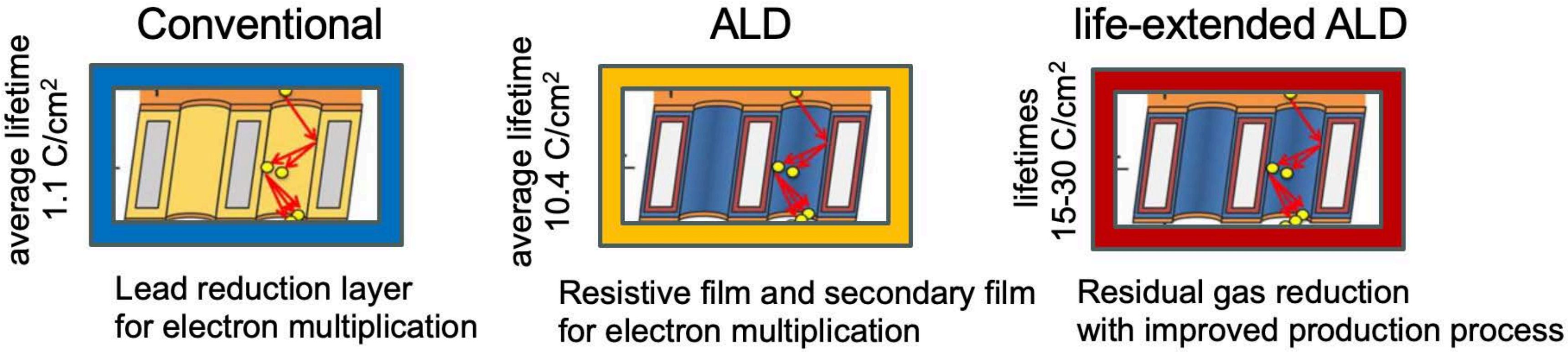
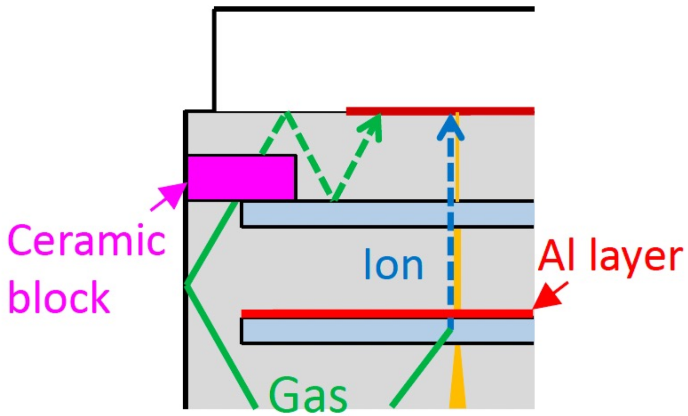
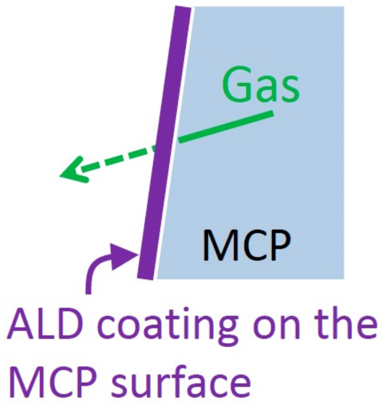
Development of life-extended MCP-PMT



