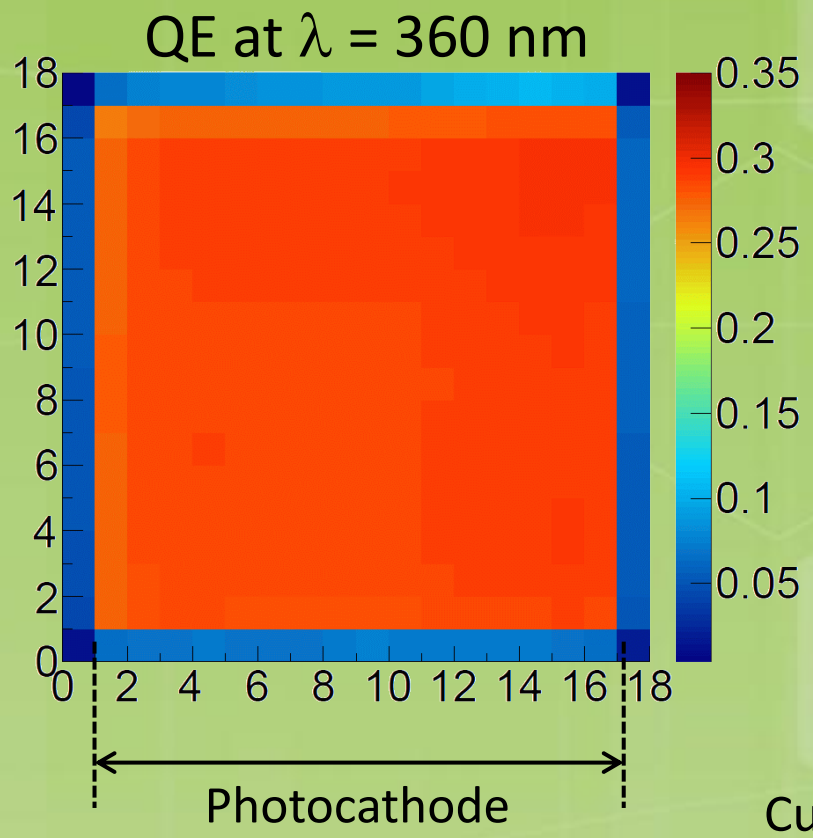


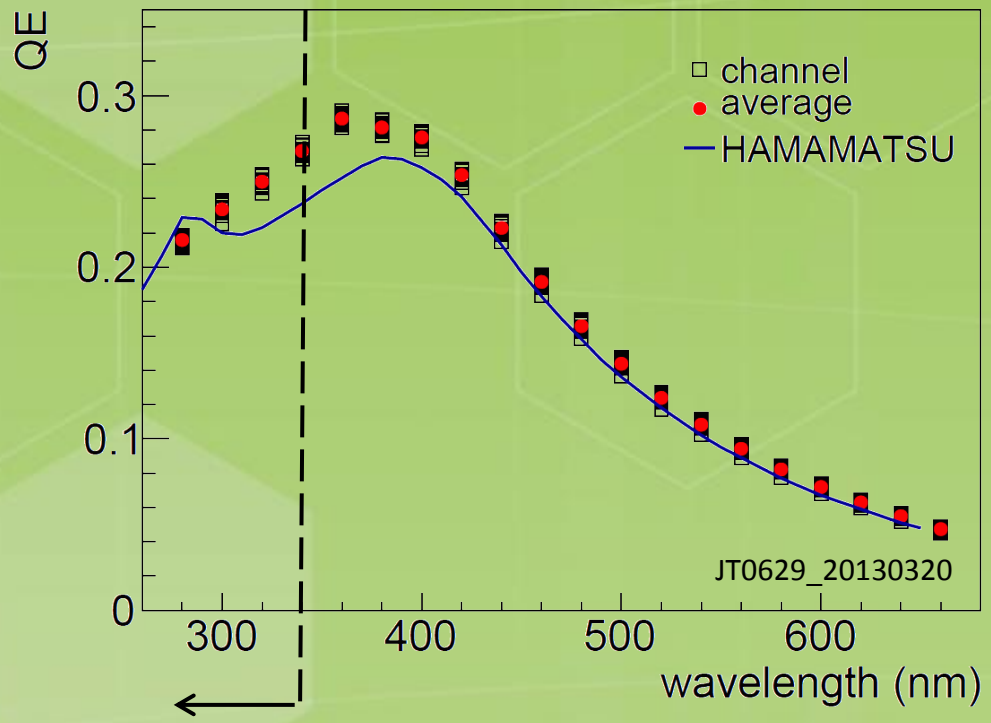




QE measurement

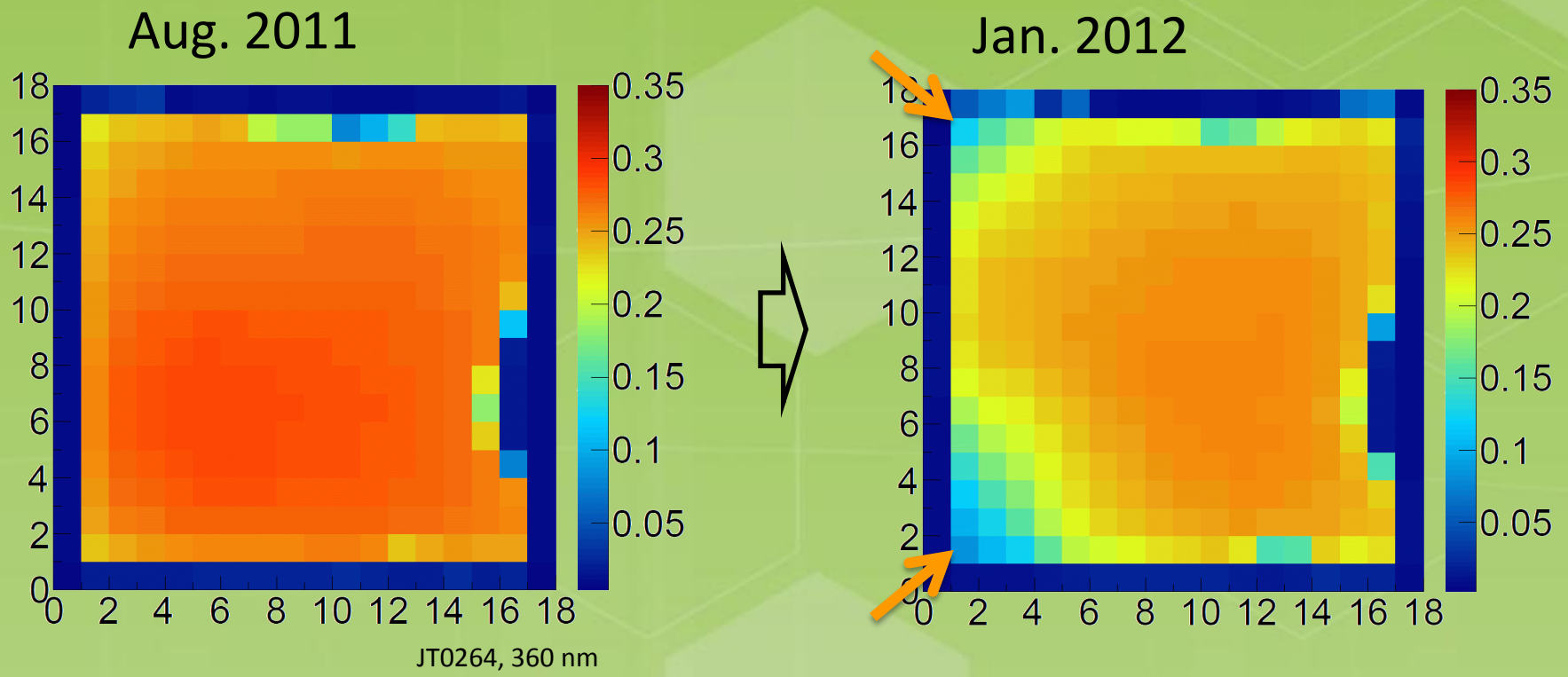
- Scan the photocathode at 18 x 18 points x 20 wavelengths.





Cut by a optical filter to suppress deterioration of time resolution by chromatic dispersion.

QE (bad case)

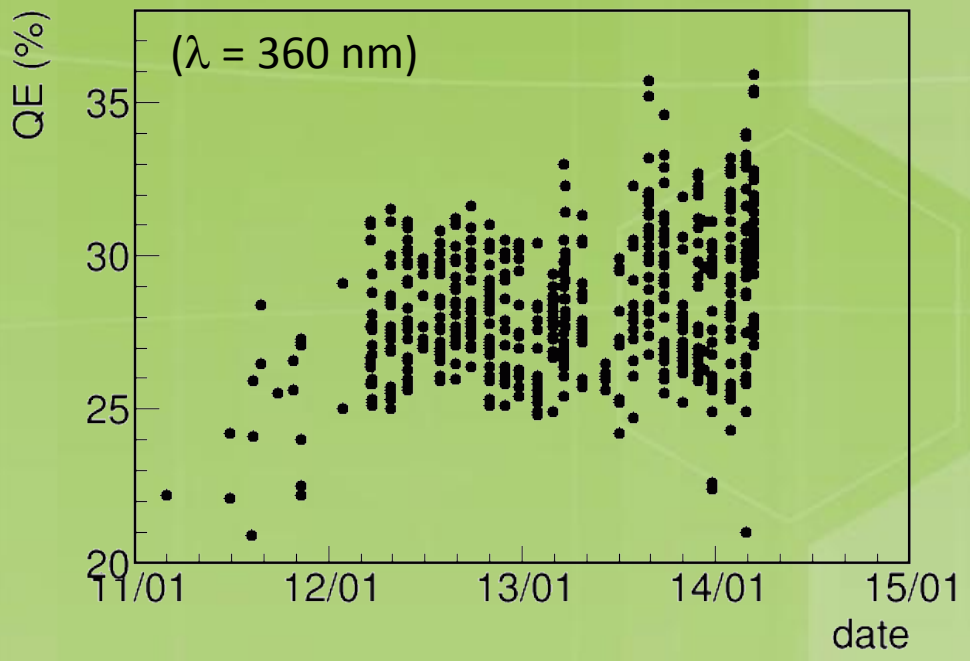


The QE decrease at the corners indicated a defect of the vacuum sealing between the window and the tube.

