Upgrade of the machine protection system toward 1.3MW operation of the J-PARC neutrino beam-line

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K.Sakashita(J-PARC/KEK), M.Friend(J-PARC/KEK),
K.Nakayoshi(J-PARC/KEK), Y.Koshio(Okayama), S.Yamasu(Okayama)
for T2K beam group

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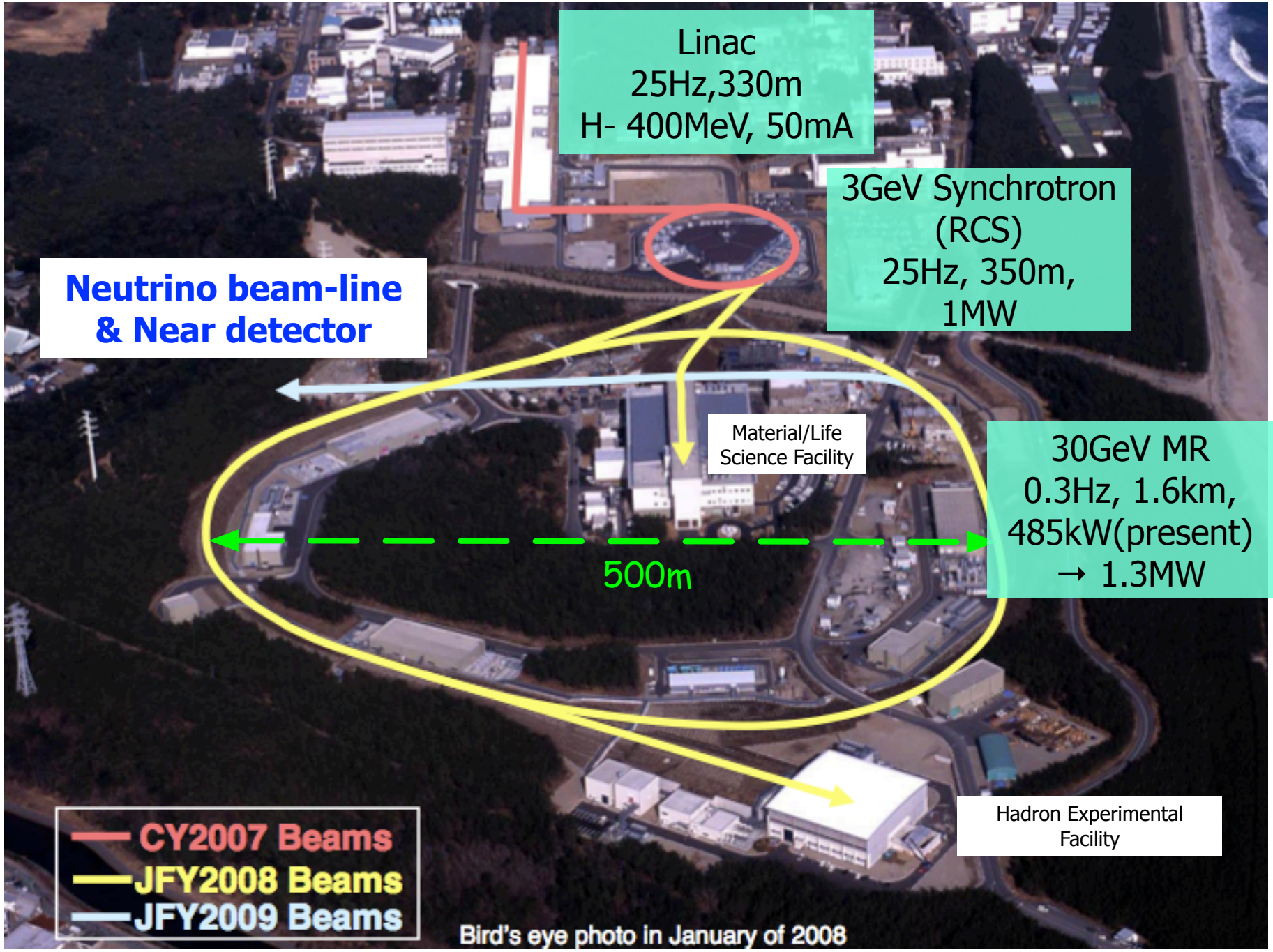
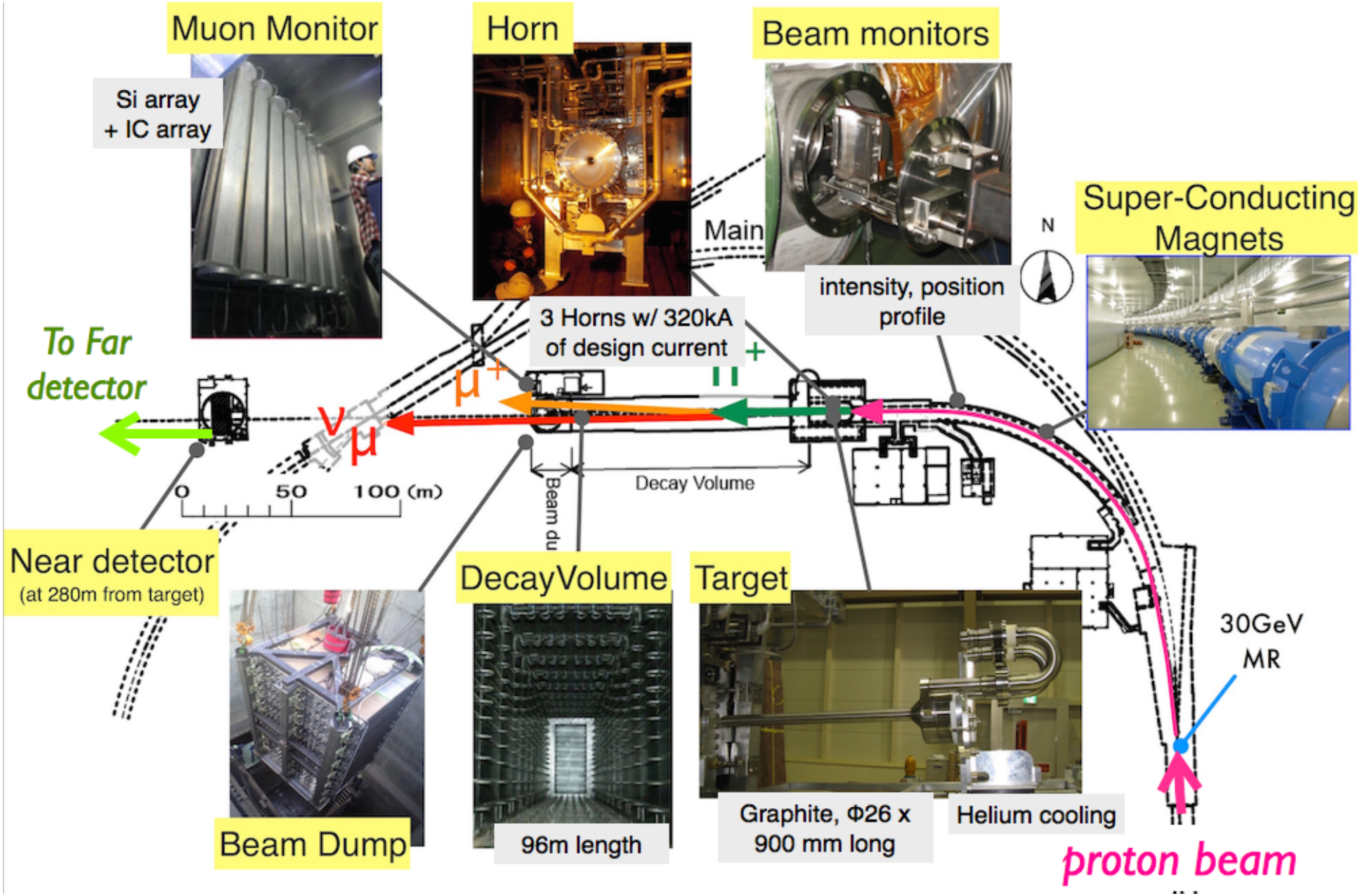
J-PARC & Neutrino beam-line



