# EMT development as a new MUMON sensor

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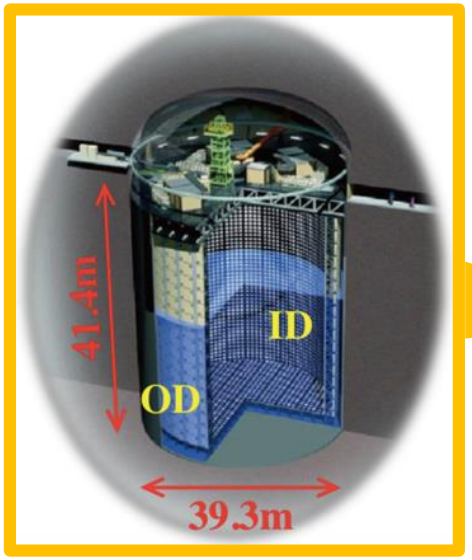
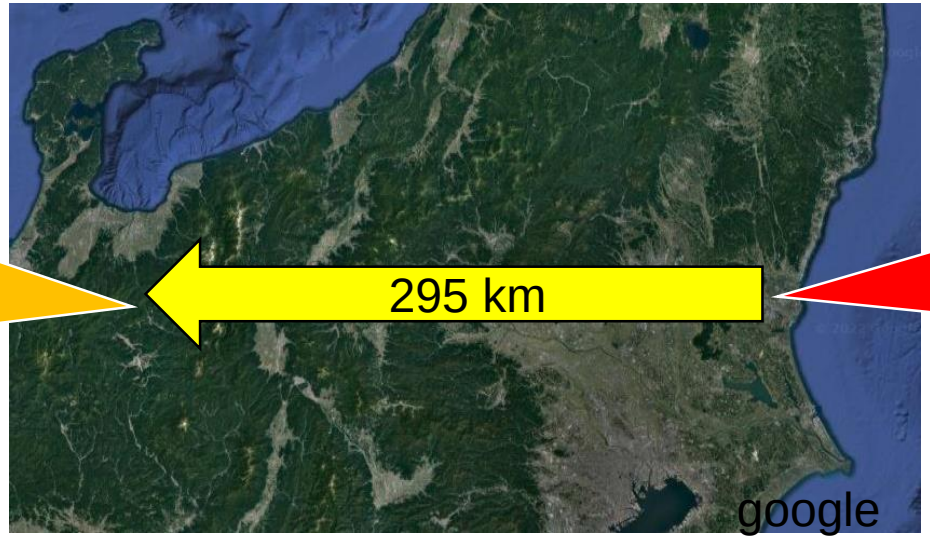
# T2K experiment

- Long baseline neutrino oscillation experiment
- Produce $\nu_\mu$ or $\bar{\nu}_\mu$ at J-PARC and detect neutrinos after oscillation at SK
- Search for CP violation in the lepton sector
- Beam power is gradually increased (current 500 kW, plan 1.3 MW)



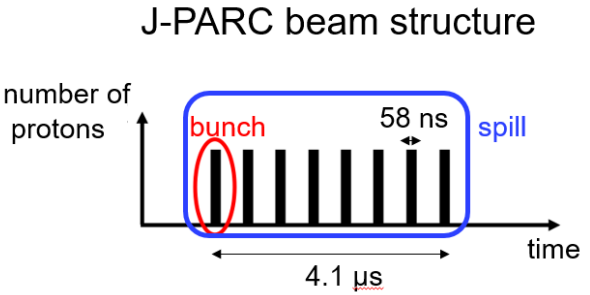




Super-Kamiokande

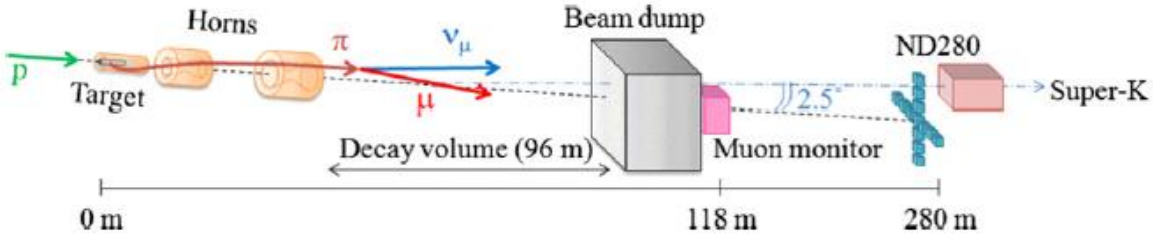
J-PARC

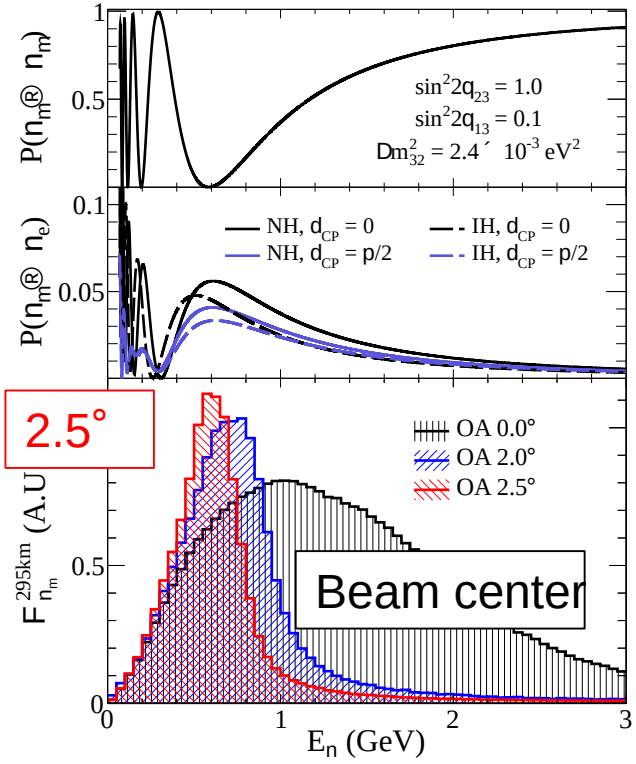
# Neutrino beam at J-PARC

- Neutrino beam production at J-PARC
  - 30GeV protons hit on the carbon target
  - Hadrons (including pions) are emitted from the target
  - Pions are focused by magnetic horns
  - Focused pions decay into neutrinos (and muons)