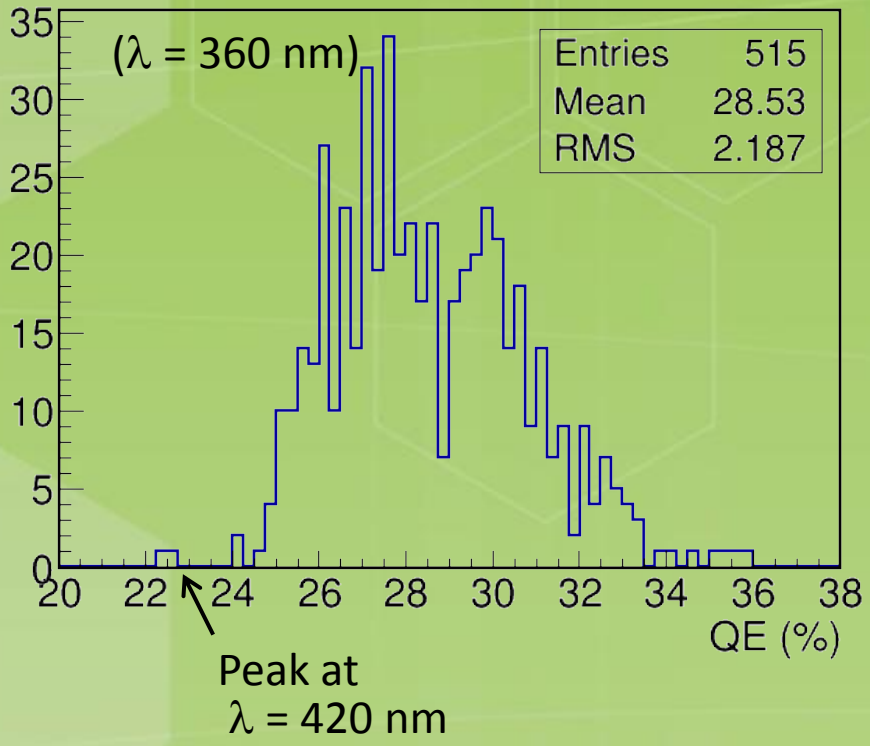
→ Shored up the sealing.

QE

All delivered



Accepted

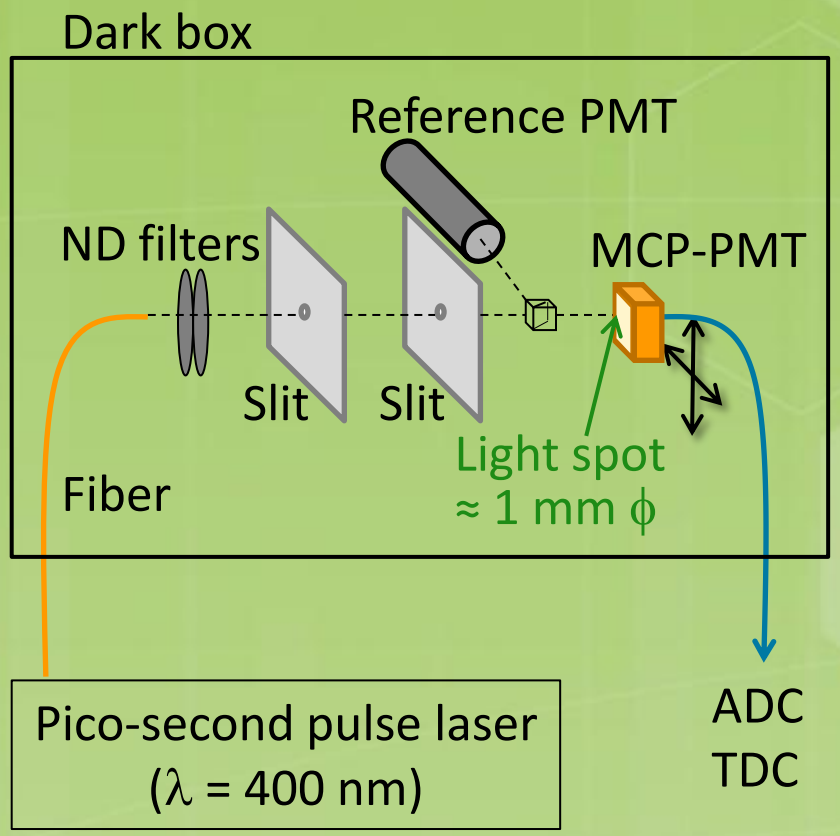


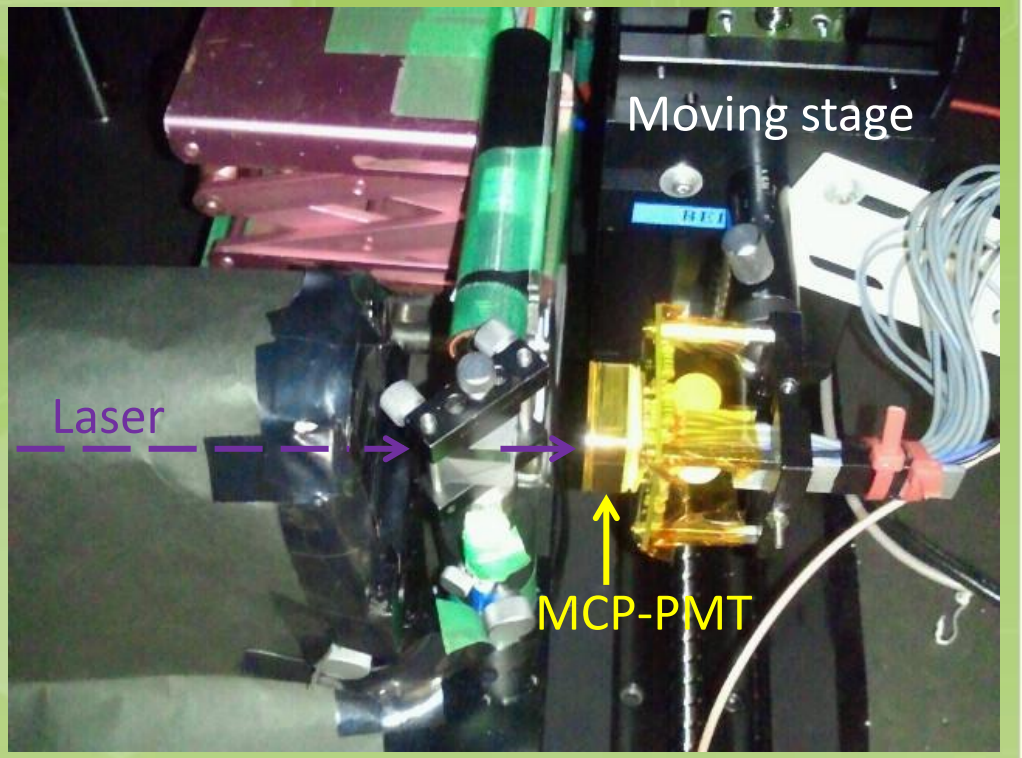
Peak at
λ = 420 nm

Average QE at the peak λ > 28%

Laser test setup

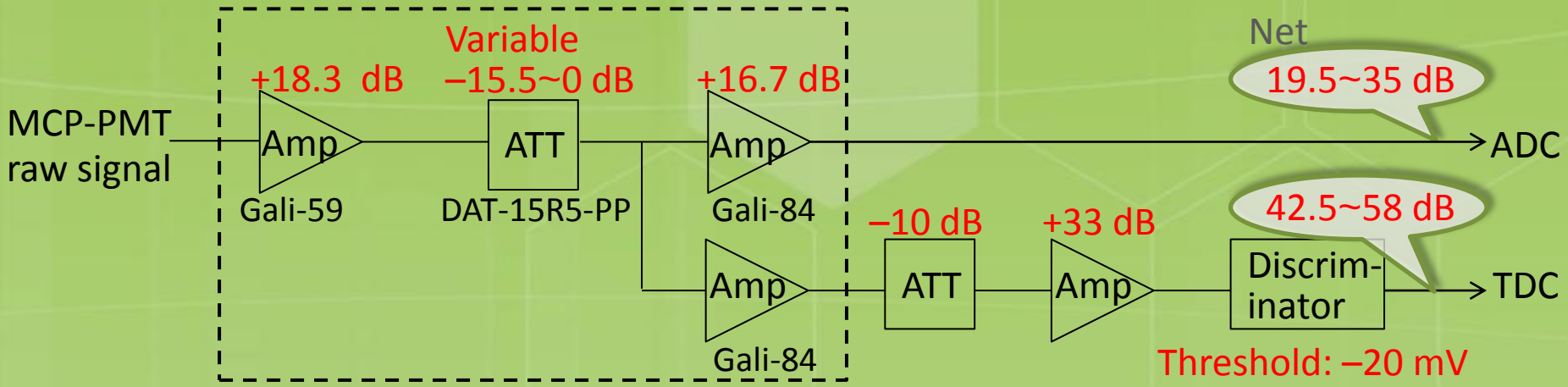
- Irradiate single photons to each channel one by one.
- Take data at 7 different HVs.
- Automated (Just leave it for 2 h after click start button).