J-PARC neutrino facility

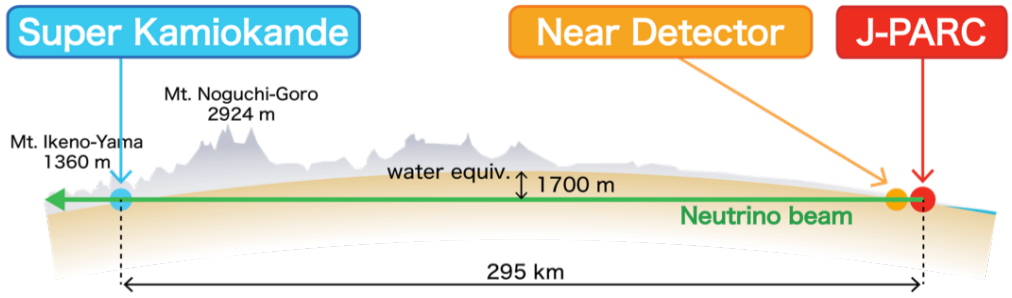


Producing a high intense neutrino beam for T2K(present), T2K-II and HK

T2K(Tokai-to-Kamioka) experiment

Super-Kamiokande
(ICRR, Univ. Tokyo)

J-PARC Main Ring
(KEK-JAEA, Tokai)



Long base-line neutrino oscillation experiment

$$Prob.(\nu_\mu \to \nu_e)$$

same?