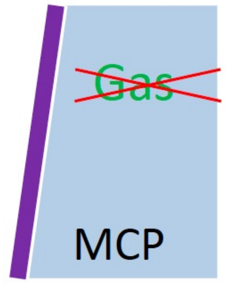
Step 1 (2011)
Conventional MCP-PMT



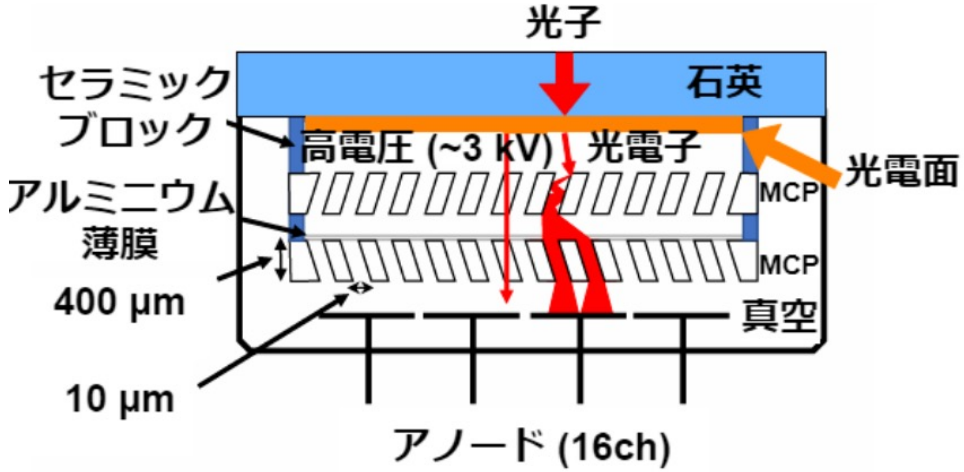
Step 2 (2013)
ALD



Step 3 (2015)
Life-extended ALD

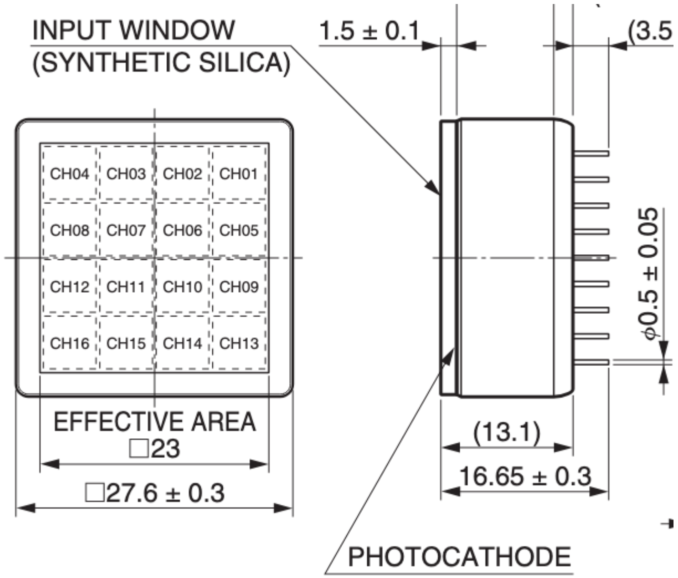


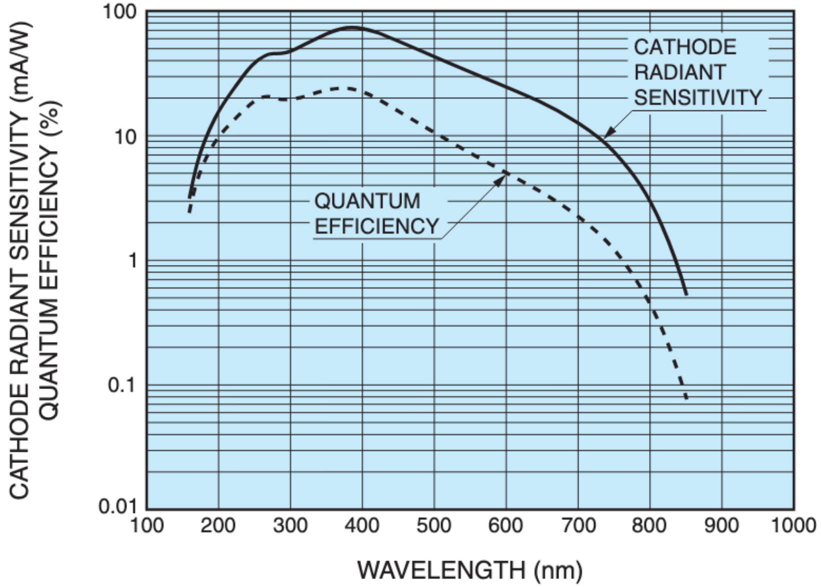
Development of life-extended MCP-PMT

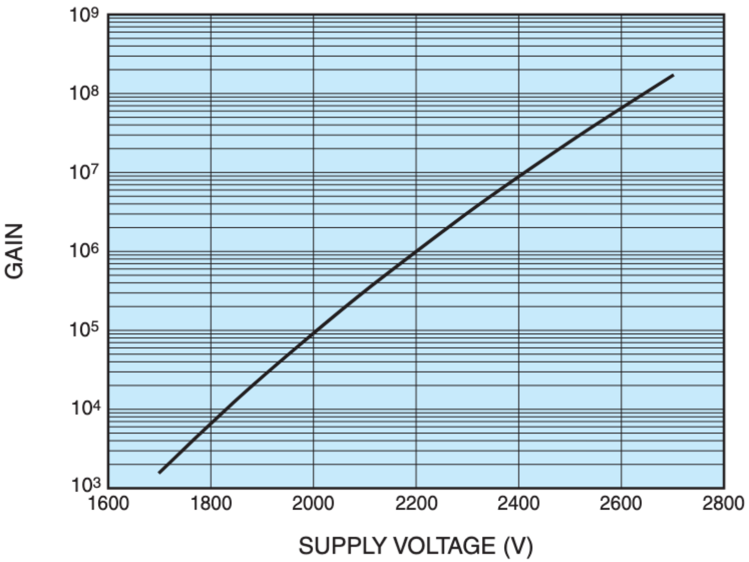


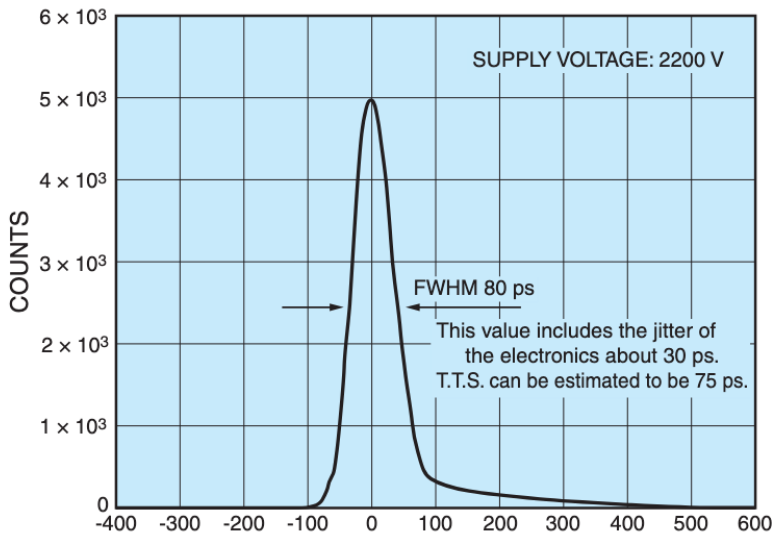
Catalog code	R10754-07-M16AN
Photo-cathode	Enhanced multi-alkali (>28% QE at peak)
MCP Channel ϕ	10µm
MCP chevron angle	13°
MCP thickness	400µm
MCP layers	2
Al protection layer	On 2nd MCP
Anode channels	4x4
Sensitive region	64%
HV	~ 2000 –3500 V