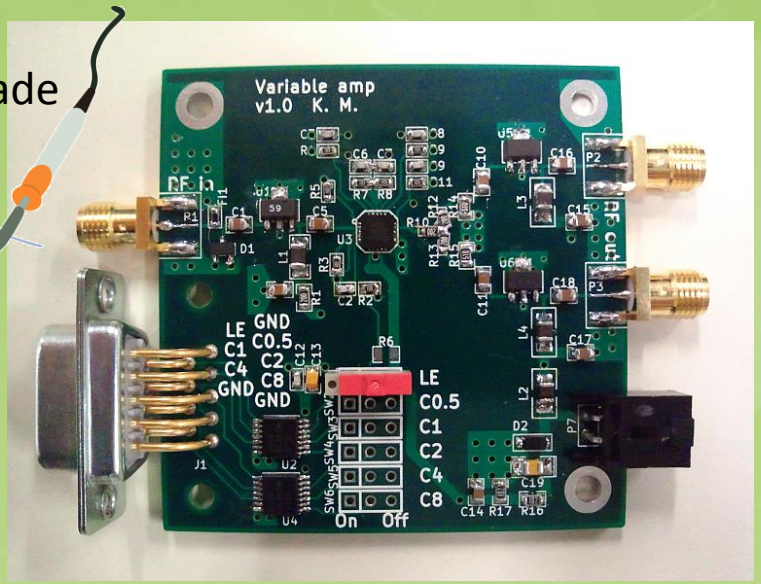


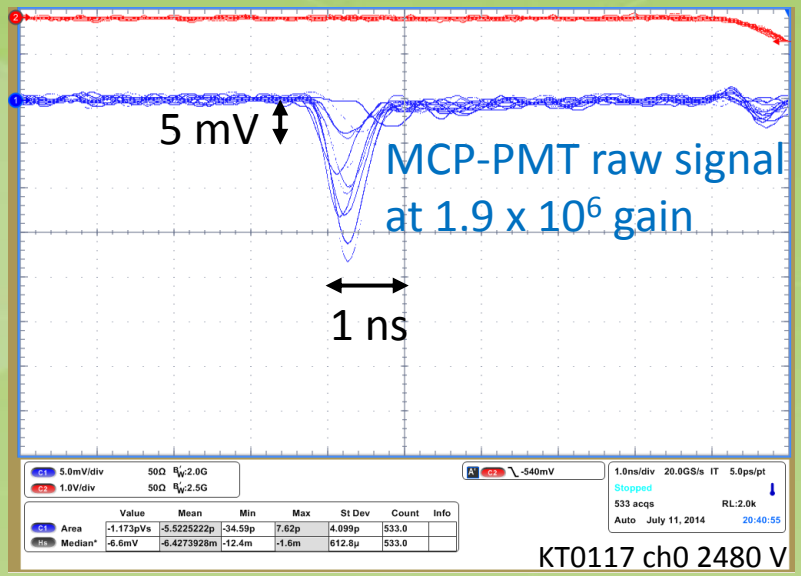
Laser test readout electronics

- Special variable-gain amp to keep ~100% readout efficiency even at a very low MCP gain below 5 x 10^5.