- Off axis beam method
  - Neutrino beam axis is shifted from the direction of Super-Kamiokande
  - Neutrino energy is tuned to maximize oscillation probability
  - Neutrino energy spectrum become narrow (background is suppressed)
  - Beam direction monitor is important

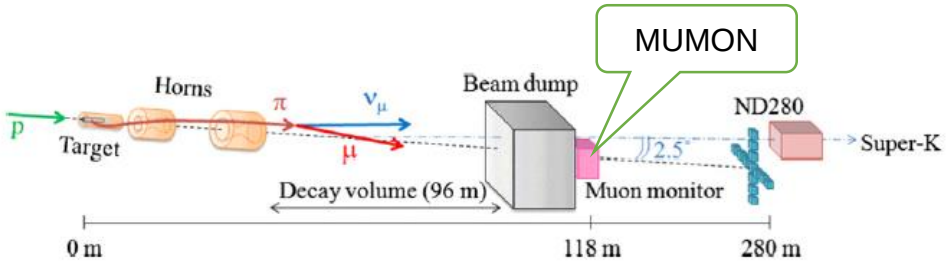


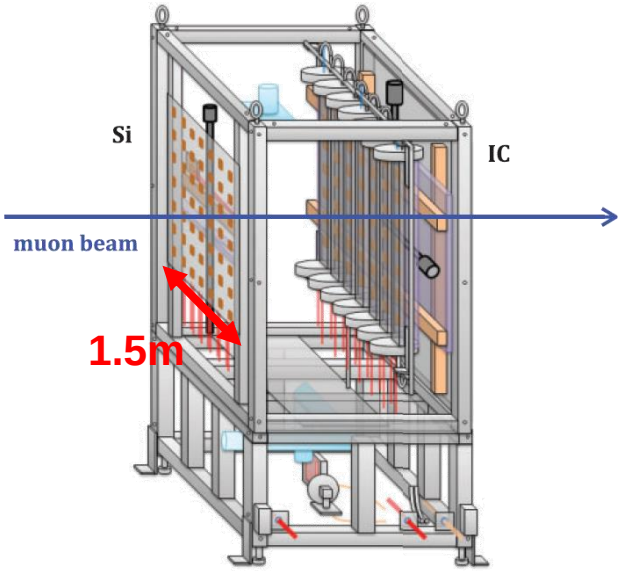



# MUMON (muon monitor)

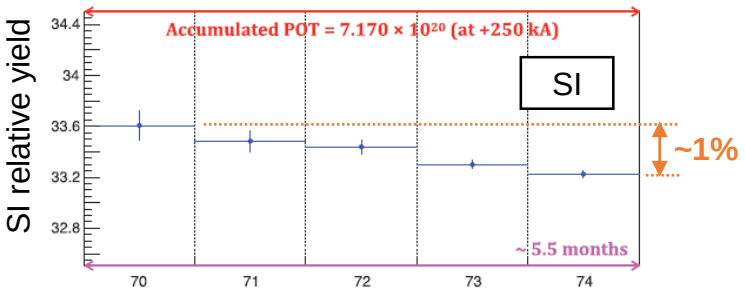
NIMA 624 (2010) 591
PTEP2015 (2015) 053C01
PTEP2018 (2018) 103H01

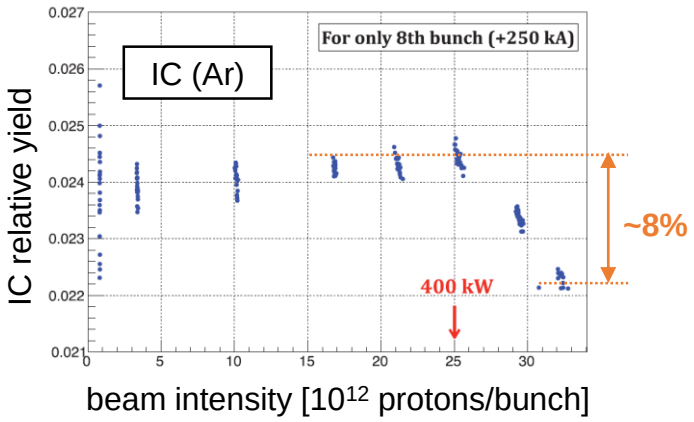
- What's MUMON ?
  - Monitor the beam direction via muon by SI/IC (0.3 mrad)
  - Real time monitoring (bunch by bunch)
  - --> necessary for beam operation



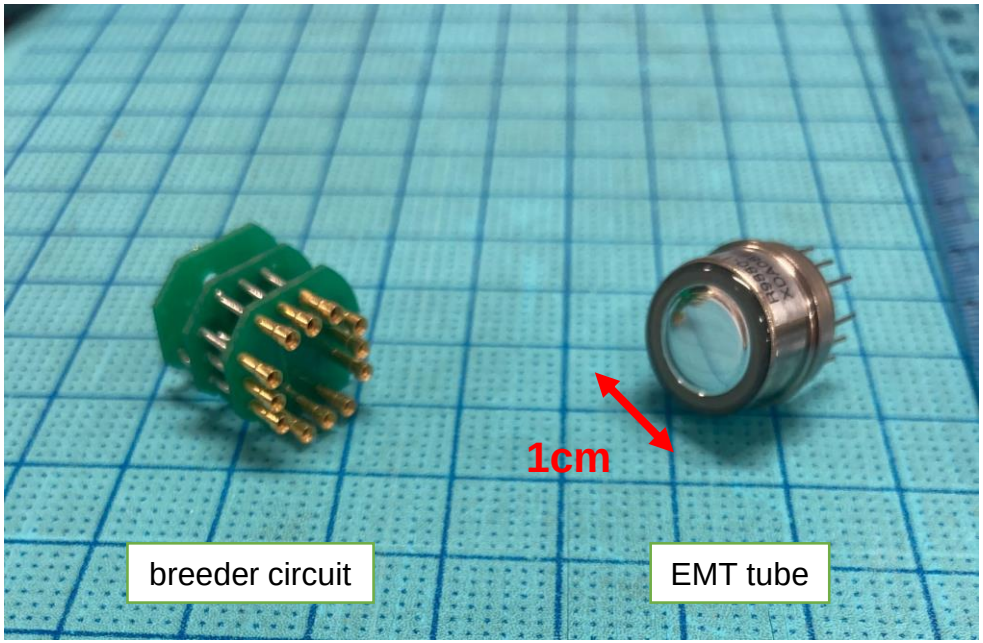

- Known Issue for high intensity beam
  - SI : yield decrease due to radiation damage
  - IC : signal saturation in higher intensity