Development of life-extended MCP-PMT



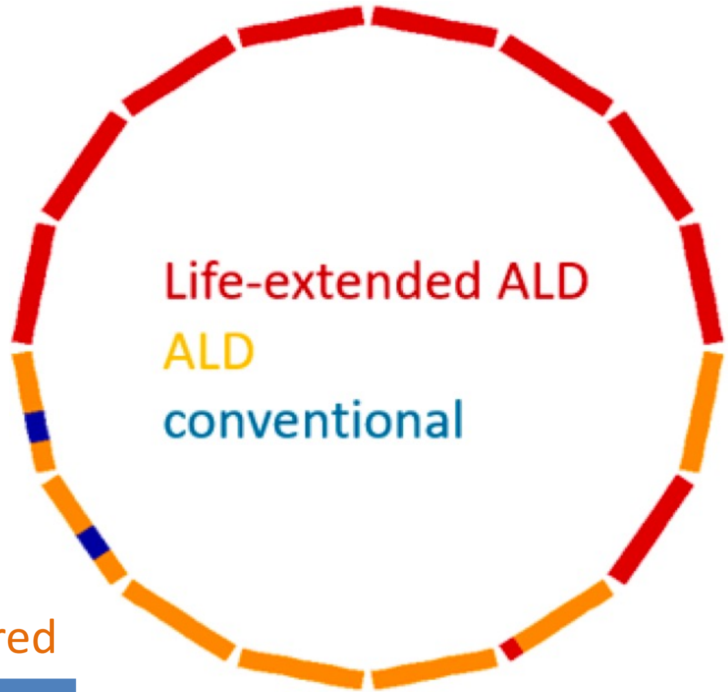






MCP-PMTs replacement plan

220 { 16 Conventional MCP-PMT
204 ALD MCP-PMT }
292 life-extended ALD MCP-PMT



220 new life-extended ALD-MCP-PMT

Delivered and tested in laboratory to be tested in magnetic field next winter

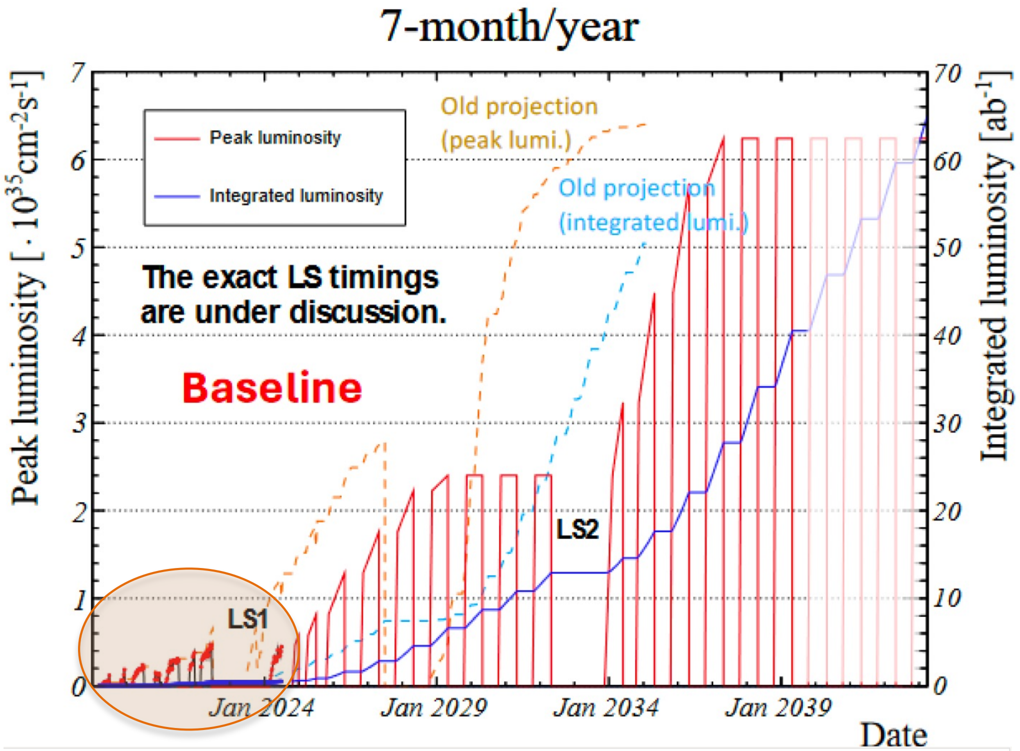