All handmade



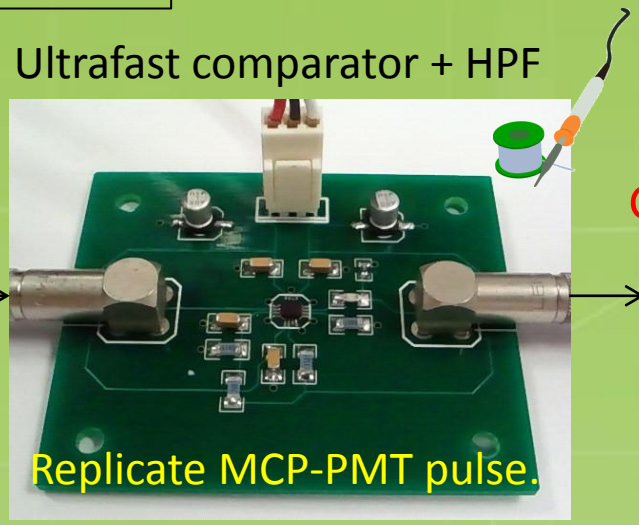


Calibration of the readout electronics

TDC tester

Time calibration

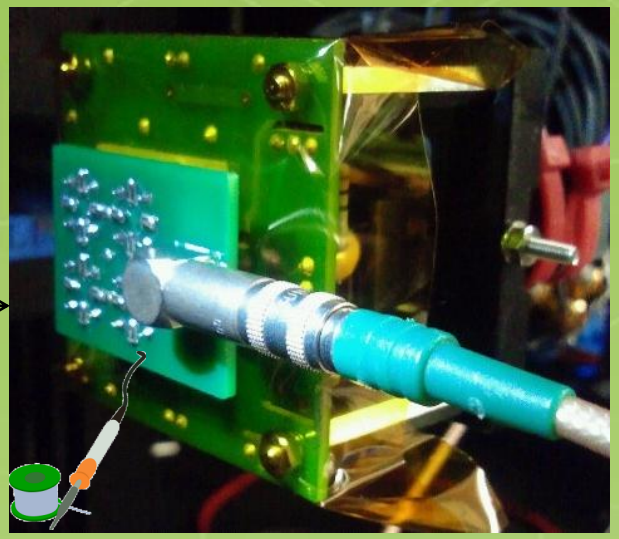
Ultrafast comparator + HPF

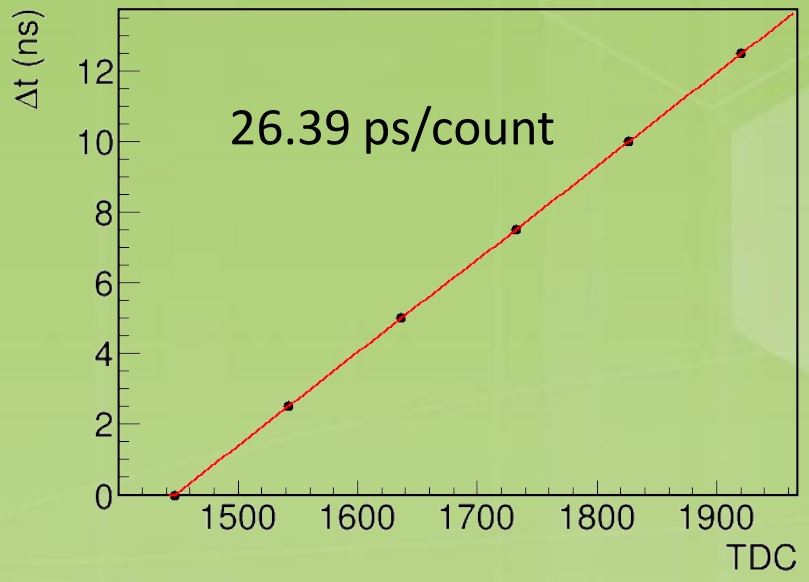


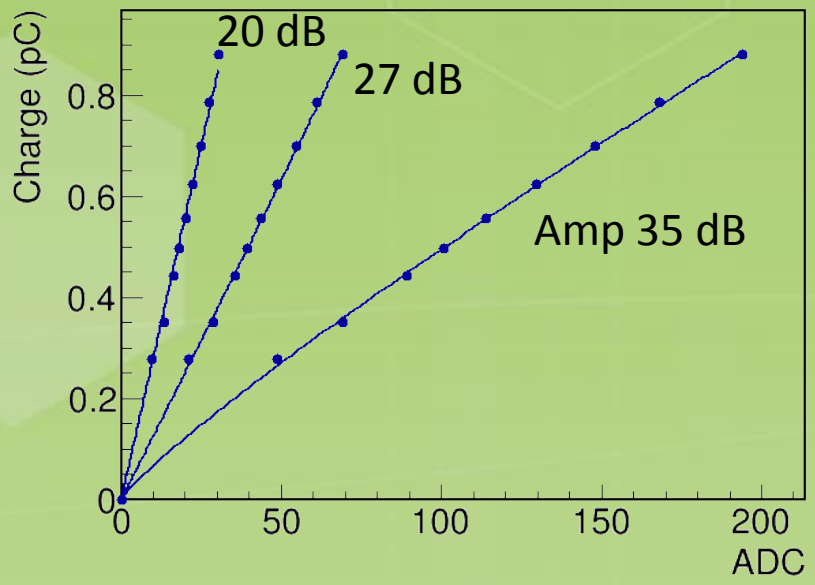
Gain calibration

Variable ATT

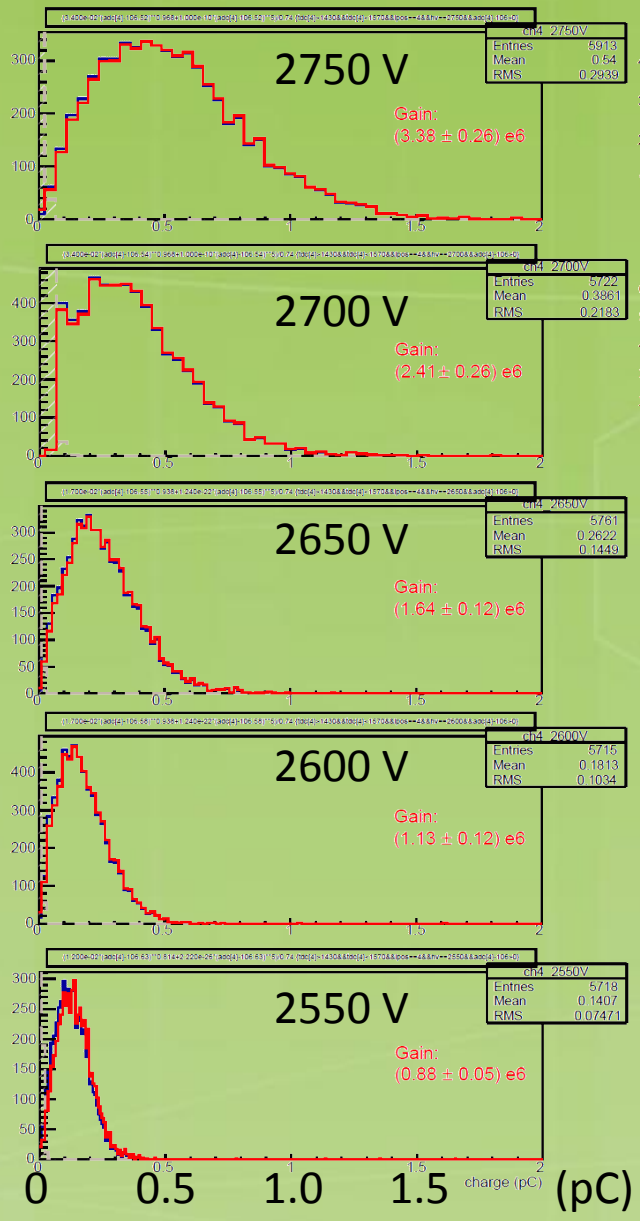
16 ch divider on the MCP-PMT socket



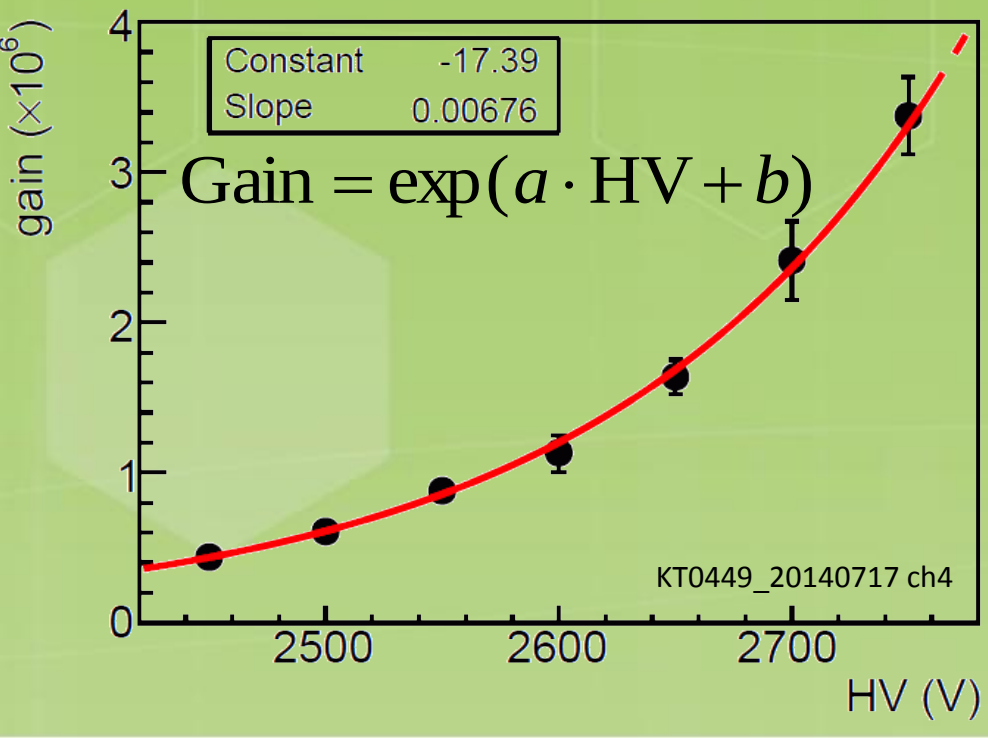




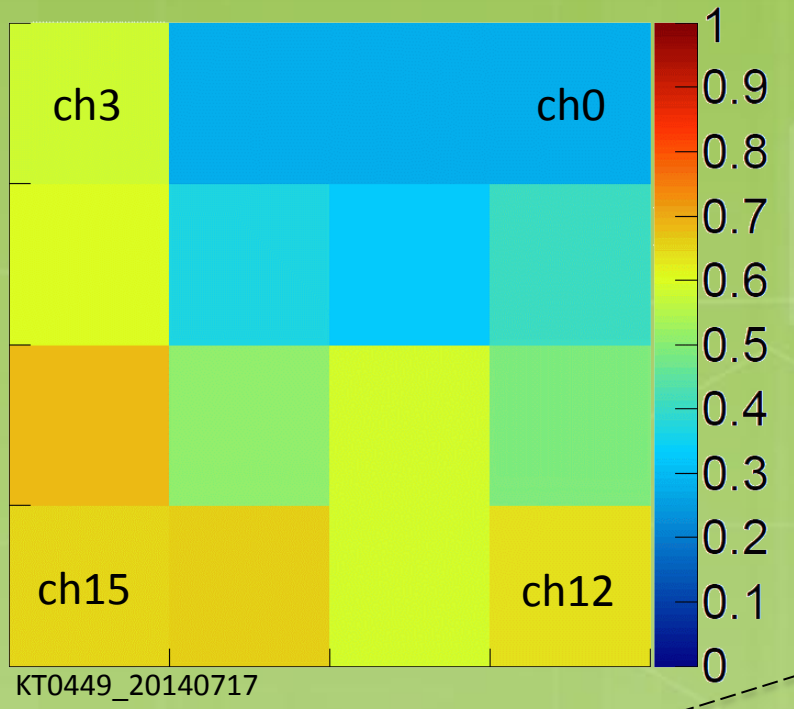
Gain measurement



Define the gain from the mean of the output charge distribution.



Gain uniformity



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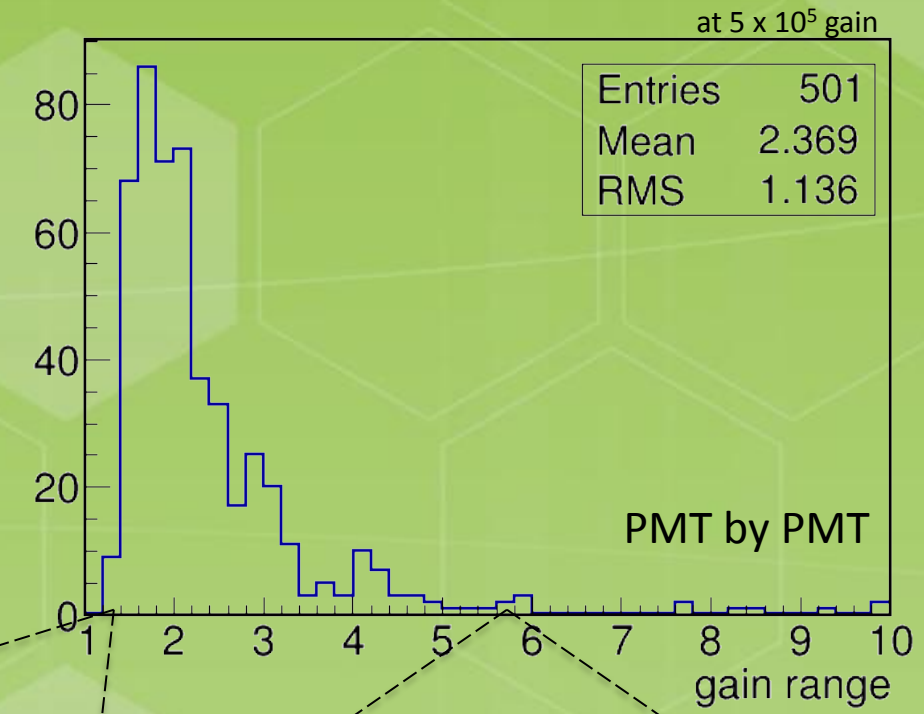
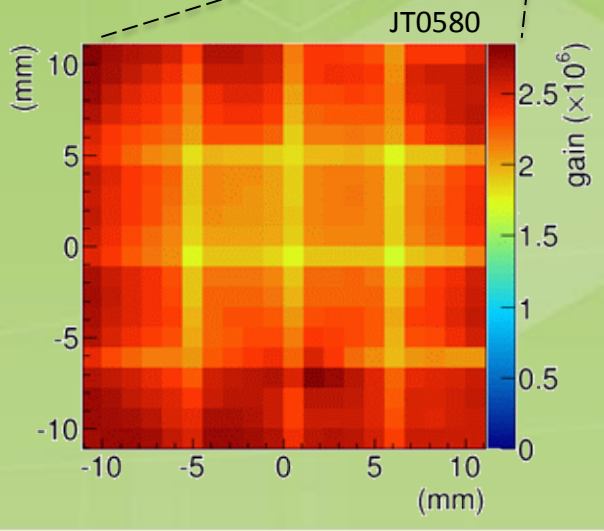
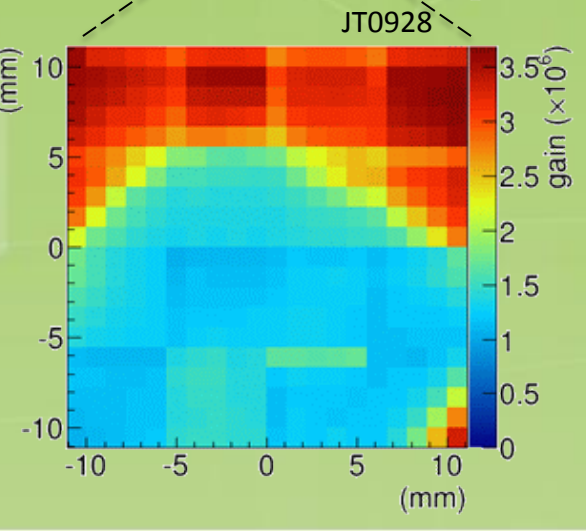
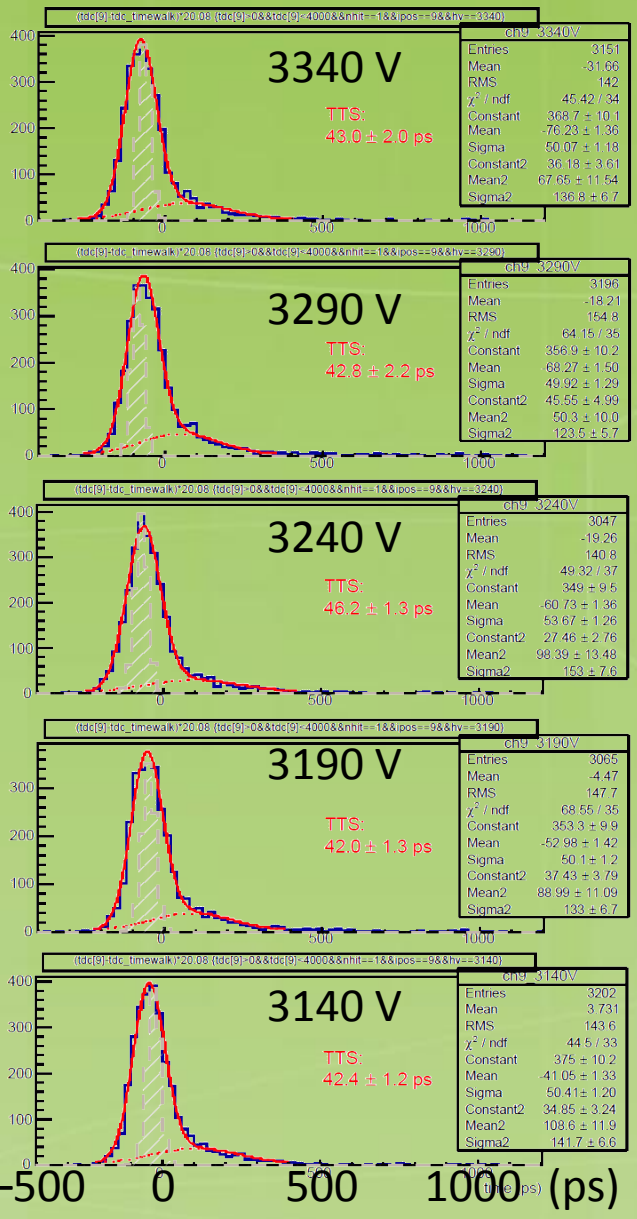