$$Prob.(\bar{\nu}_\mu \to \bar{\nu}_e)$$

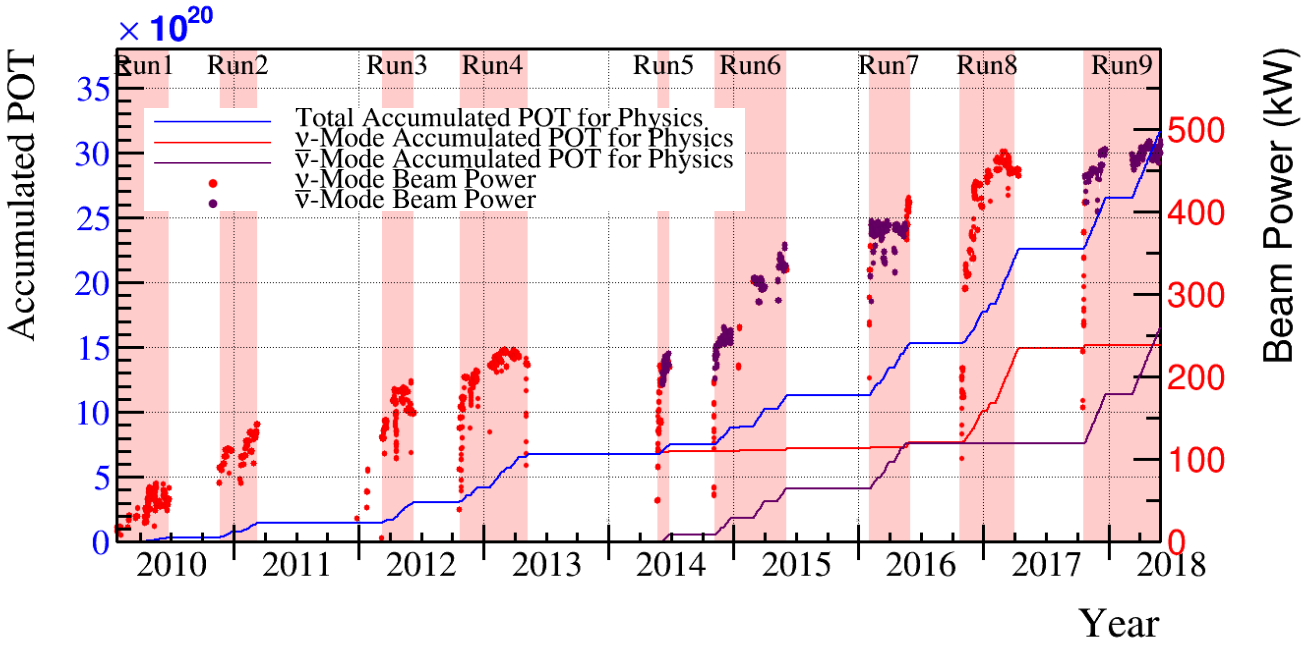
One of main physics motivations is

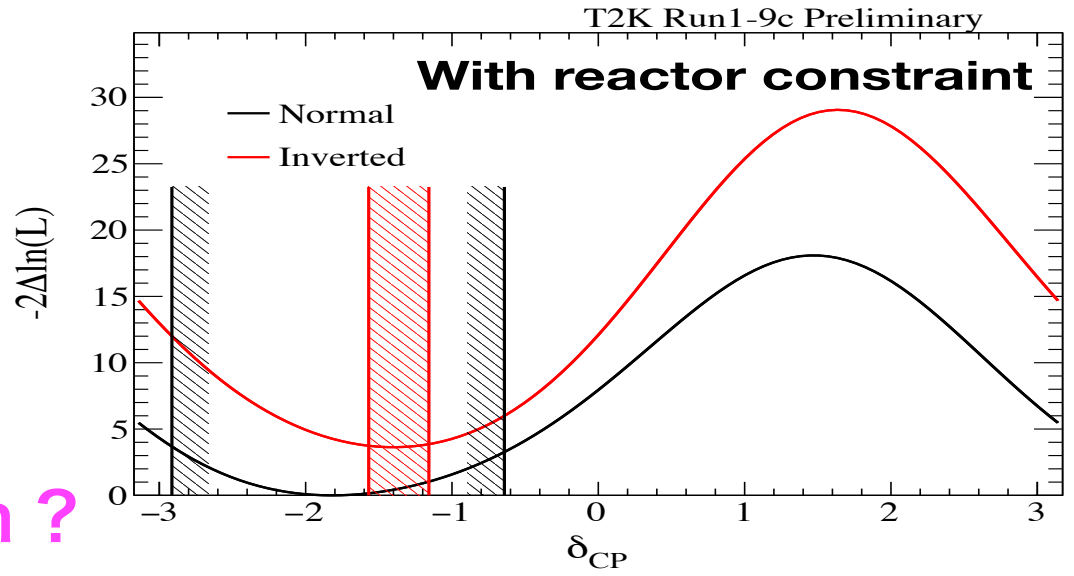
- **CP violation in neutrino oscillation**

→ hint for the origin of matter dominate universe

T2K current status

- **Recently, 485kW stable operation**
- 3.16x10^{21} protons on target (POT) collected until the end of May 2018
- Based on data collected until Dec. 2017, CP conserving values(0,$\pm\pi$) are outside of 2σ region



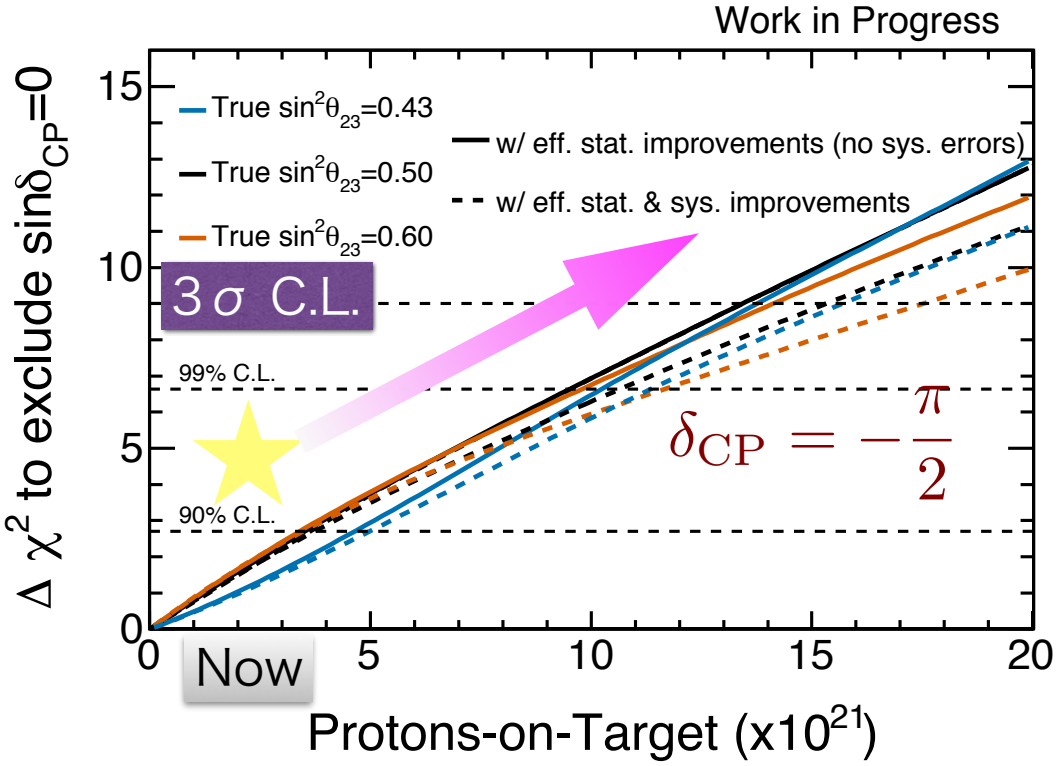


Indication of CP violation ?