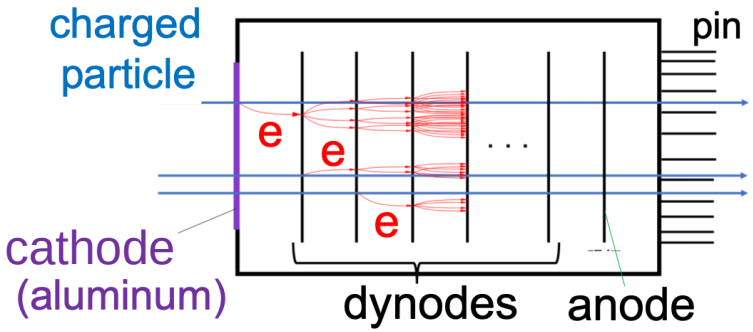


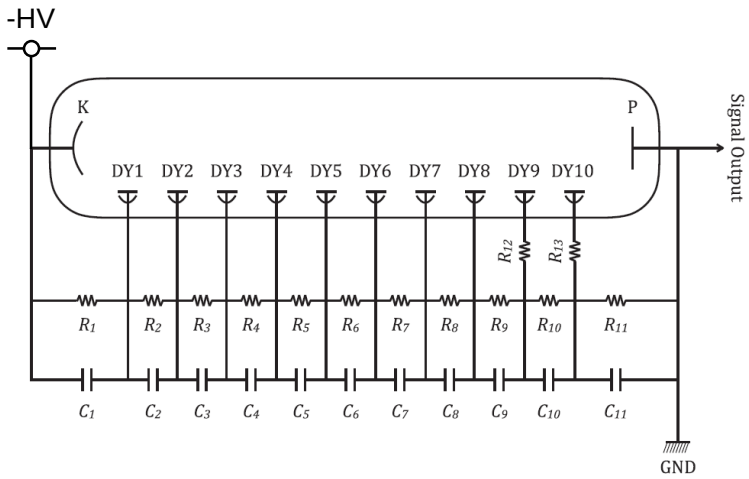



# EMT: electron multiplier tube

- Next candidate sensor for MUMON
- similar to PMT, but Al is deposited on the cathode
- secondary electrons are produced by charged particles at cathode and dynodes

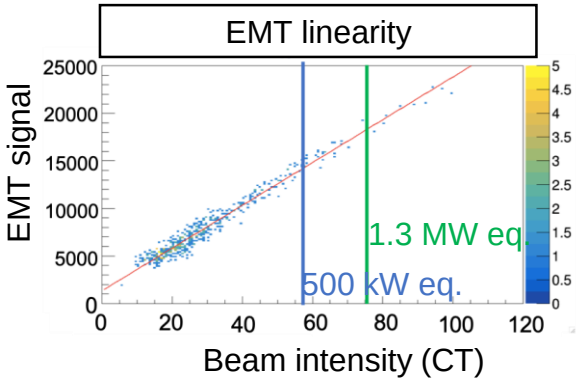


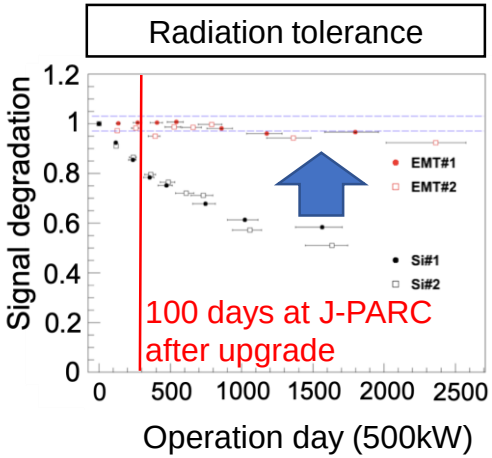



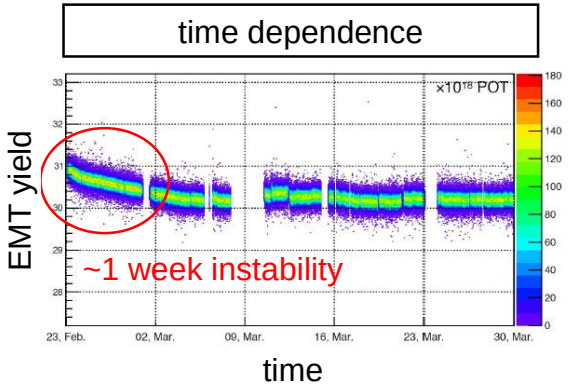



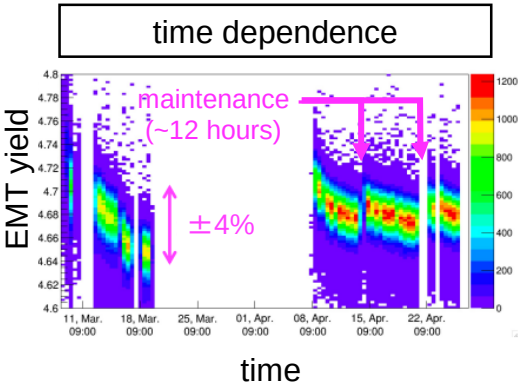
# Previous beam test results

- 1st ELPH (linac electron) beam test
  - Linearity for high intensity is OK
- 2nd ELPH (linac electron) beam test
  - Radiation tolerance of EMT is much better than that of SI
- T2K beam at MUMON-pit
  - succeeded to install and take data
  - initial instability (~1 week yield decrease) was seen
  - instabilities were seen after beam stop