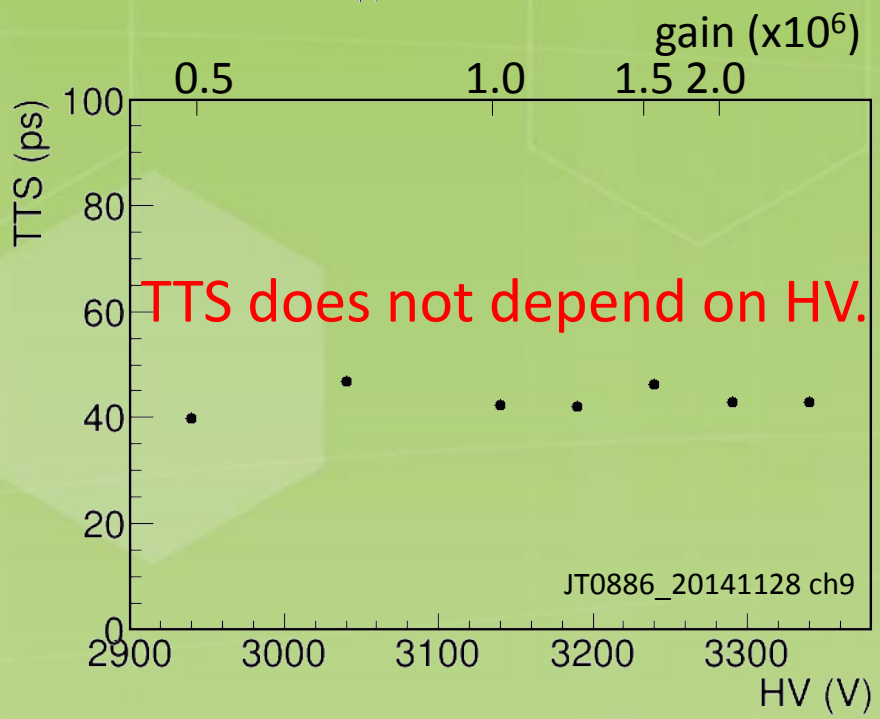




TTS measurement

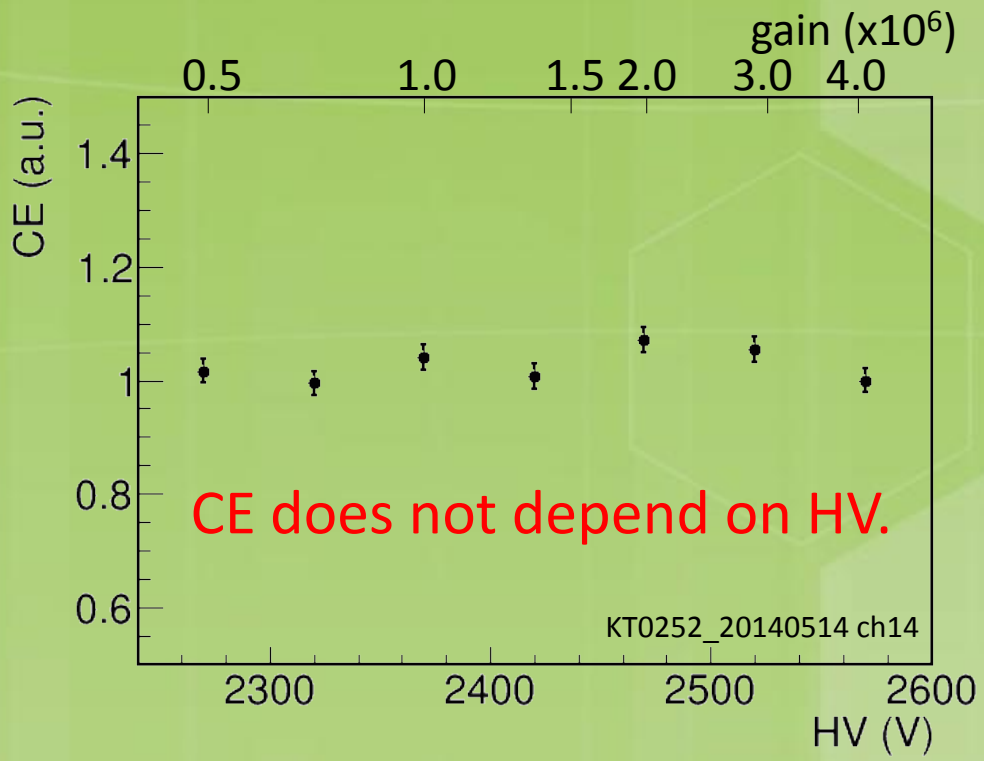


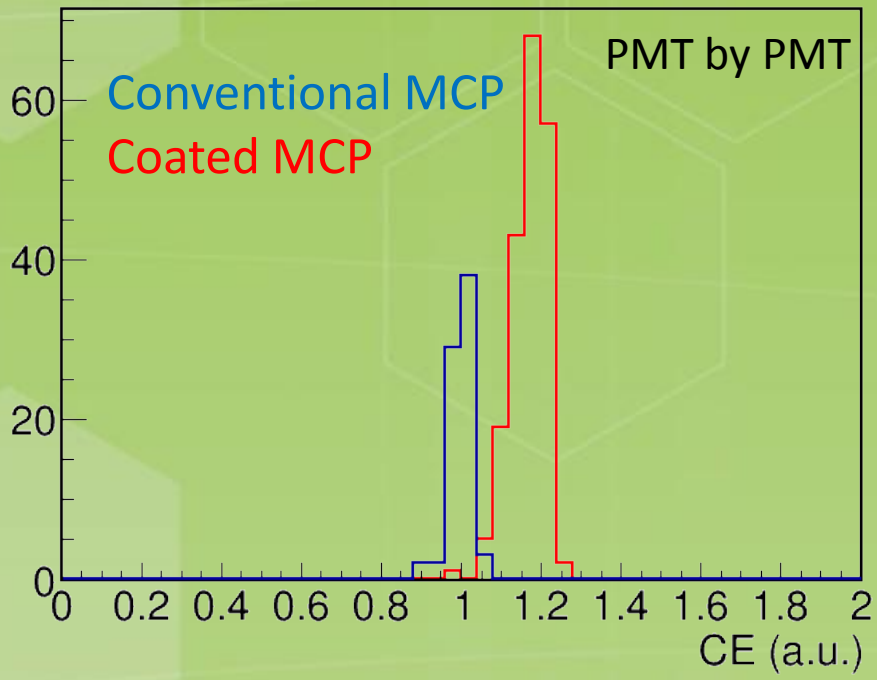
Fit double Gaussian to the TDC distr. after time-walk correction.
Define TTS from σ of the 1st Gaussian.



Collection efficiency measurement

- CE ∝ Number of TDC hits / QE
- Variation of the laser intensity is corrected by the reference PMT.