Toward discovery of CPV

Plan to accumulate more data up to 2×10^{22} POT by 2026 (T2K extension proposal, J-PARC E65 [T2K-II])

- **Increase of MR beam power up to 1.3MW**
- Increase of signal statistics by both hardware and analysis improvement
- Improvement of systematic uncertainty by the near detector upgrade

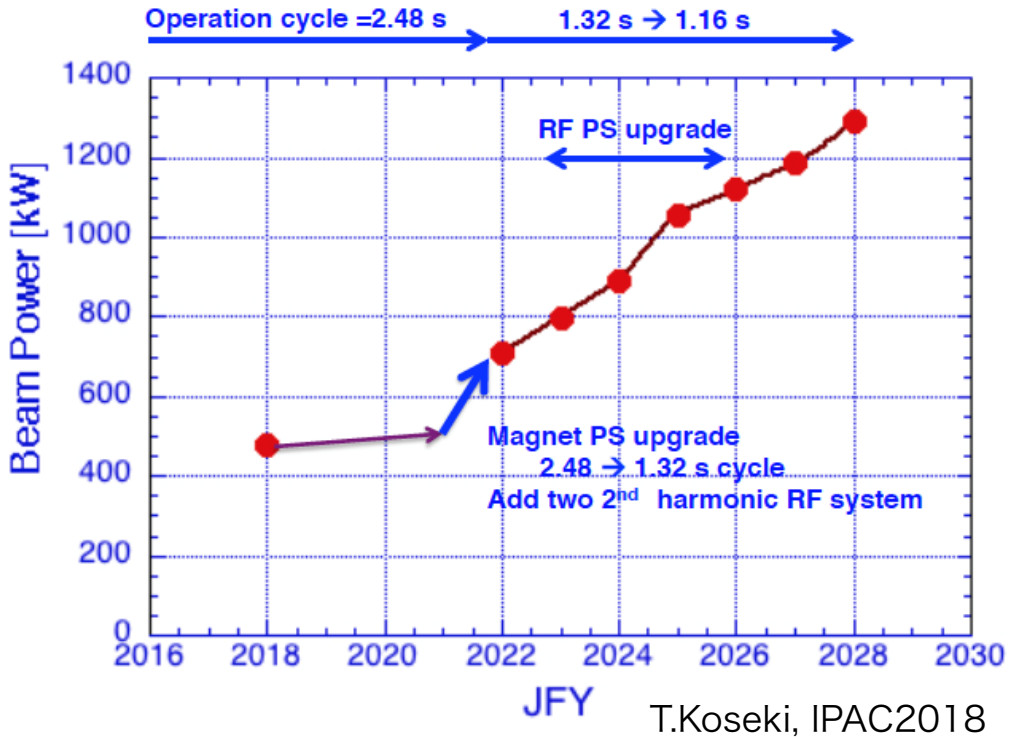


>3σ CPV sensitivity

Beam power upgrade scenario

- Increase the MR beam power up to 1.3MW by increasing the number of protons per pulse (p/pulse) and shortening the repetition time ($T_{rep.}$)
  - Power ∝ 30GeV x # of protons x $1/T_{rep.}$
  - 520kW w/ 2.48sec, 2.7x10^{14} p/pulse (1.1MW equivalent beam) has been successfully tested
  - Plan to upgrade MR main power supply in 2021
  - Upgrade of RF, collimator and Inj./FX devices are also planned

	Achieved	Target
Beam power [MW]	0.49 →	1.3
# of protons per pulse	2.5 x 10^{14} →	3.2 x 10^{14}
Rep. Time [sec]	2.48 →	1.16



T.Koseki, IPAC2018

Neutrino beam-line upgrade plans

- All of the components were designed for 0.75MW with original beam parameters
  - Already tolerable for the thermal shock
- To realize 1.3MW operation, we plan to upgrade :
  - Cooling capability of target, horn etc.
  - Horn, DAQ for ~1Hz operation
  - Capacity of the radioactive waste (activated cooling water etc.)
  - Beam monitors
  - Machine Protection System (MPS)

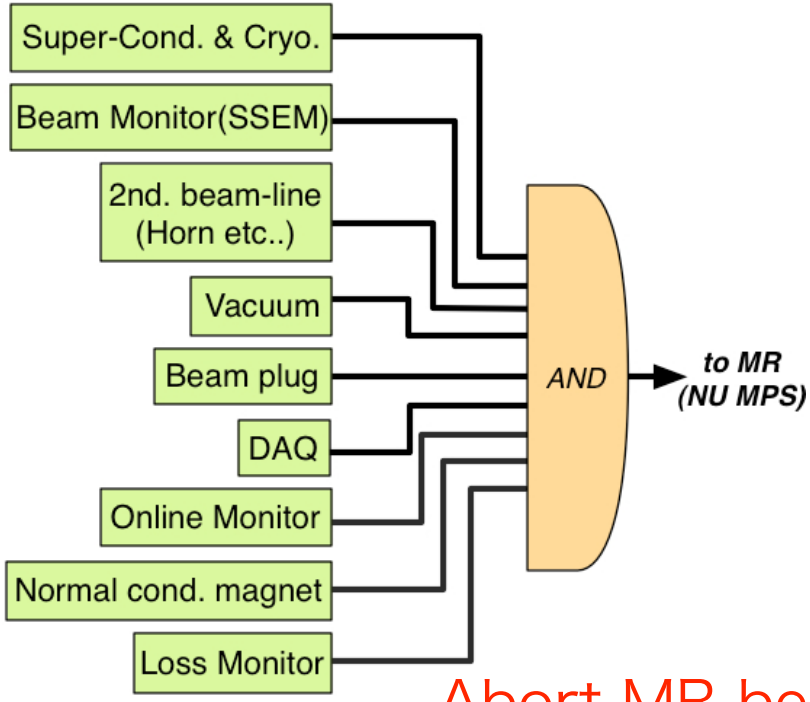
	Original	New
Beam power [MW]	0.75	1.3
# of protons per pulse	3.3×10^{14}	3.2×10^{14}
Rep. Time [sec]	2.1	1.16

See also related posters :