To be delivered

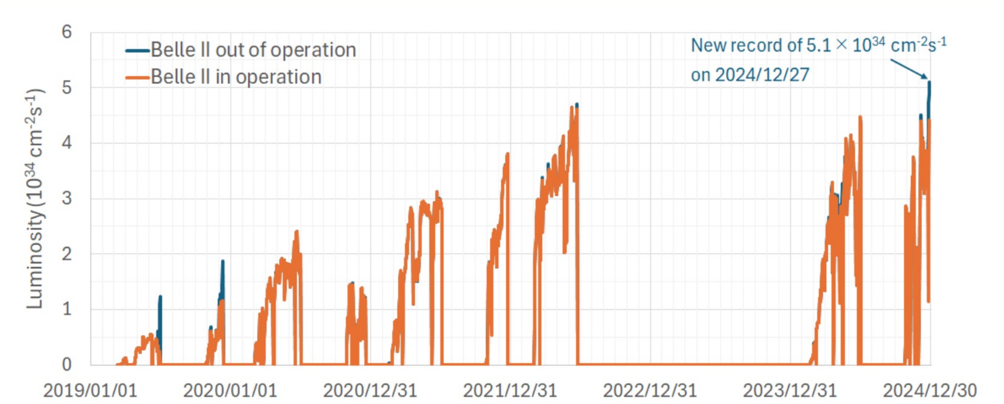
JFY	2023	2024	2025	2026
MCP-PMT production	66	150	10	
TOT		**216**(*)	226	
Installation readiness				

(*) 60 to be tested in laboratory

Luminosity and QE projections

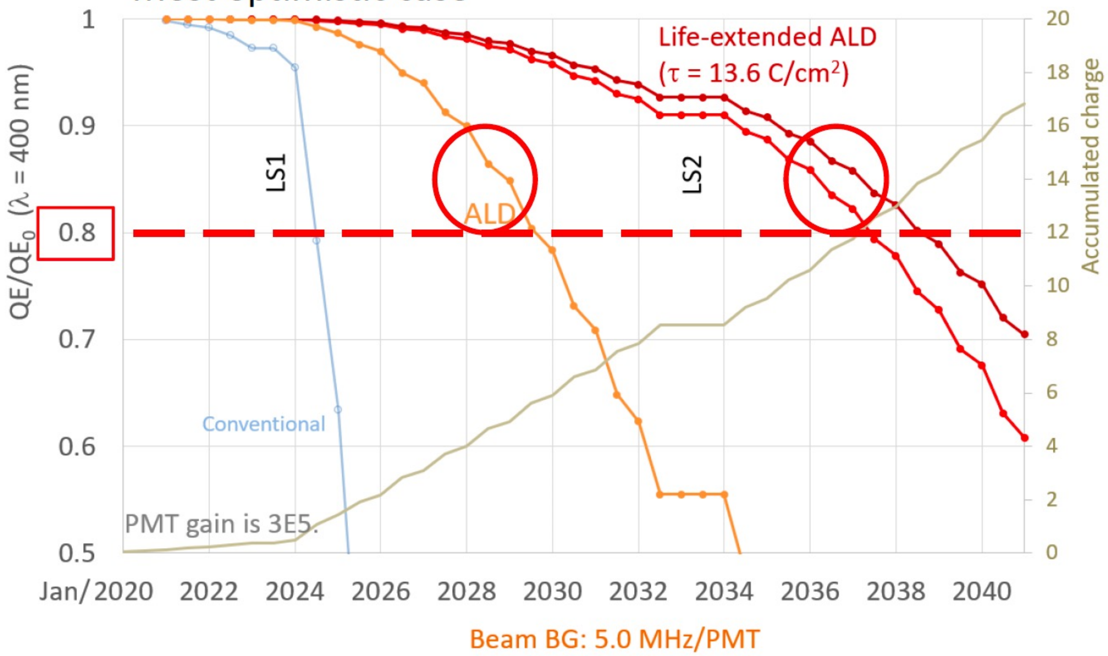
The baseline luminosity projection has been considered for the QE lifetime projection