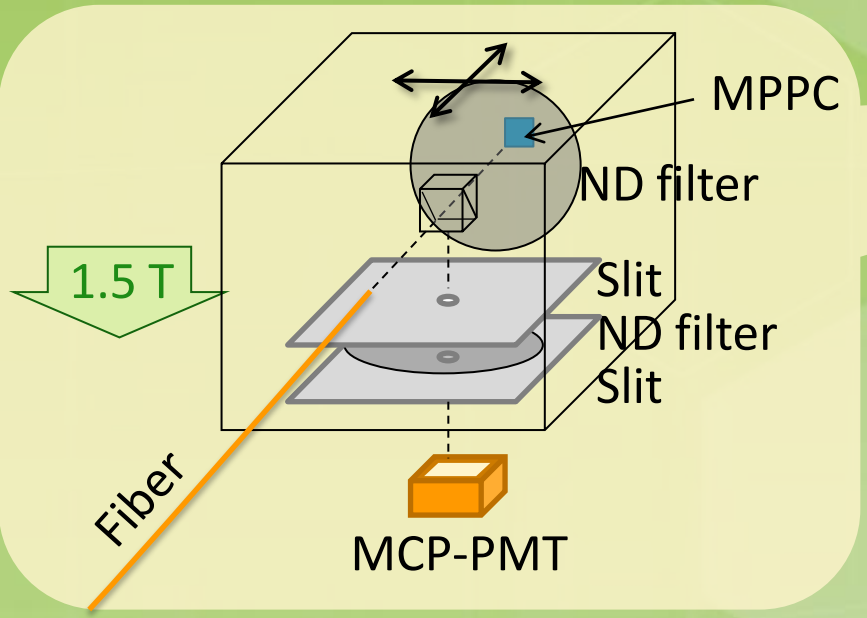




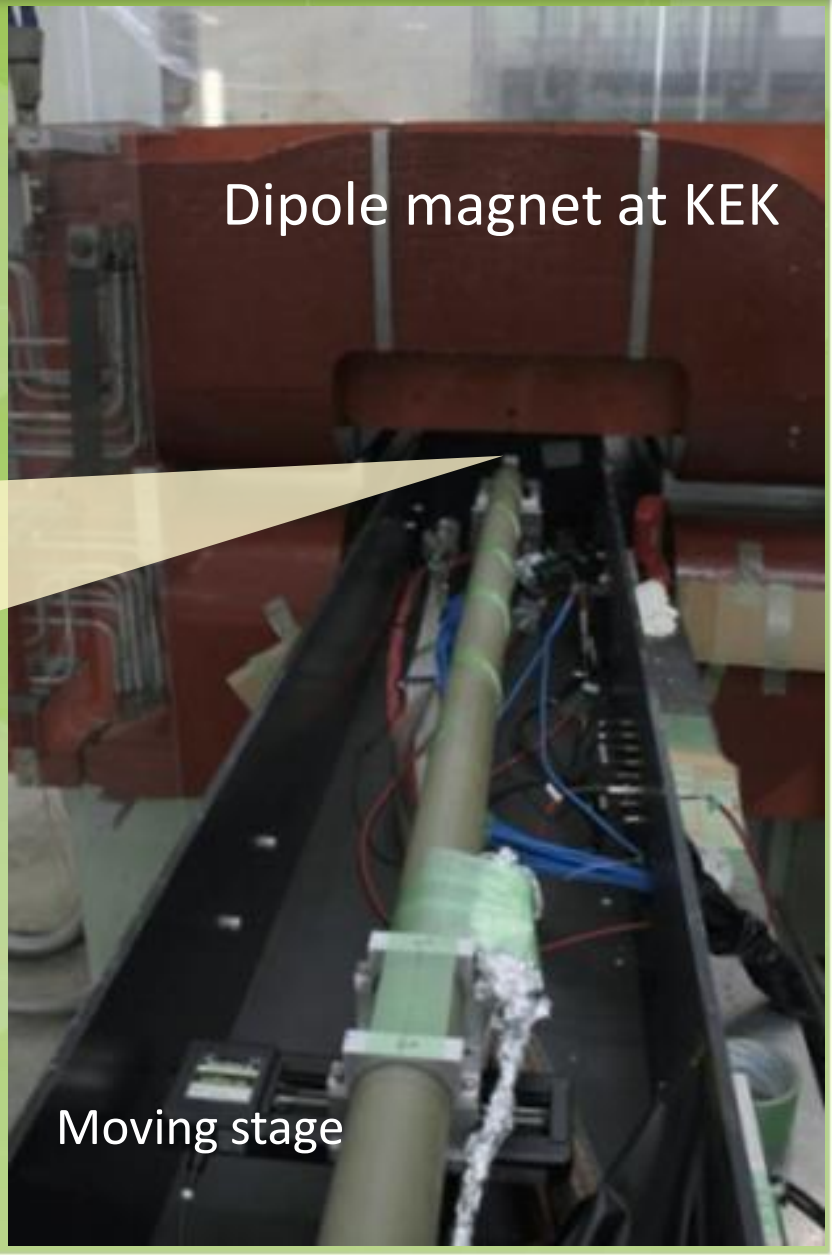
Higher CE of the coated MCP by ~17% than the conventional one.

Laser test setup in 1.5 T

- Fix the MCP-PMT not to be moved by magnetic force.
- Use an MPPC (insensitive to magnetic filed) as a reference.

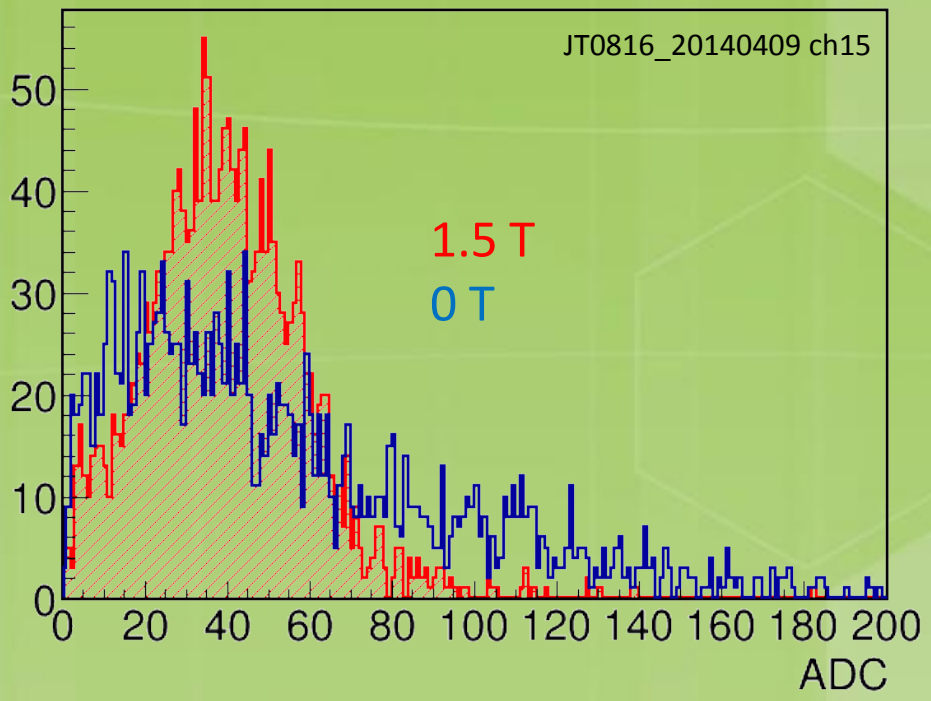


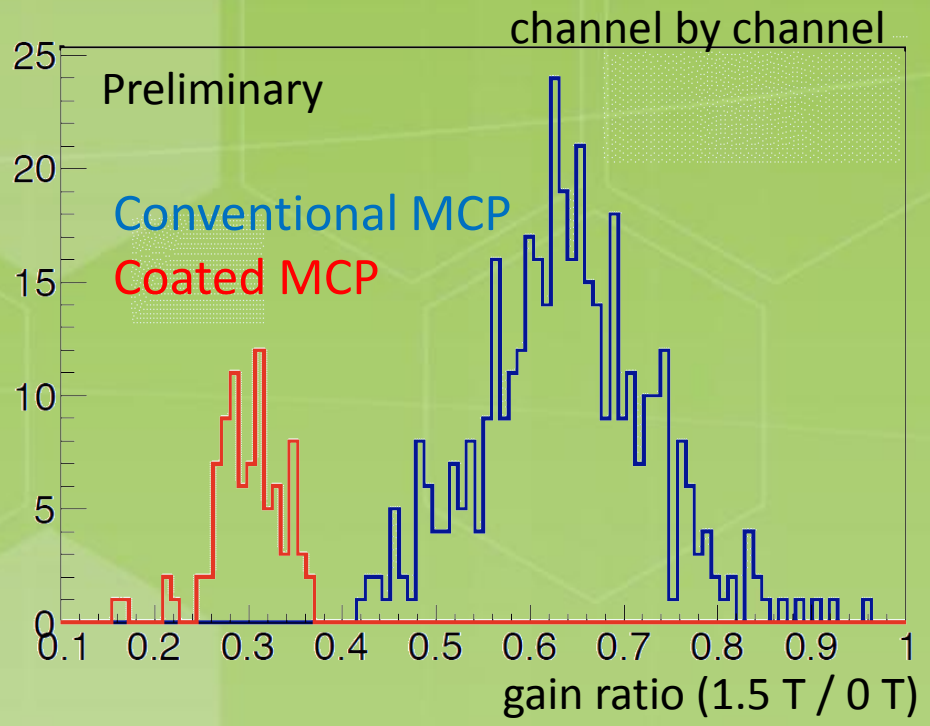
- Take two data sets with the magnet off and on.