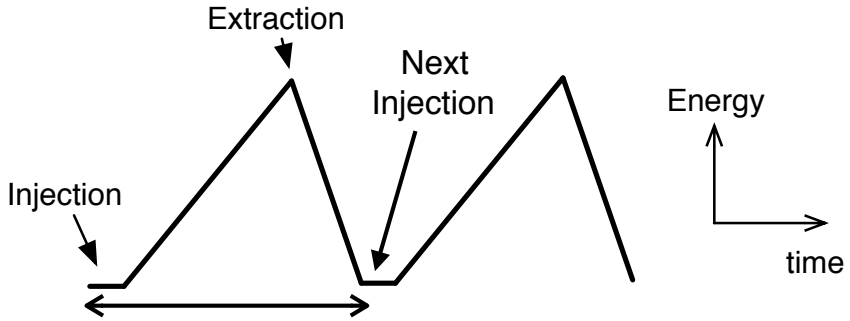
- MOPB07 : Beam Parameter Measurements for the J-PARC High-Intensity Neutrino Extraction Beamline, M.Friend (J-PARC/KEK)
- MOPC18 : Development of a Beamline Expert System Using Machine-Learning, K.Nakayoshi (J-PARC/KEK)
- WEPC08 : Optical System of Beam Induced Fluorescence Monitor Toward MW Beam Power at the J-PARC Neutrino Beamline, S.Cao (J-PARC/KEK)

MPS at neutrino beam-line

- MPS is one of the essential components to realize safe operation of 1.3MW beam
  - e.g. 3.2x10^{14} p/pulse → 1.6MJ/pulse
- In order to reduce any potential risks during the high intensity beam operation, we plan to upgrade the MPS



Abort MR beam and stop next beam injection to MR



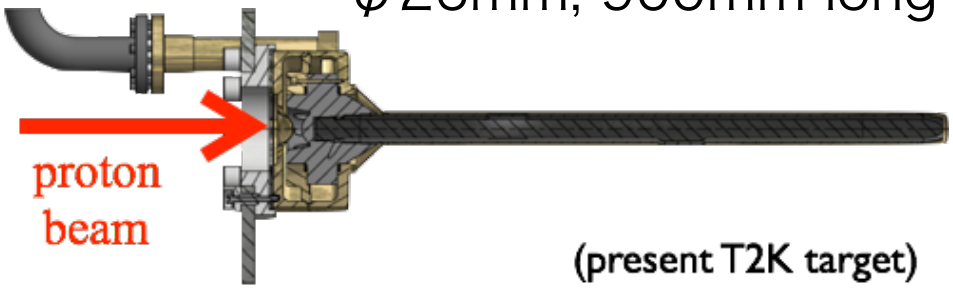
2.48s →1.3s →1.16s

One of MPS upgrade items

Serious damage on the target if beam continuously hits off-centered at the target

Graphite target

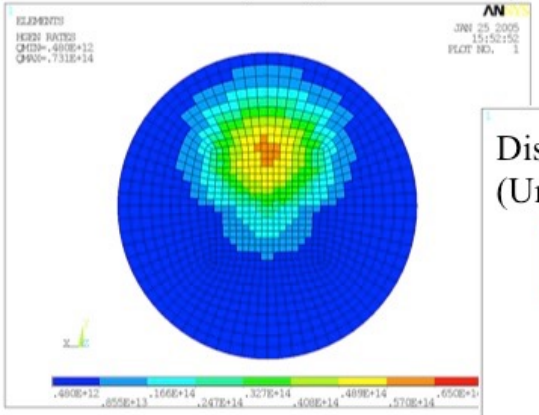
ϕ 26mm, 900mm long



(present T2K target)

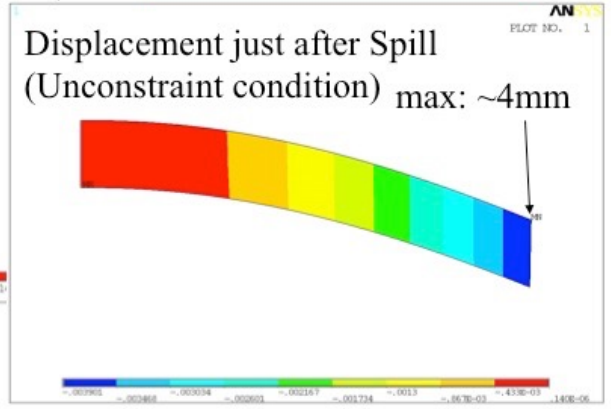
Stress Analysis for off-center beam

- C. Densham, J. Butterworth (RAL)
  - Input: Energy deposit calculated by MARS
  - → Stress, displacement by ANSYS



Beam shifted by 0.5cm

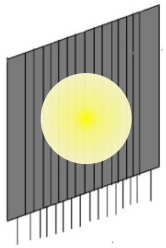
Target can be one piece?
Or should be divided?



In order to avoid this case, we're developing a new interlock for beam position and profile on the target

Development of a new interlock for beam position and profile

Present scheme

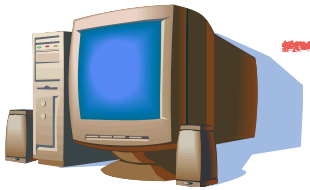


Beam profile monitor near the target

analog signal

attenuator + ADC

calculate the beam position in PC and issue an interlock if beam position on the target is shifted >1.5mm



~1sec

ΔT(extraction - next injection) is ~0.95s

Development of a new interlock for beam position and profile

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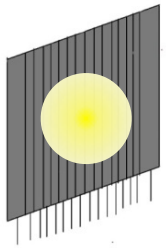

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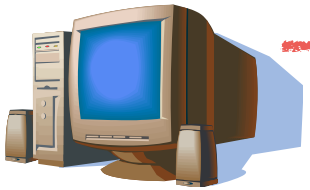
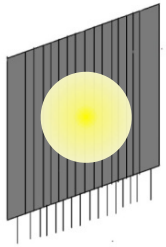