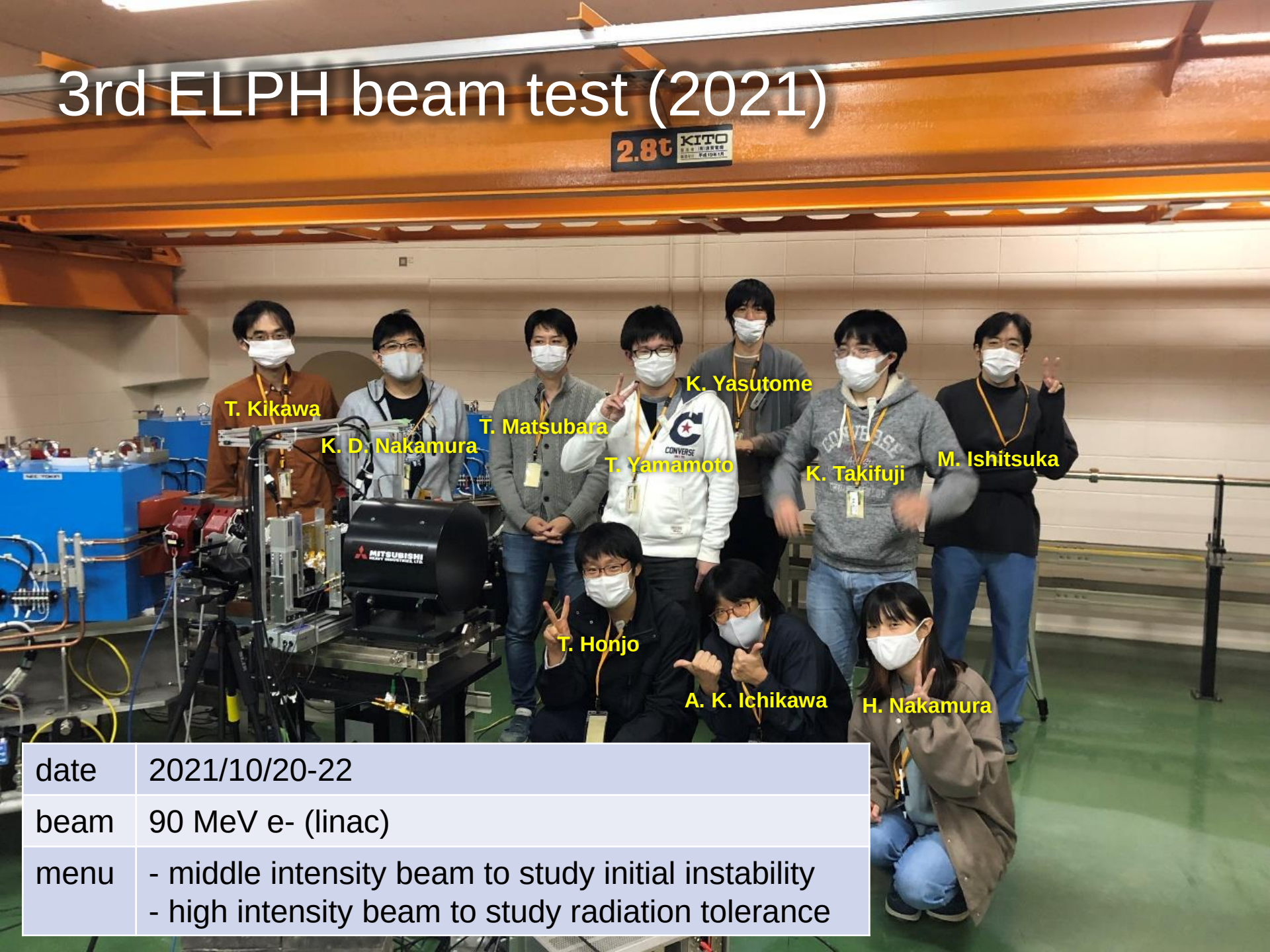


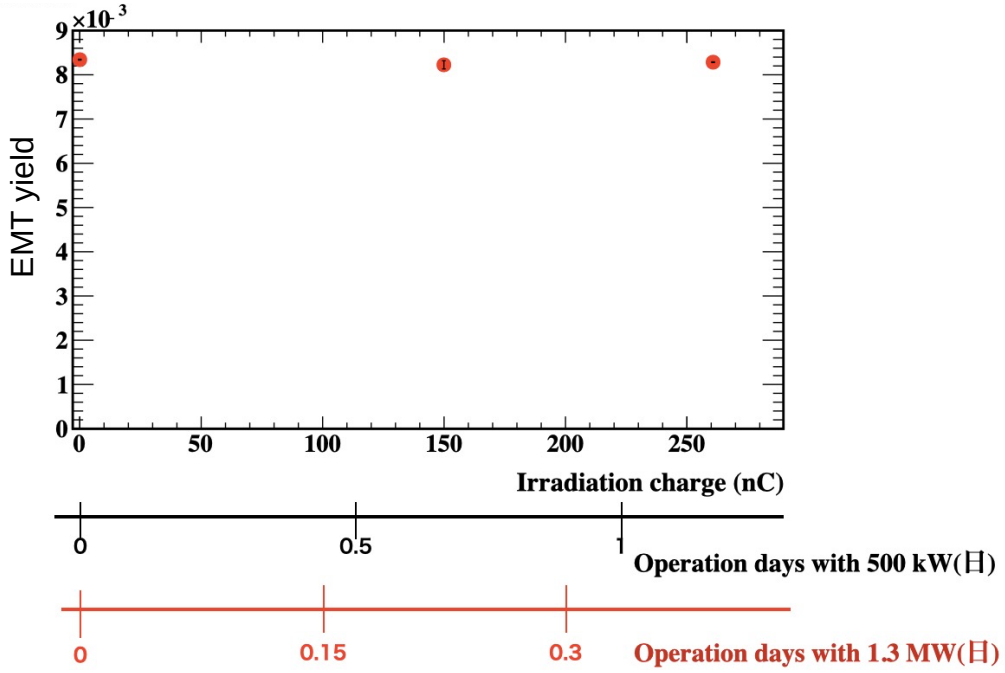
# 3rd ELPH beam test (2021)




| | |
|---|---|
| date | 2021/10/20-22 |
| beam | 90 MeV e- (linac) |
| menu | - middle intensity beam to study initial instability<br>- high intensity beam to study radiation tolerance |