Gain in 1.5 T

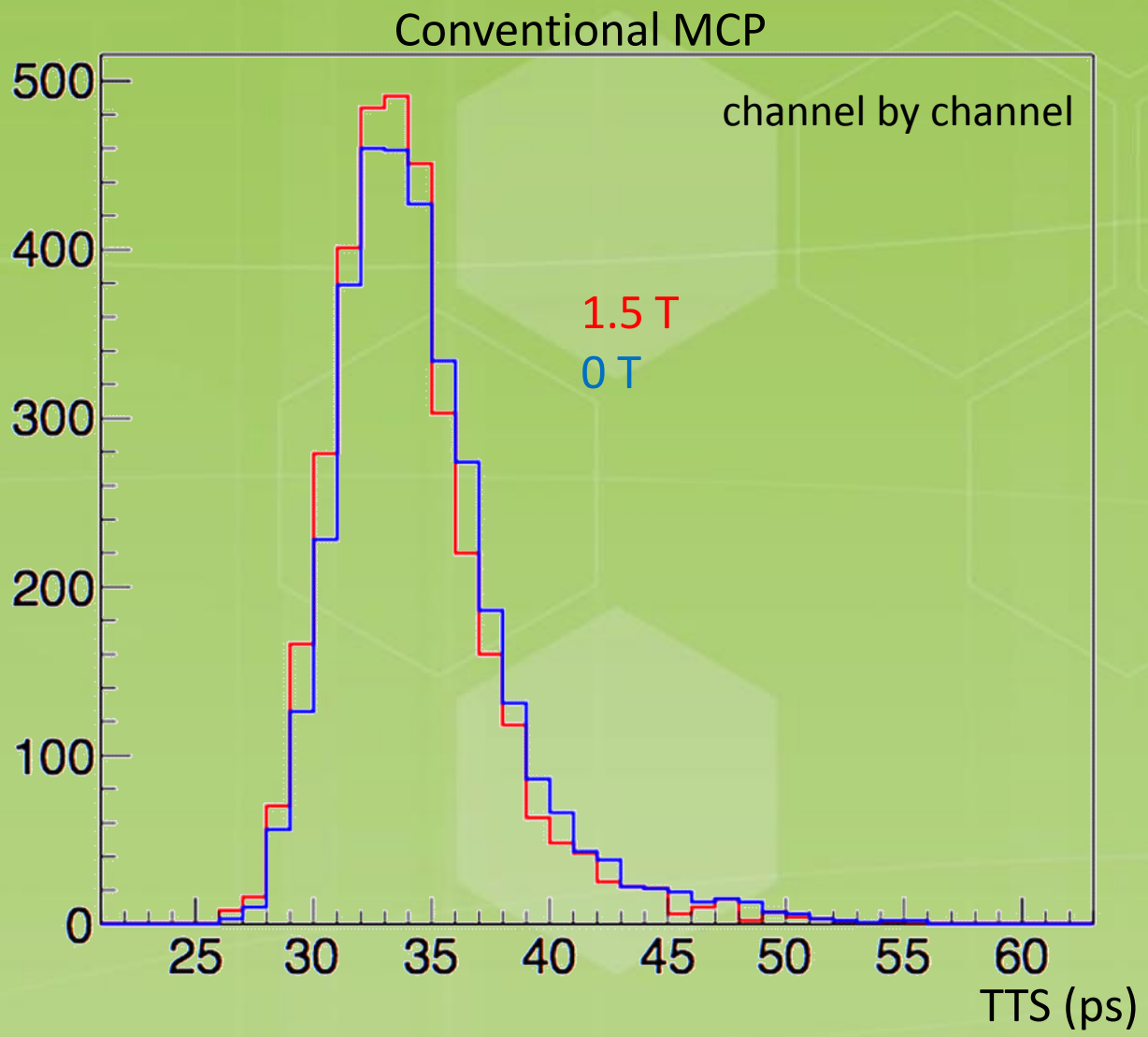
The gain decreases in 1.5 T.





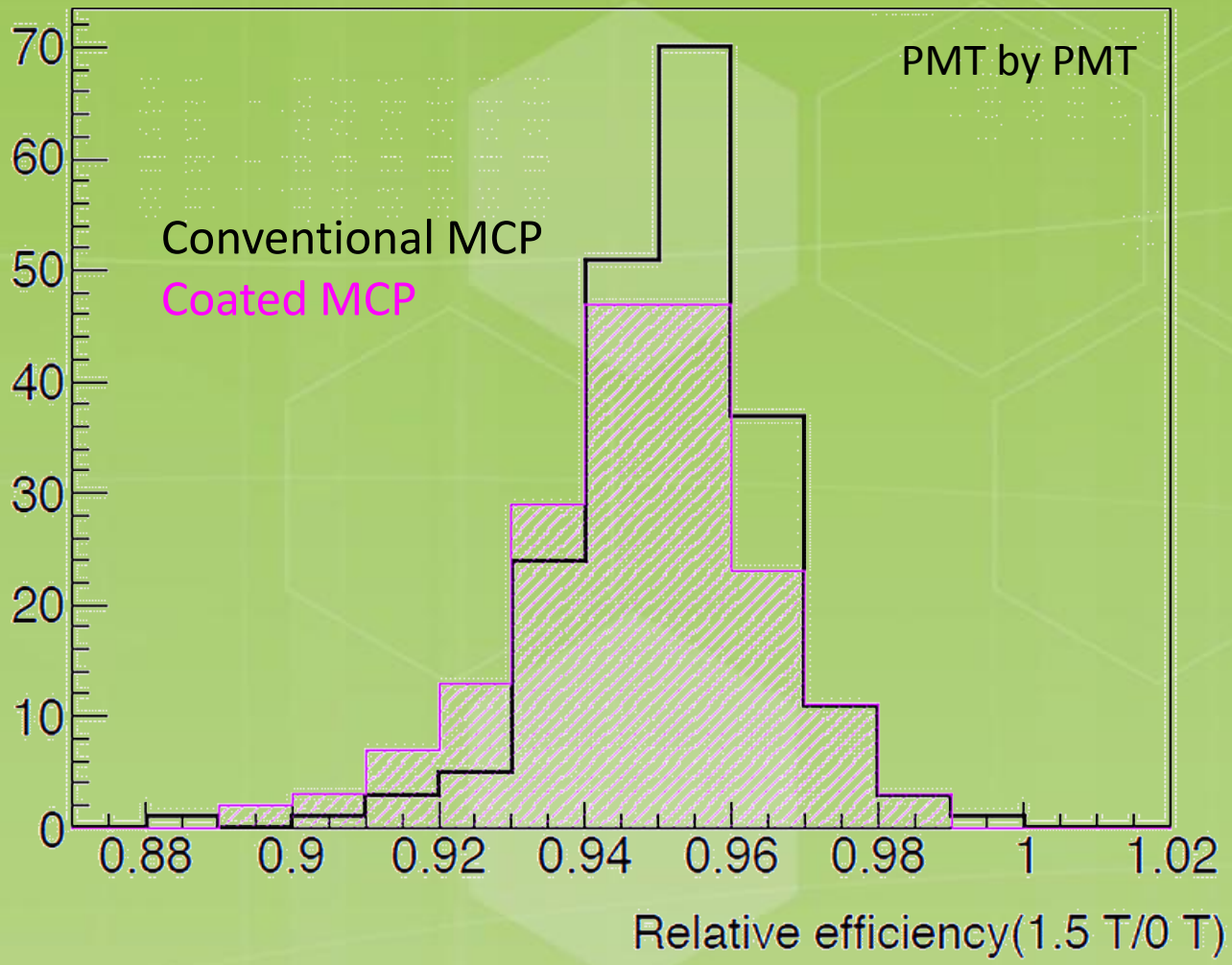
Rate of decrease is different between the conventional and coated MCP-PMTs.

TTS in 1.5 T



TTS does not change in 1.5 T.

Collection efficiency in 1.5 T



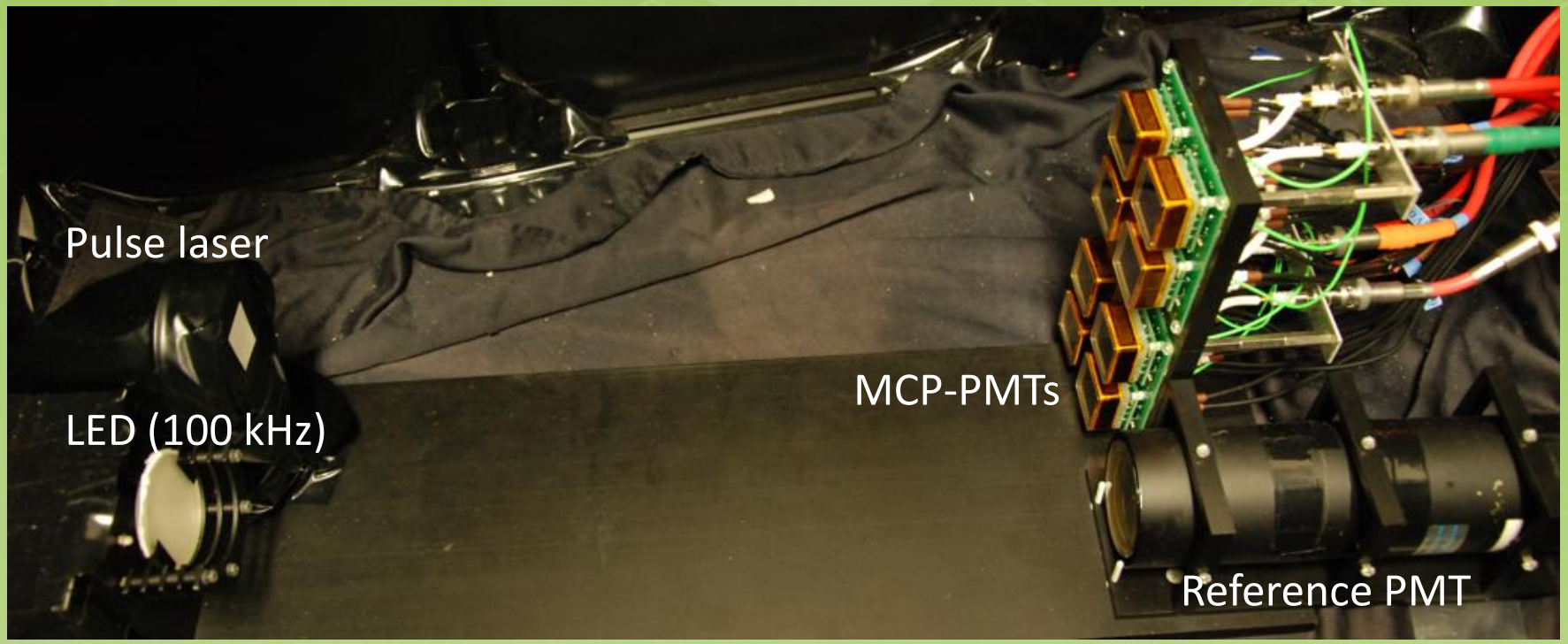
The collection efficiency decreases by ~5% in 1.5 T.