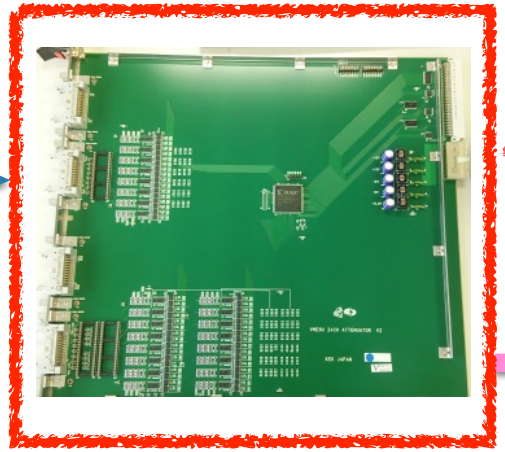
~1sec

ΔT(extraction - next injection) is ~0.95s

Developing a new electronics board which can calculate the beam position & profile using FPGA and issue a interlock

New scheme





the latency is significantly improved

<1msec

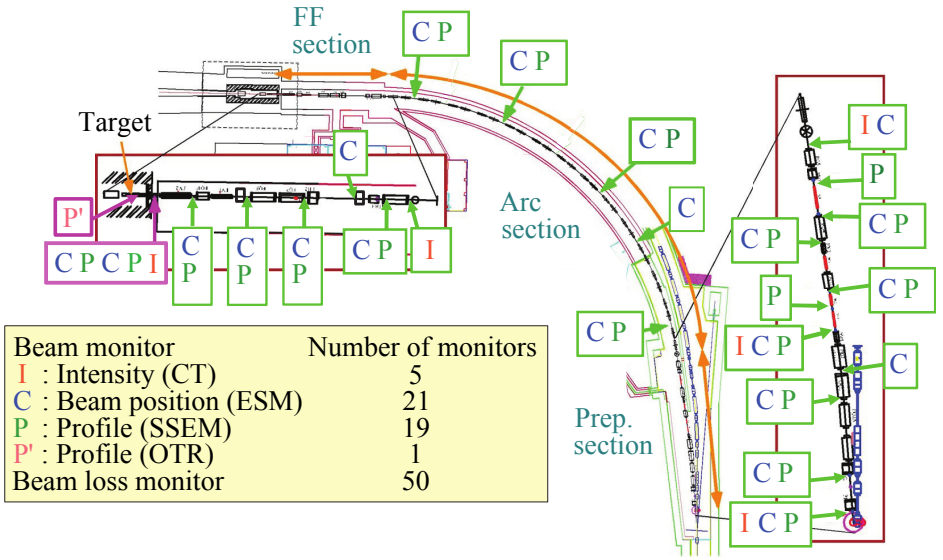
PAPILLON board : http://openit.kek.jp/project/beam_monitor_interlock/beam_monitor_interlock

Development : Okayama-U and KEK

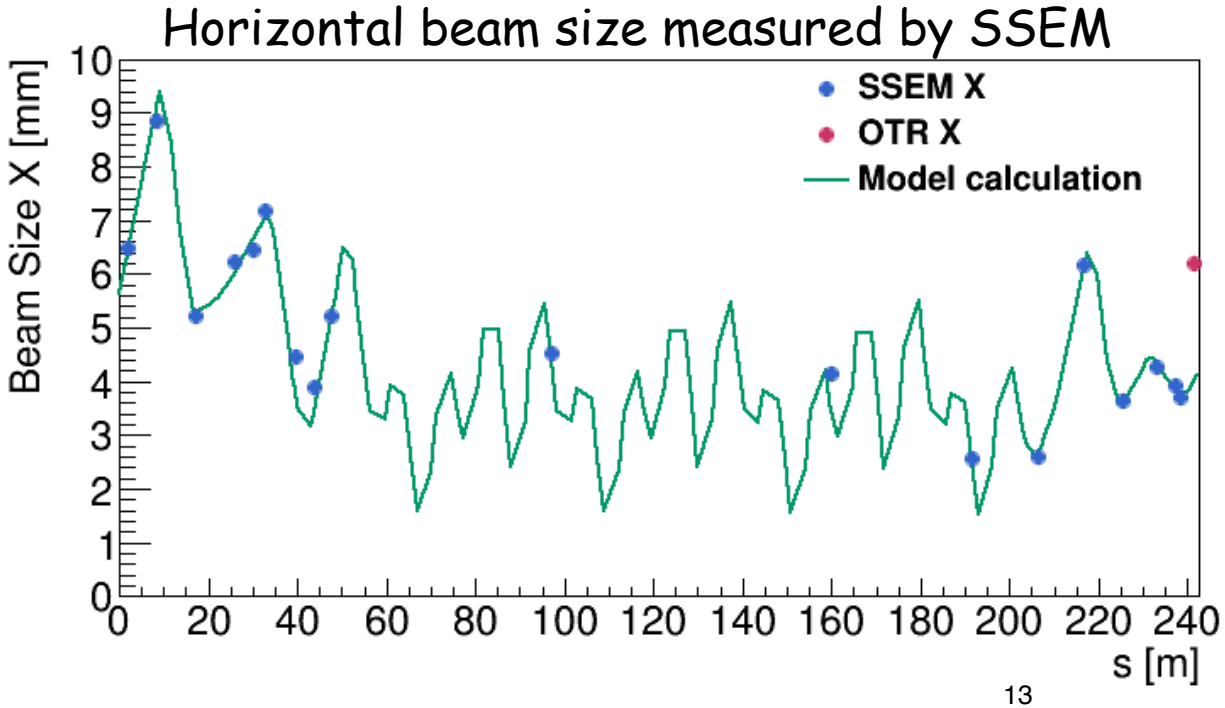
openit
Open source consortium of Instrumentation