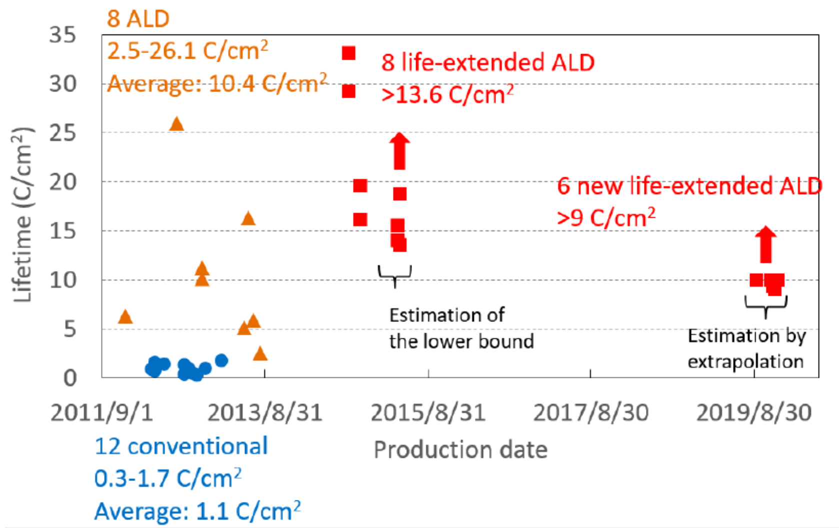
Luminosity and QE projections

Most optimistic case



lifetimes measured in laboratory

MCP type	Lifetime for test samples
Conventional	1.1 C/cm² (Average)
ALD	10.4 C/cm² (Average)
Life-extended ALD	>13.6 C/cm² (Minimum) (>9 C/cm² for recent sample)



QE expected lifetime for MCP-PMTs has been updated:

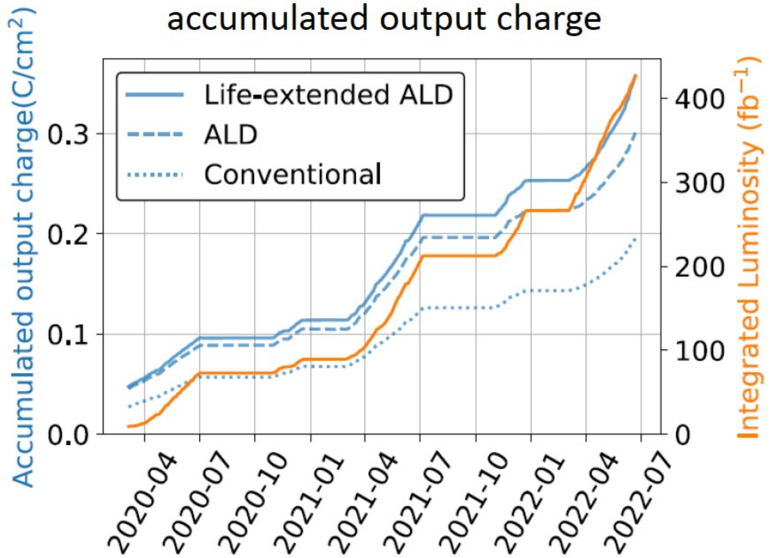
- considering the new luminosity projection;
- considering mean lifetimes measured in laboratory, and assigning a Poisson distribution to the actual lifetime of each photodetector;
- considering a beam background of 5 MHz / PMT and MCP-PMT gain of 3×10^5

We must replace ALD MCP-PMTs in 2028-2029, life-extended ALD MCP-PMTs in 2036-2037
In case of higher background rate from 2025 (5MHz/PMT→7MHz/PMT)
we must replace ALD MCP-PMTs in 2027-2028, life-extended ALD MCP-PMTs in 2035-2036

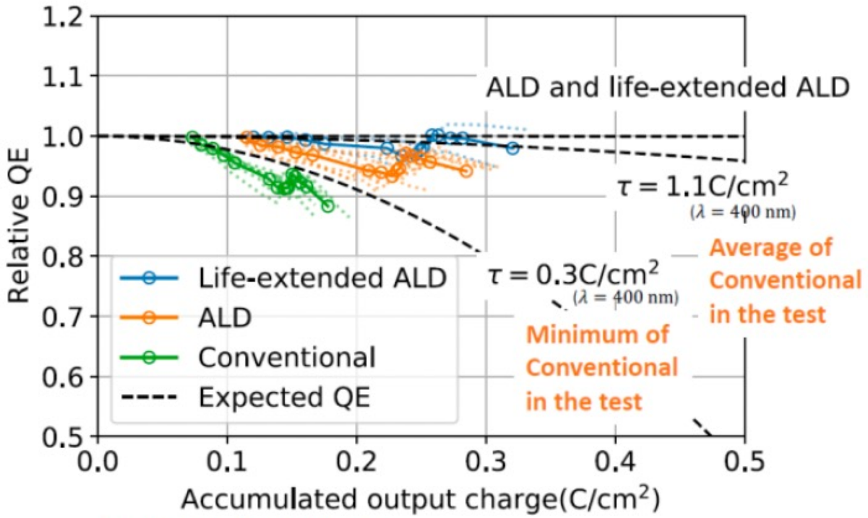
Luminosity and QE projections

Relative QE, for MCP-PMTs installed in the TOP detector, can be estimated by measuring the hit rate.
QE degradation in the experiment is faster than expected QE degradation from laboratory measurements.
Anyway, estimation with hit rate has large error and small accumulate charge. The accumulated charge of 0.3 C/cm^2 (for 400 fb^{-1}) can not provide a sensitive measurement for life-extended ALD