The RMS is consistent with the statistical error of each measurement.

Lifetime

Life test setup

- Load the output charge of the MCP-PMTs by the LED.
  - The output charge is measured by a CAMAC ADC.
- Monitor the hit rate (∝QE) by the laser single photons.

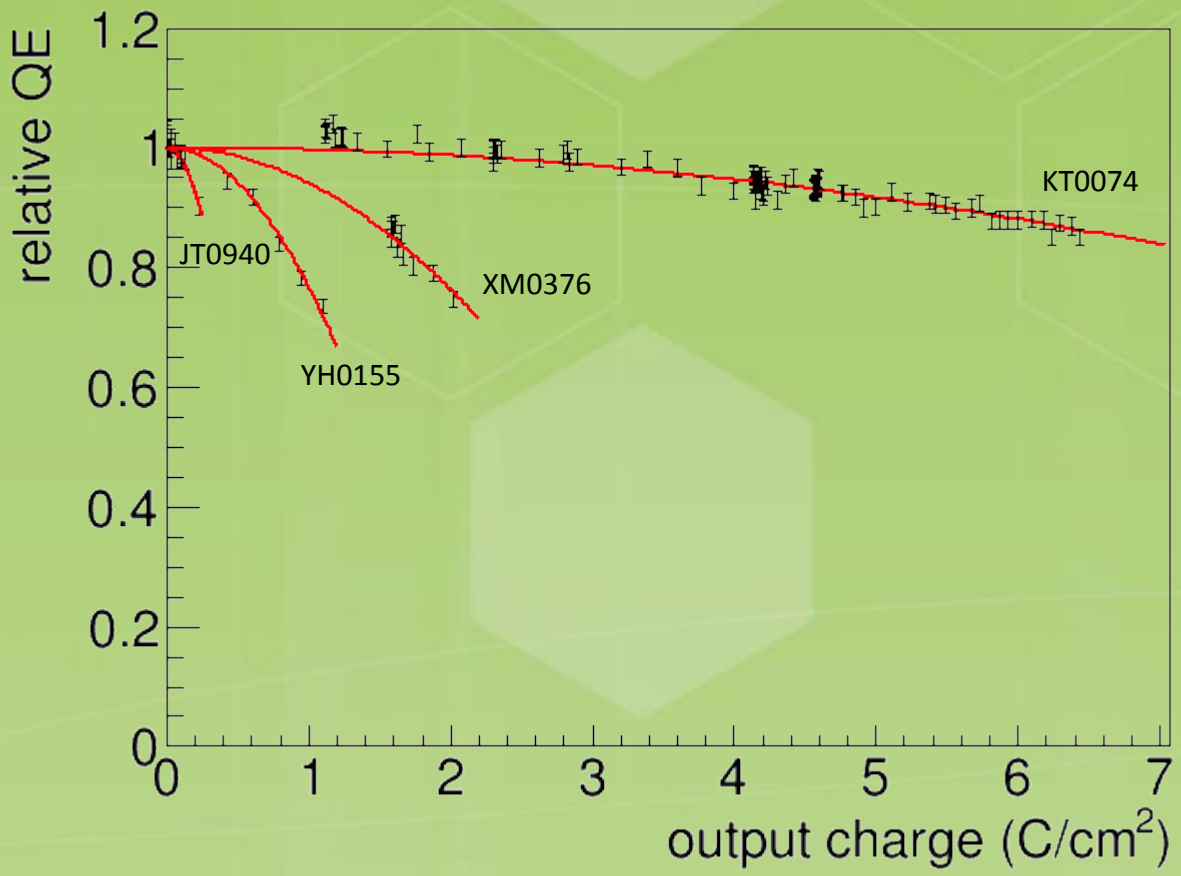


QE vs. output charge

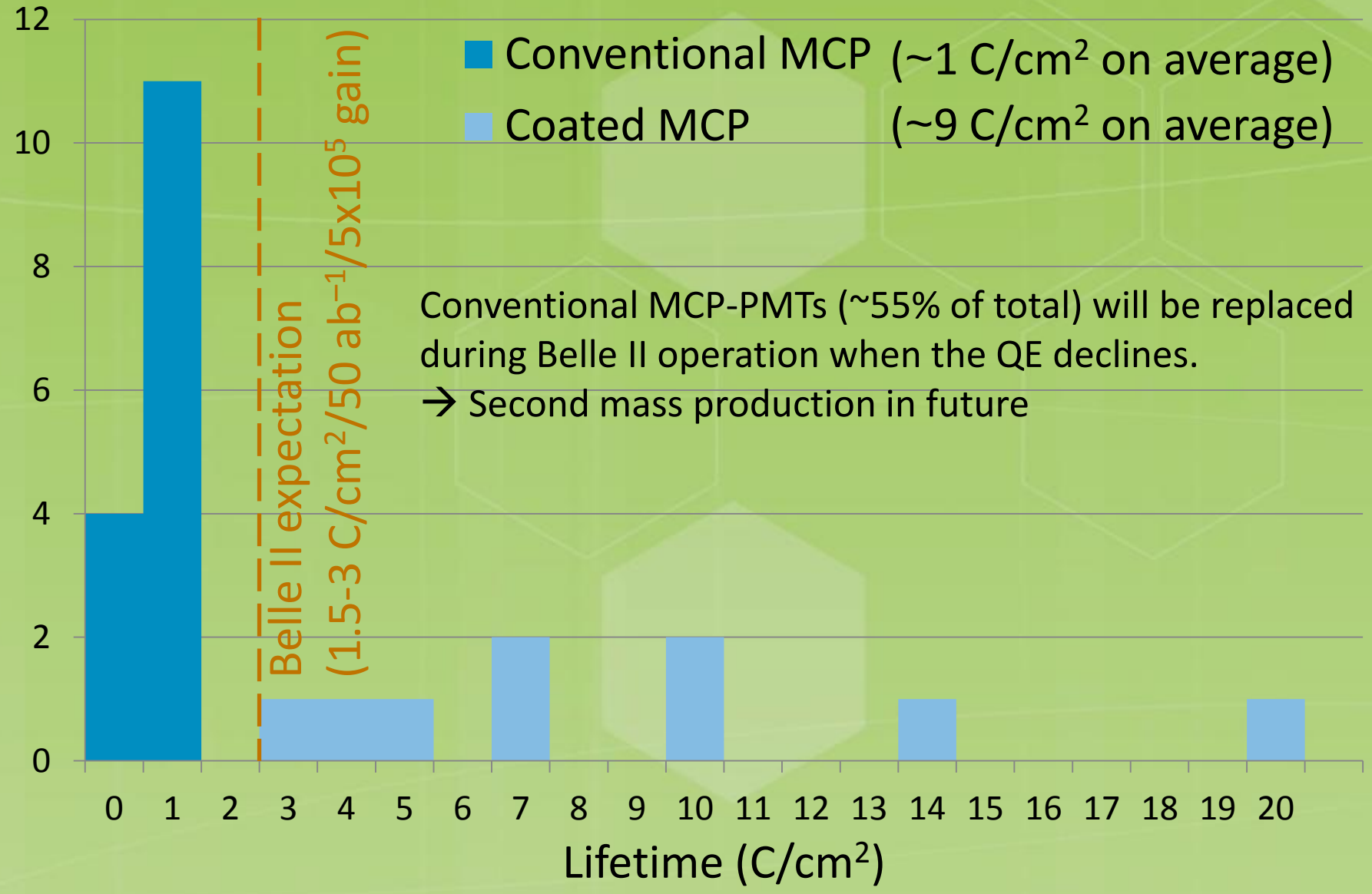
- QE declines as a quadratic function of total output charge:

$$\frac{\mathrm{QE}(Q)}{\mathrm{QE}(0)} = 1 - \left(\frac{0.447}{Life} Q\right)^2$$

Life: Output charge at QE(Q)/QE(0) = 0.8

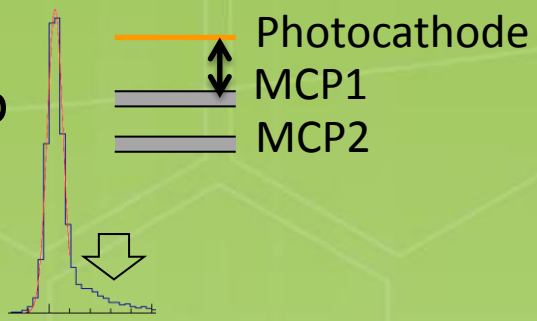


Lifetime


Conventional MCP (~1 C/cm² on average)
Coated MCP (~9 C/cm² on average)
Belle II expectation
(1.5-3 C/cm²/50 ab⁻¹/5x10⁵ gain)
Conventional MCP-PMTs (~55% of total) will be replaced during Belle II operation when the QE declines.
→ Second mass production in future
0
2
4
6
8
10
12
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Lifetime (C/cm²)

Prospects of performance improvement

- Uniform gain?
  - Production process of MCPs may affect the uniformity.
- Better timing resolution?
  - Shorter distance from the photocathode to MCP1 would suppress the TDC tail due to the electron recoil on the MCP1 surface.



- Higher collection efficiency?
  - ~17% difference between the conventional and coated MCP may be a hint for improvement.
- Lifetime improvement for the coated MCP-PMT.
  - R&D is ongoing for future production.

- Improvement of the efficiency would be most significant in terms of the TOP PID performance.

Summary

- We succeeded in mass production of 512+α MCP-PMTs for the TOP counter.
  - Achieved good quality as virtuous cycle of **[production -> performance check -> production]** created.

- Systematic measurement of a large number of MCP-PMTs for the first time:
  → Understand the performance of the MCP-PMT well.
  → Improve the performance for future production.