Beam profile monitor

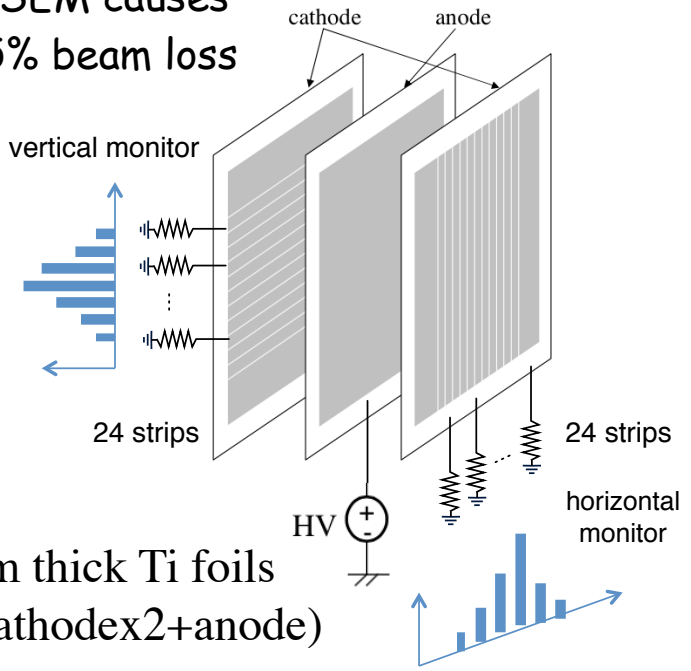
- 19 Segmented Secondary Emission Monitors (SSEMs) are placed along beam-line to measure beam position and profile
- During continuous beam operation (i.e. T2K physics run), only **SSEM19** is inserted in the beam-line
  → continuous measurement of the beam position/profile for target protection



Beam monitor	Number of monitors
I : Intensity (CT)	5
C : Beam position (ESM)	21
P : Profile (SSEM)	19
P' : Profile (OTR)	1
Beam loss monitor	50

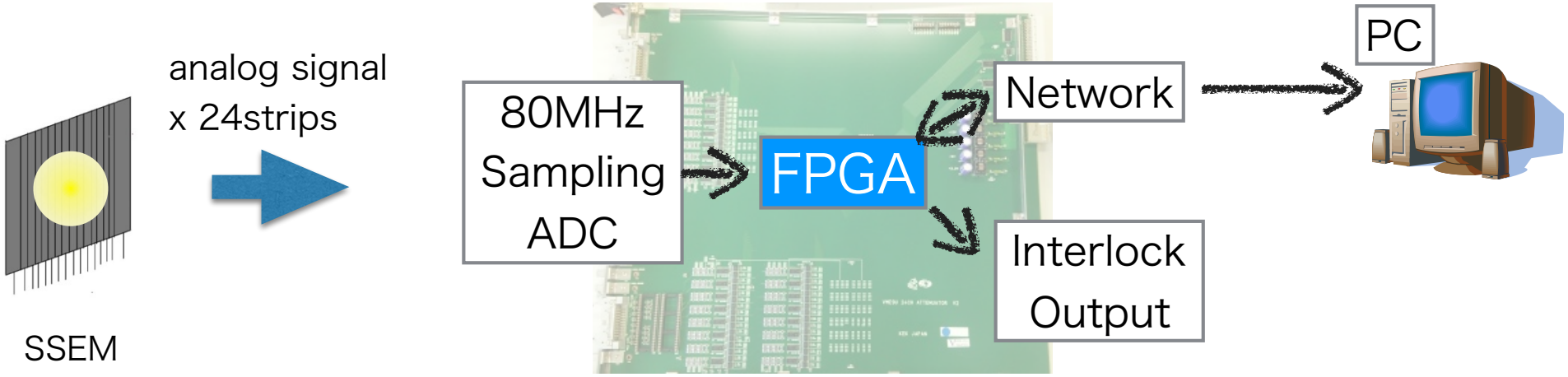


each SSEM causes ~0.005% beam loss

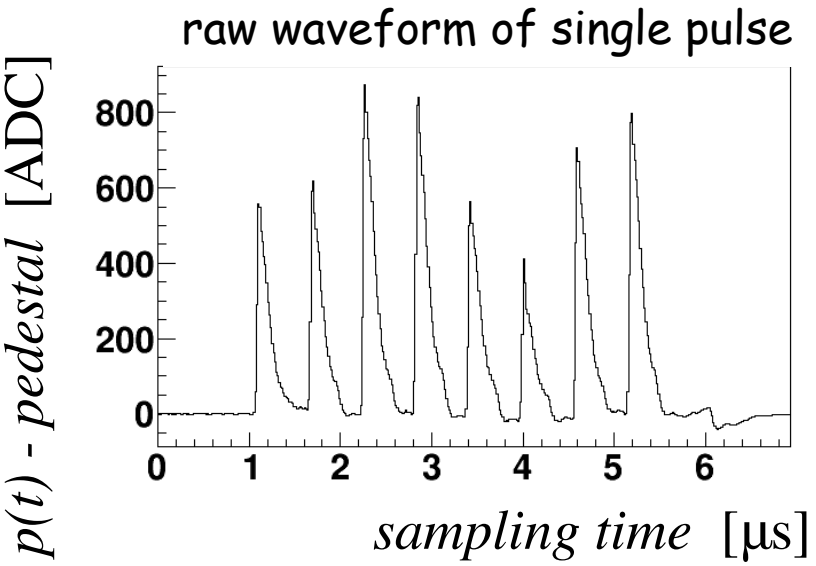


5μm thick Ti foils
(x3; cathodex2+anode)