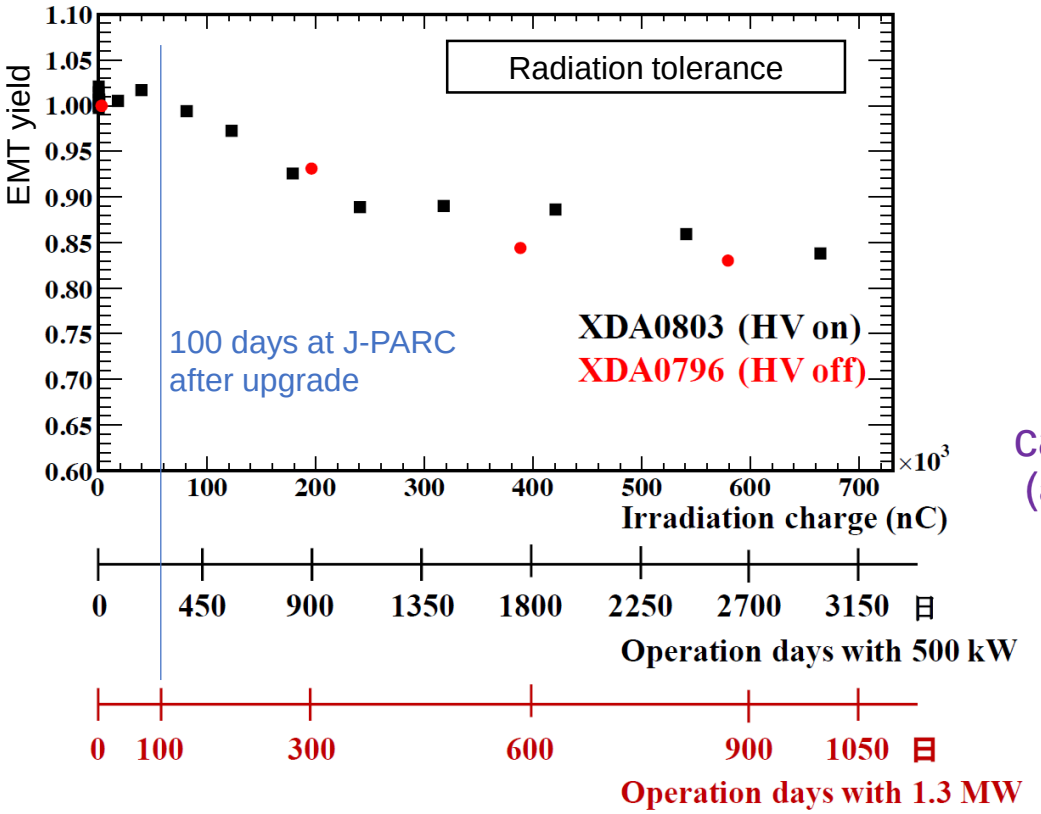
# Initial instability (3rd beam test)

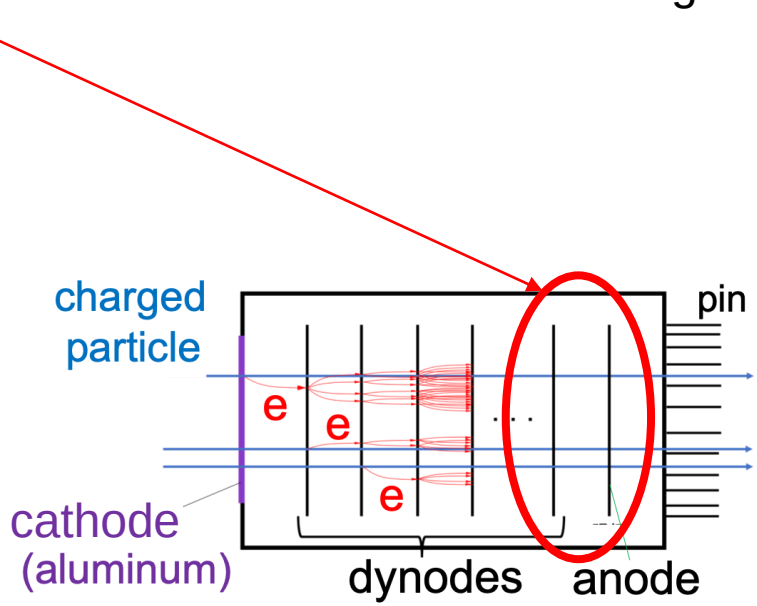
- Initial instability is not seen in ELPH beam test
- Different from the measurement at J-PARC
- This time, we took data 30 min after HV applied
- Temperature dependence was seen at J-PARC?