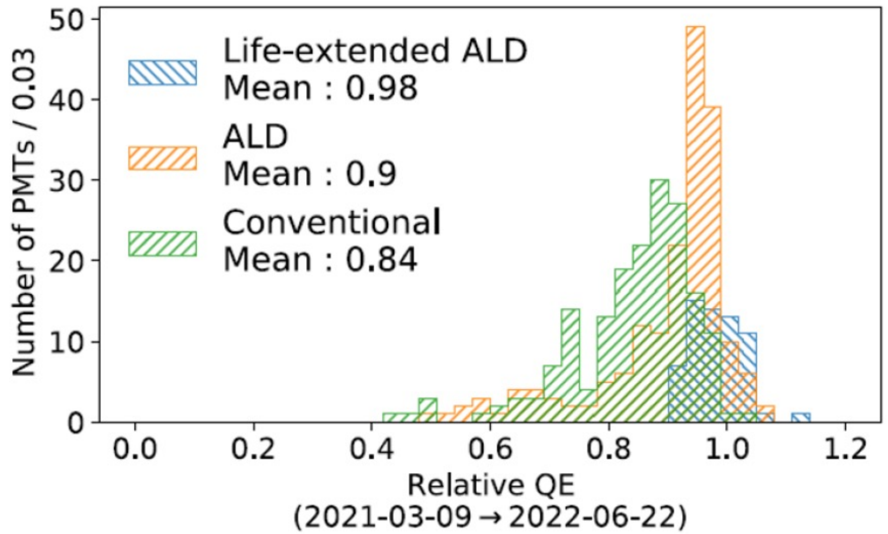
History of Luminosity and accumulated output charge



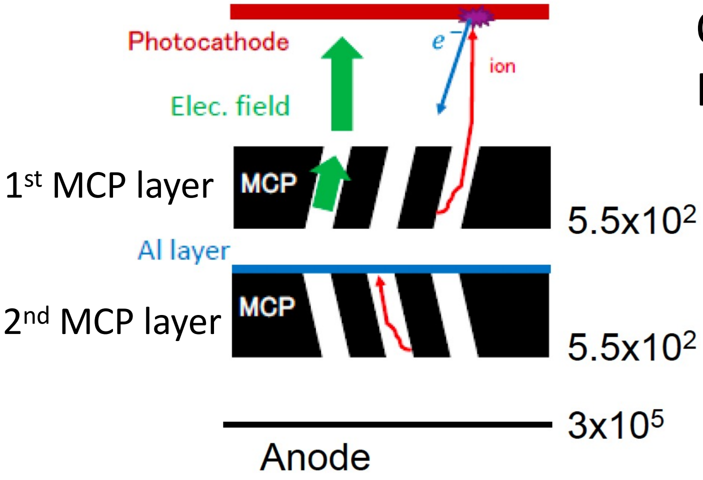
lifetimes in the detector using hit rate



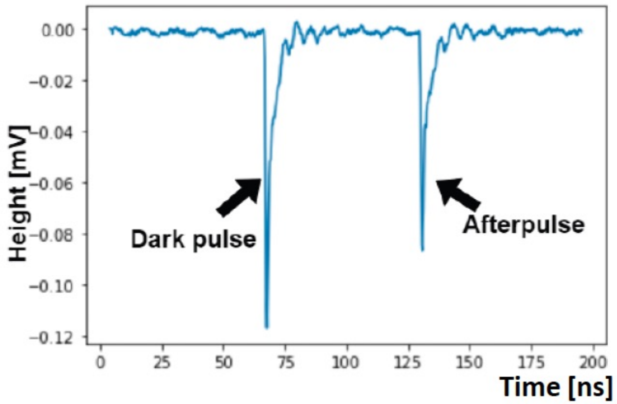
Dotted line : SLOT average
Solid line : Type average



Photodetector upgrade



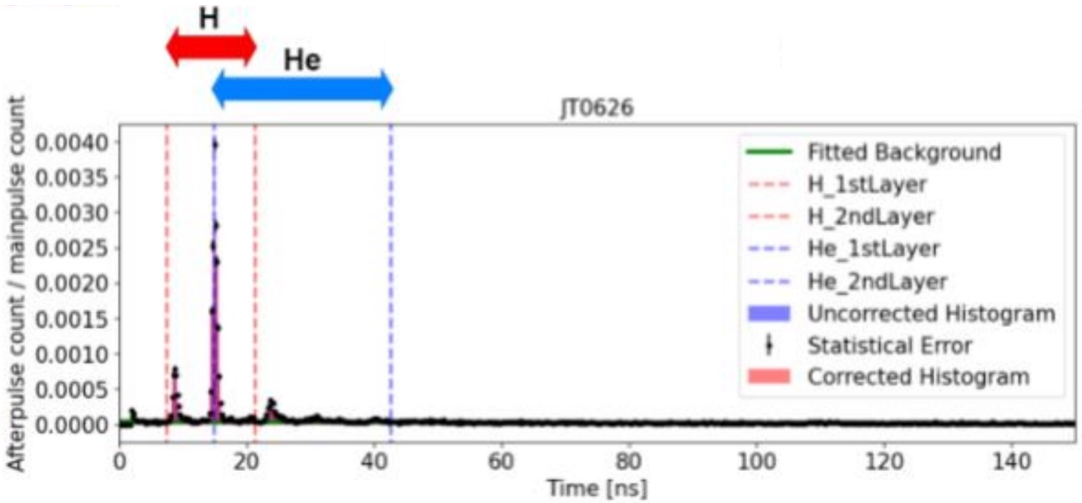
QE degradation due to feed-back ions.
Is not easy to further improve the life-extend ALD technology