Beam position calculation in the new board

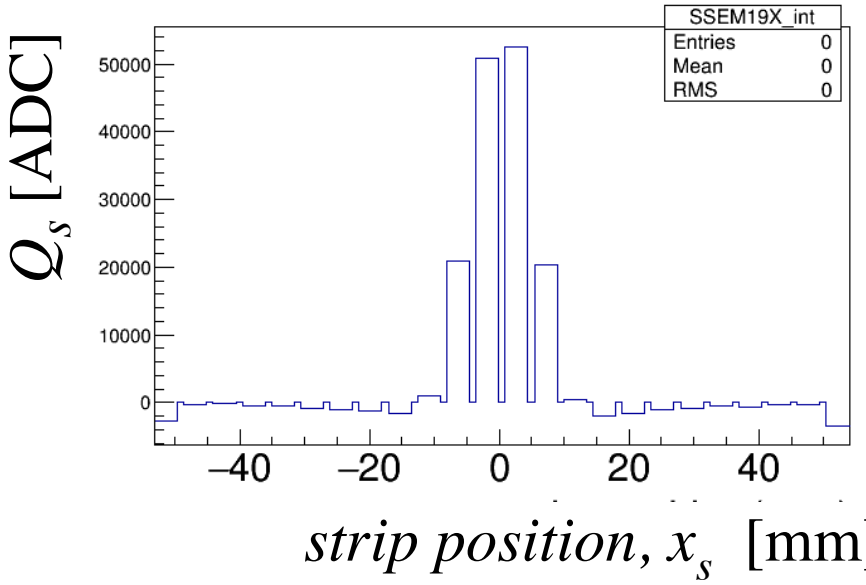


(1) calculate an integrated charge of each strip



$$Q_s = \sum_{t}^{t<=8\mu s} (p(t) - pedestal)$$

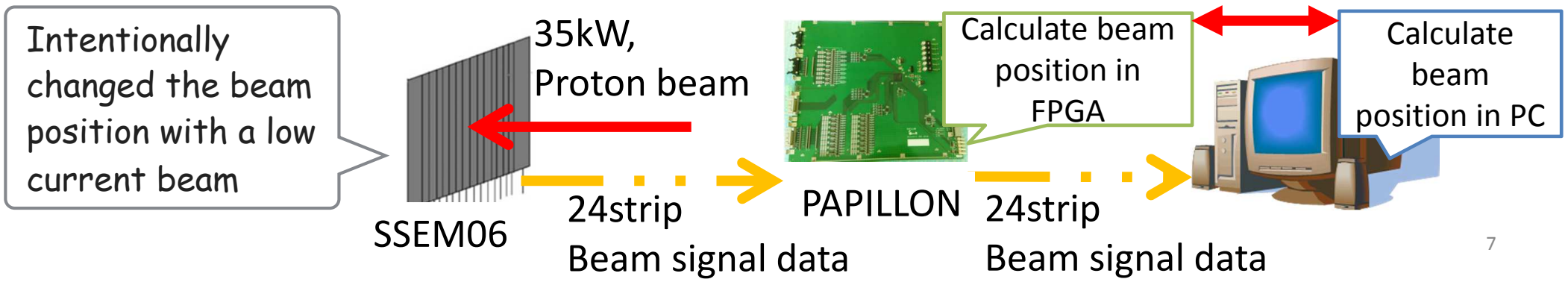
(2) calculate a weighted mean

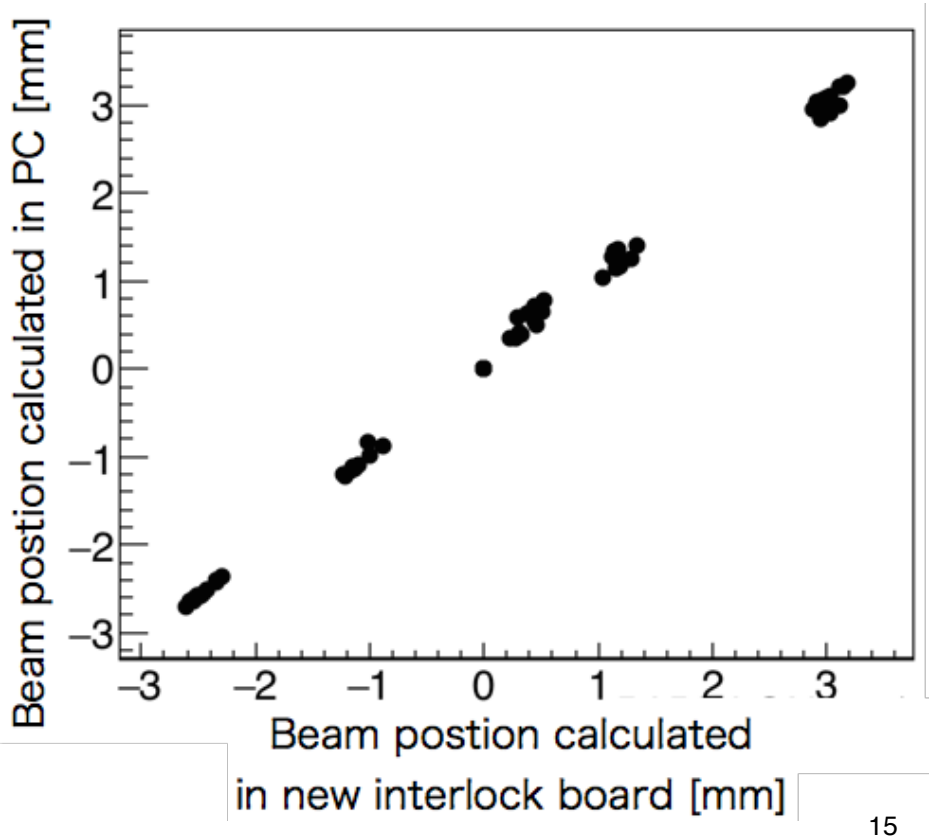


$$\text{beam center [mm]} = \frac{\sum_{s=0}^{23} Q_s \times x_s}{\sum_{s=0}^{23} Q_s}$$

Verification test w/ beam

Setup configuration of verification test w/ beam





Confirmed that the beam position calculation in the new board is consistent with one calculated in PC

Prospect of the new interlock

- Further verification tests are also planned to confirm its long-term stability and to check potential intensity dependence etc.
- Beam profile (width) is also important. FPGA firmware is under development
- Plan to finish R&D and install before MR starts operation with shortened repetition time

Summary

- Toward discovery of the CPV in neutrino oscillation, J-PARC MR/neutrino beamline will be upgraded for 1.3MW beam power.
- The Machine Protection System is the essential components to realize safe operation with the 1.3MW beam.
- A new interlock for the beam position and profile is under development as one of MPS upgrade items. The basic performance was verified. This new interlock is promising.