# Radiation tolerance: last dynode

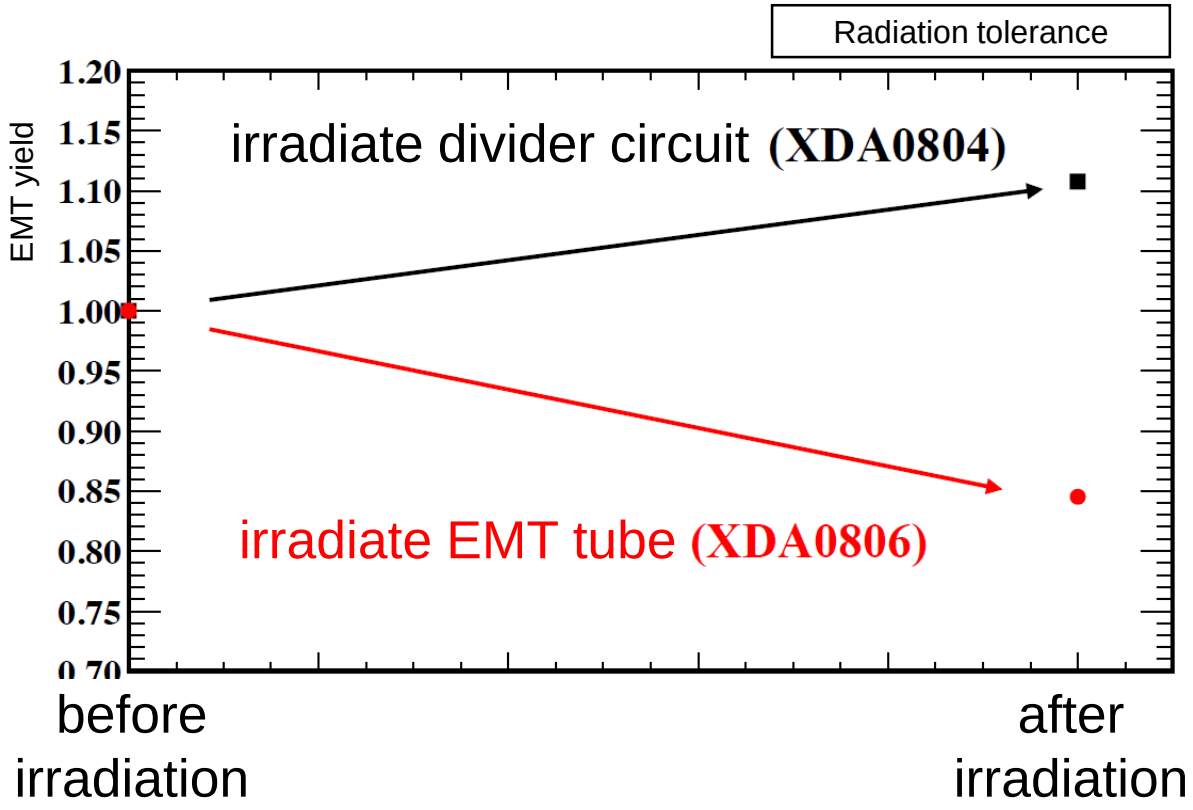
- OK for 100 days operation in 1.3 MW beam
- Signal yield decreased for large irradiation
- Even irradiated with HV off, signal decreased
  - "too much electron multiplication at the dynode" is not the main cause of damage



# Radiation tolerance: circuit

- Irradiate to the breeder circuit and EMT individually
- breeder circuit irradiation: signal yield increased a little
- EMT tube irradiation: signal yield decreased
  - EMT tube itself is damaged

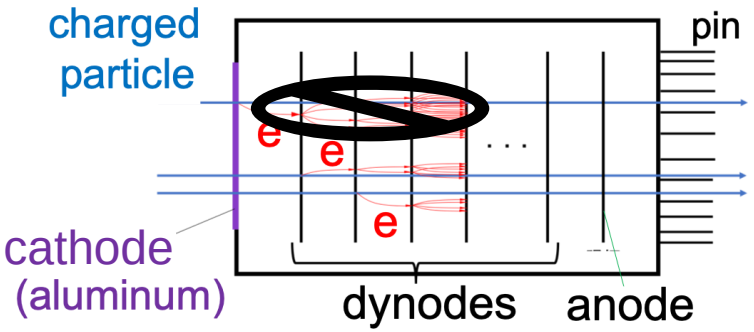


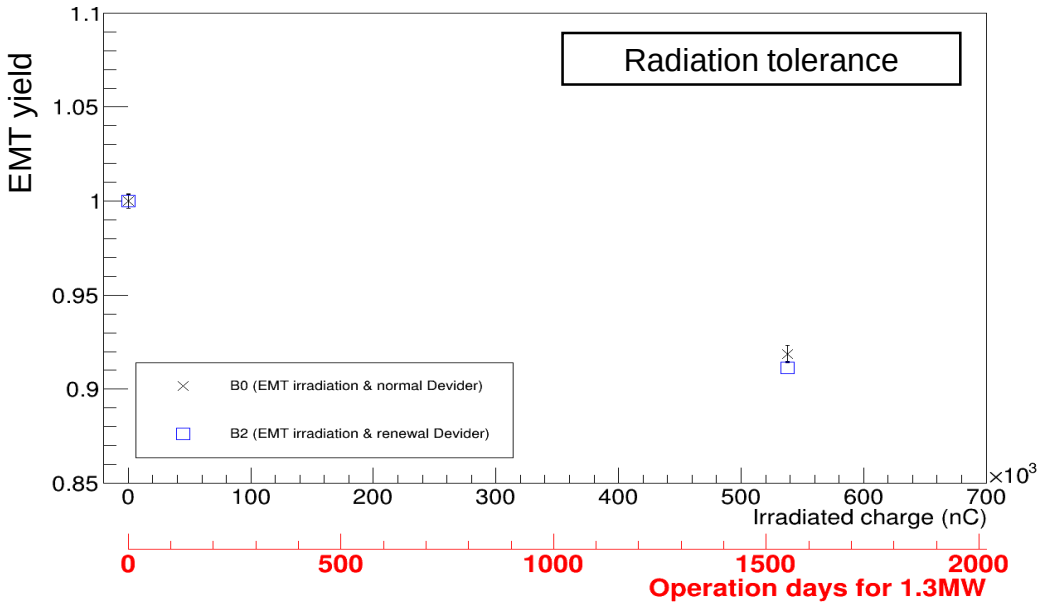
# 4th ELPH beam test (2022)

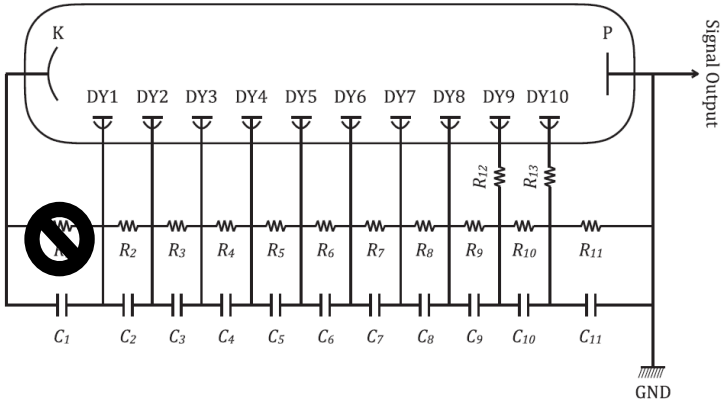

| | |
|---|---|
| date | 2022/11/15-17 |
| beam | 90 MeV e- |
| menu | - new breeder circuit for cathode damage check<br>- temperature dependence |