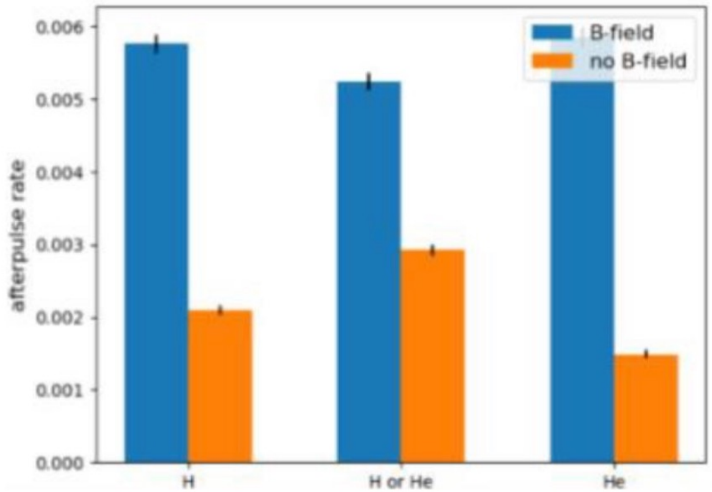


Study of afterpulse signals produced by ions

Different ions have different drift times

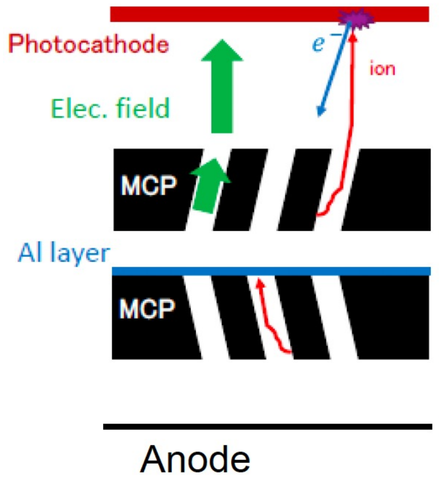
The time difference between different ions is not large enough to always identify the type of ion and its origin. Anyway, looking at He ions it looks like the favored emission is from the first MCP layer, probably due to Al layer. Results show higher afterpulse rate in 1.5 T B-field.





Photodetector upgrade

R&D for lifetime with modified HV divider



5.5×10^2	↓	Decrease HV in first MPC
5.5×10^2	↑	Increase HV in second MPC
3×10^5		Keep gain constant

Measure with different HV divider ratio: time resolution, afterpulse rate, QE lifetime check at 1.5 T B-field

MCP-PMTs do not need to be modified/replaced, the HV divider is inside the HV board.

Schedule:	now -> June	production and test of new HV boards
	September	test with modified HV divider

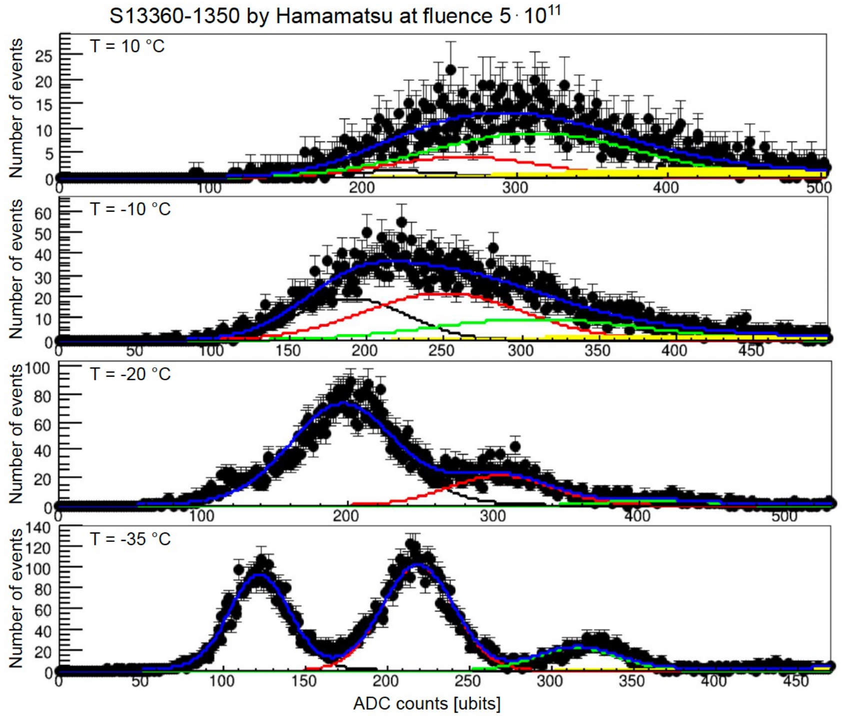
SiPM option

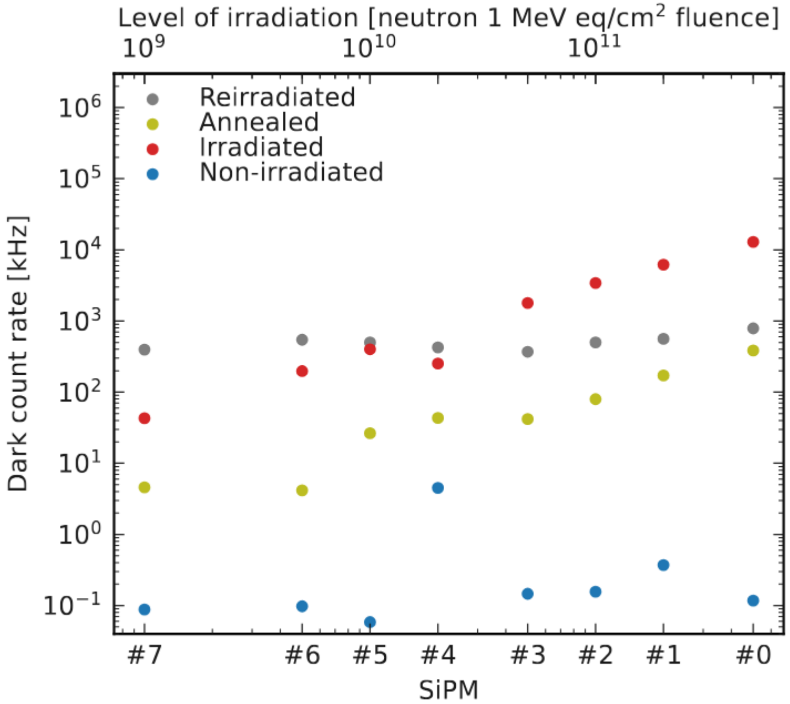
Several studies of SiPMs and R&D are ongoing in different laboratory.
In Padova a study with 32 SiPMs from different producers has been completed.

Producer	Code	Index	Size [mm×mm]	Pixel [μm]	Irradiation [1 MeV n eq cm^{-2}]
Hamamatsu	S13360-1350PE	0 - 7	1.3×1.3	50	$5.0{\cdot}10^{11}$ - $1.0{\cdot}10^{9}$
FBK	NUV-HD-RH-3015	8 - 10	3×3	15	$1.0{\cdot}10^{10}$ - $1.0{\cdot}10^{9}$
FBK	NUV-HD-RH-1015	11 - 14	1×1	15	$2.0{\cdot}10^{10}$ - $1.0{\cdot}10^{9}$
Hamamatsu	S14160-3050HS	15, 30, 31	3×3	50	$1.0{\cdot}10^{9}$ - $1.0{\cdot}10^{10}$
Kektek	PM3315-WL	16, 17	3×3	15	$1.0{\cdot}10^{10}$, $1.0{\cdot}10^{9}$
Kektek	PM3335-WL	18, 19	3×3	35	$1.0{\cdot}10^{10}$, $1.0{\cdot}10^{9}$
OnSemi	10035	20, 21	1×1	35	$1.0{\cdot}10^{10}$, $1.0{\cdot}10^{9}$
OnSemi	30035	22, 23	3×3	35	$1.0{\cdot}10^{10}$, $1.0{\cdot}10^{9}$
Hamamatsu	S13360-3025PE	24, 25	3×3	25	$1.0{\cdot}10^{10}$
Hamamatsu	S13360-3050PE	26, 27	3×3	50	$1.0{\cdot}10^{10}$
Hamamatsu	S14160-3015PS	28, 29	3×3	15	$1.0{\cdot}10^{10}$

SiPMs have been irradiated up to $5{\times}10^{11}$ 1 Mev neq /cm^2 ,
annealed at 150 °C for 8 weeks and re-irradiated up to $1{\times}10^{10}$ 1 Mev neq /cm^2

SiPM option





- For SiPMs 1.3 x 1.3 mm^2 size, photon spectra can be fitted also after irradiation of 5×10^{11} 1 MeV neq /cm^2 but low temperatures (-20 / -30 °C) are required.
- For SiPMs 3 x 3 mm^2 is very difficult to fit photon spectra, even at low irradiation level.
- Annealing significantly reduces the Dark count rate.

With current SiPMs we are far from being able to use 3x3 mm^2 size with limited cooling. R&D are ongoing to have lower dark count rate with ultra-low filed and back side illuminated technology.

Jakub Kandra PD24 Conference

Acknowledgment to Jennifer2 included in proceedings

Summary

- Replacement of ALD MCP-PMT in 2028-2029

- Prepare the replacement of the life-extended ALD MCP-PMT installed in 2016 and in 2023. About 320 photodetectors will be required.
  Not easy to find the budget: 1.6 M$ ≒ 2.3 oku ¥
  Try to Increase lifetime of current MCP-PMTs e.g. with modified HV divider.

- Continue SiPMs R&D

- Define the photodetector long-term within 2026 JFY