# Radiation tolerance: cathode

- Special breeder circuit
  - Resistor between cathode and first dynode is set to 0 ohm
  - Cathode does not contribute to signal --> we can check the damage from other part separately
- Result
  - despite of using special breeder circuit, signal yield decreased



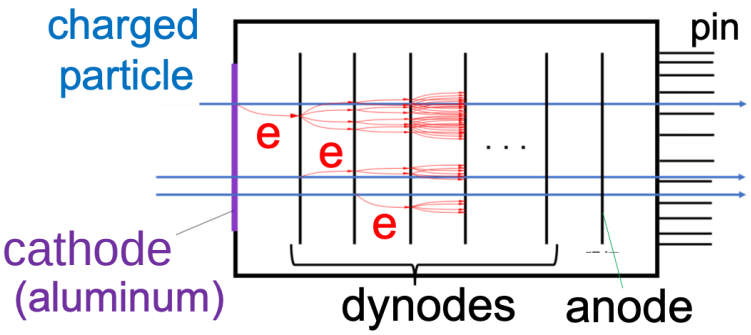



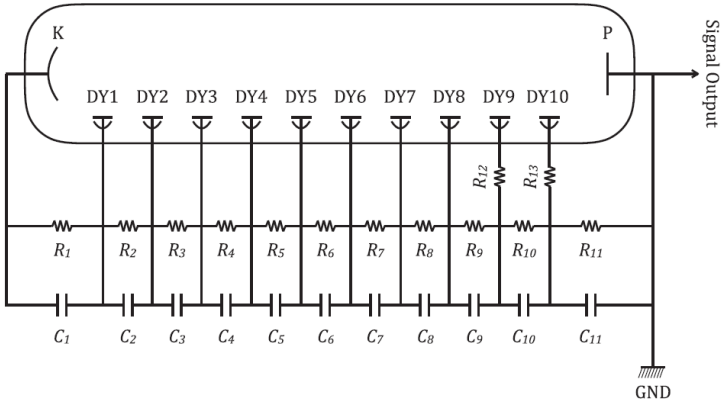
# Radiation tolerance: summary

- The following hypotheses were **rejected**
  - **last dynode** is damaged by too much electron multiplying process
  - **circuit** (resistor or capacitor) is damaged
  - **cathode** (aluminum is deposited) is damaged

- Remaining possibility
  - **dynodes** (antimony is deposited) are damaged by radiation
  - very first stage of R&D, w/o antimony EMT was tested --> gain was too small

- We isolated the cause of EMT deterioration and confirmed the best way to use it

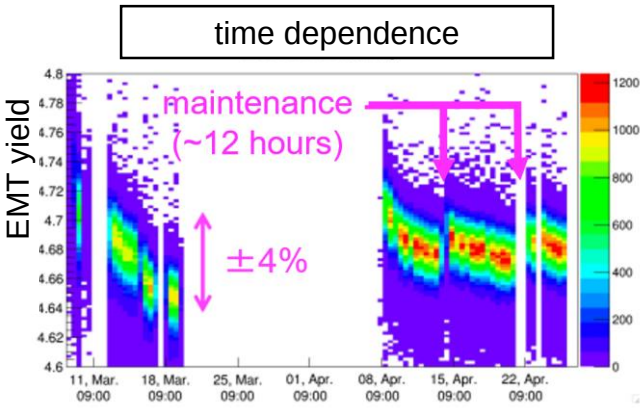


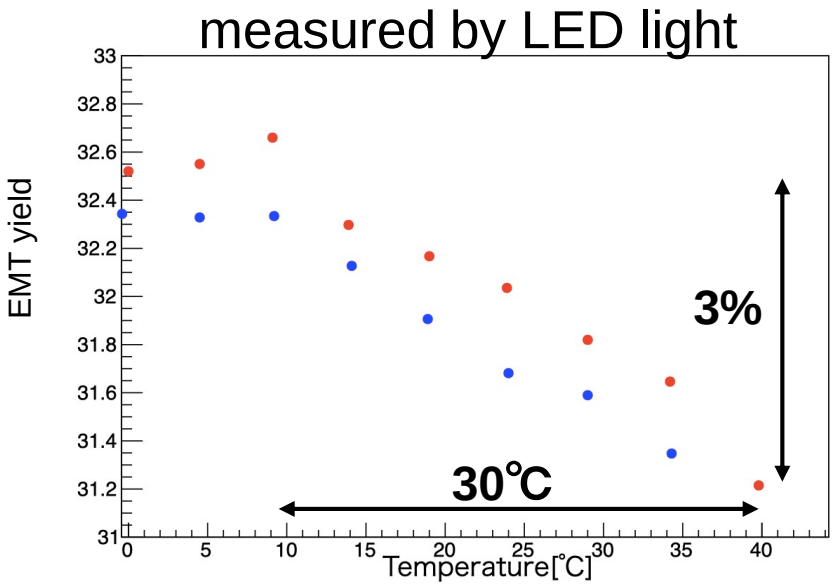



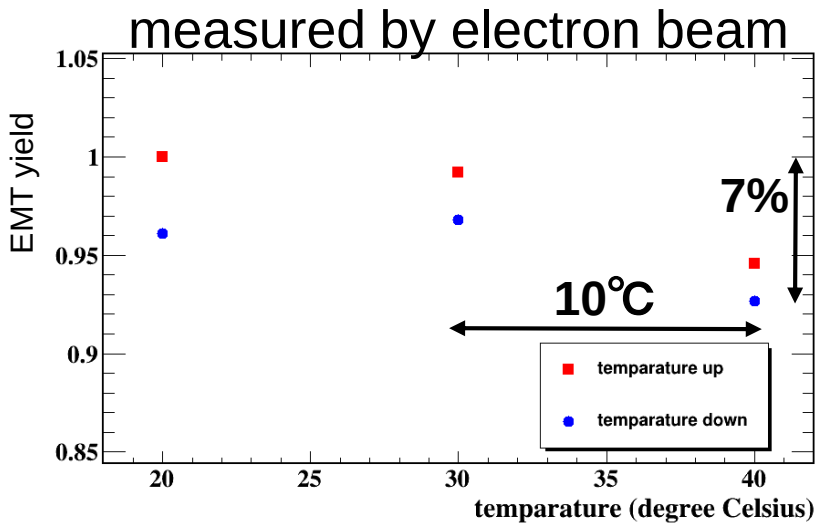
# Temperature dependence

- Measured by LED light
  - about 0.1%/℃ of signal decrease
  - Equivalent temperature change is 40℃ at MUMON-pit, a bit unlikely

- Measured by electron beam
  - about 0.7%/℃ of signal decrease
  - Equivalent temperature change is 6℃
  - --> This could be the case at the MUMON-pit when accelerator is turned on



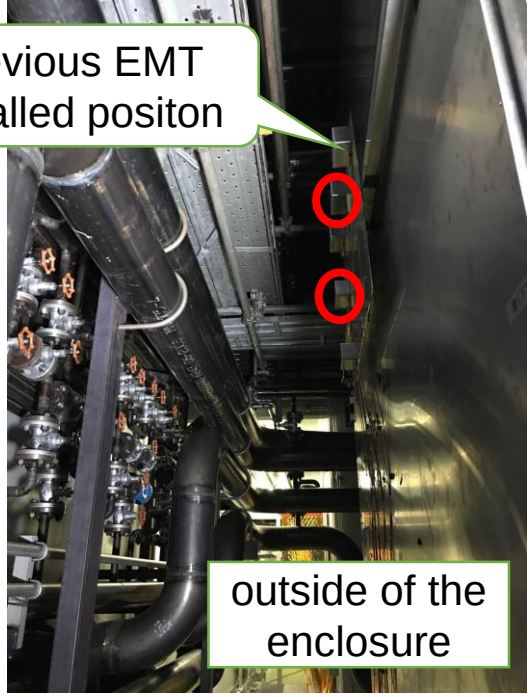



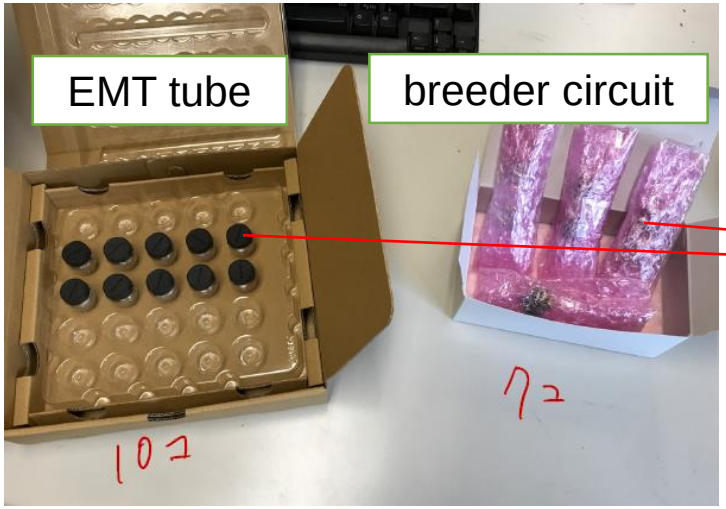
# Next T2K beam: RUN12 (2023)

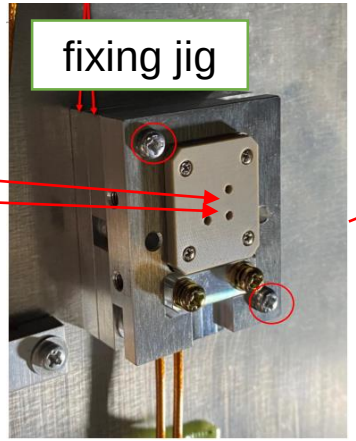
photo by Takashi Honjo

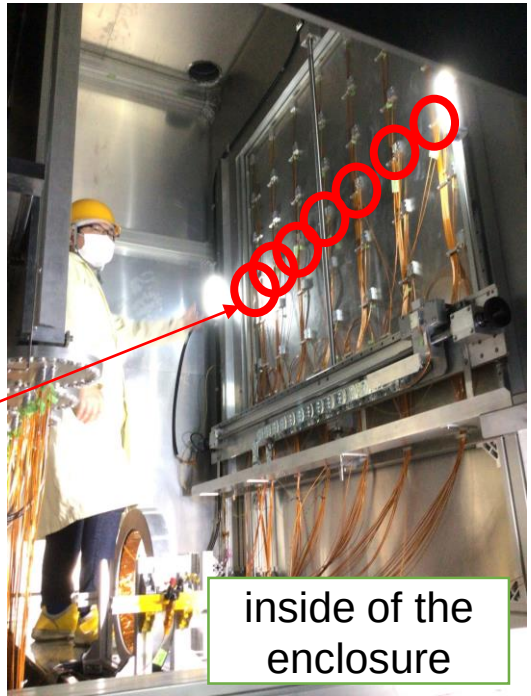
# EMT installation

- Purpose
  - measure profile by EMT
  - check temperature effect
- Status
  - 7 EMTs are installed on top of SI sensors inside of temperature controlled enclosure
  - 2 EMTs are installed outside of the enclosure
  - additional temperature sensors are also installed
- Looking forward next T2K beam!

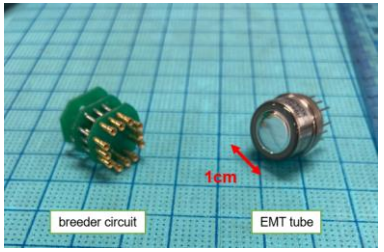


# Summary




- T2K experiment
  - long baseline neutrino oscillation experiment with off-axis method
  - beam direction monitor is important

- EMT as a MUMON sensor
  - MUMON sensor must be upgraded together with the beam power upgrade
  - EMT (electron multiplier tube) is promising candidate for the new sensor
  - Good linearity, good radiation tolerance

- ELPH beam test (3rd, 4th)
  - Radiation-damaged component seems dynodes (antimony deposited)
  - Temperature dependence exist, and may have affected in the previous J-PARC measurement (outside of enclosure)

- Next T2K beam (RUN12 will be start from 4/17)
  - We will measure 1 dimensional beam profile by 7 EMTs
  - Check the temperature dependence with 2 EMTs at outside of the enclosure