Toward MW-class High Power Proton Beam at the J-PARC Neutrino Beamline

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on behalf of T2K collaboration

NEUTRINO 2020

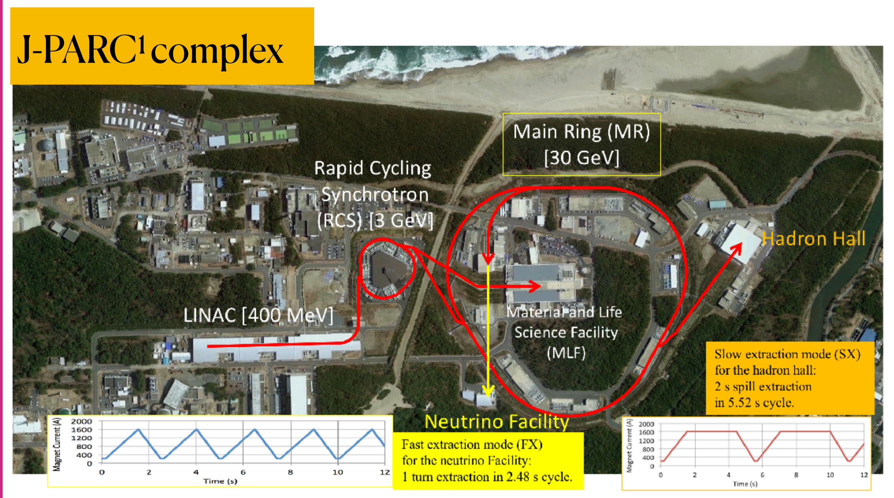
The T2K experiment, by producing a highly intense and almost pure beam of muon (anti-)neutrinos at the J-PARC accelerator complex and sending them 295km across Japan, aims to explore the properties of neutrinos, extraordinary misfits in the Standard Model. To provide a huge amount of neutrinos to T2K and the approved future Hyper-Kamiokande experiment, an upgrade of the J-PARC accelerator and the neutrino beamline toward 1.3MW is proposed. This will increase the beam intensity up to 3.2e14 protons-per-pulse (ppp) and reducing the repetition rate down to 1.3s, over what have been achieved recently with stable 515 kW beam operation with 2.66e14 ppp cycled at 2.48s. This report focuses on recent achievements to realize essential upgrades to the J-PARC neutrino extraction beamline, including our first observation of beam-induced fluorescence in a non-destructive beam profile monitor under development, progress in improving the cooling and radioactive water disposal systems, and the remote handling plan for highly radioactive equipment.

J-PARC MW Proton Beam for Neutrino Intensity Frontier

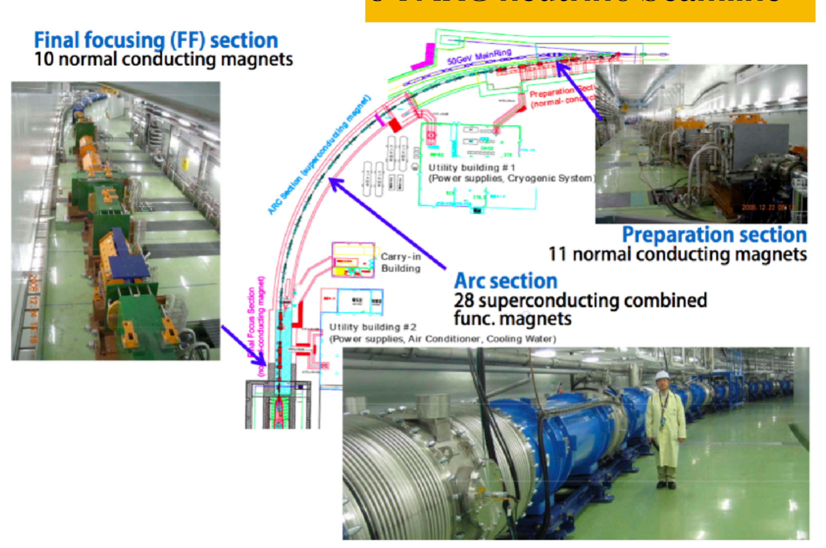
MW beam power, main driver for neutrino intensity frontier, to produce muon (anti-)neutrino beam to T2K[2] and HK[3] experiments

Goal: unravel nature of neutrino by measuring precisely *neutrino oscillations*.

J-PARC[1] complex



J-PARC neutrino beamline



Upgrade[4] J-PARC neutrino beam

Beam power	515 kW (achieved)	750 kW (proposed)	1.3 MW (proposed)
Beam energy	30 GeV	30 GeV	30 GeV
Beam intensity (ppp)	2.65×10^{14}	2.0×10^{14}	3.2×10^{14}
Repetition cycle	2.48 s	1.32 s	1.16 s

To realize MW beam, equipment robustness against high intensity, beam loss tolerability, handling the radioactive waste and precisely and continuously monitoring the beam profile are essential.

[1]KEK-REPORT-2002-13 [2]NIMA 659, 106(2011) [3]arXiv: 1805.04163 [4]arXiv: 1908.05141

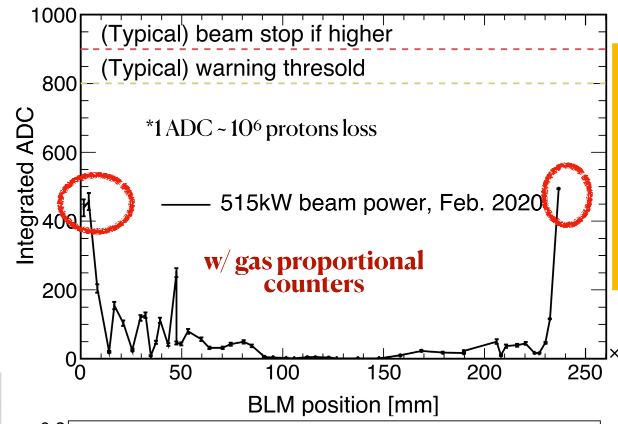
Beam Loss Monitor & Radioactive Waste Handling

Challenges of high beam loss:

- Irradiation/damage of components
- High residual dose → difficult to maintain

Action taken

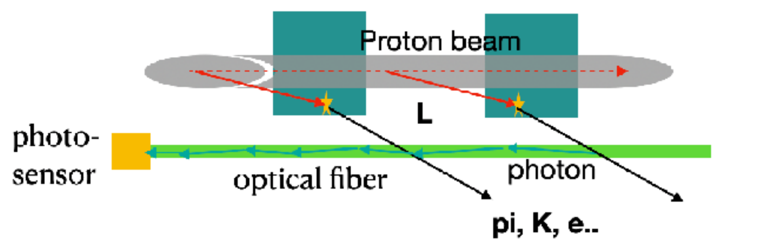
- ☑ Work w/ accelerator experts to reduce loss
- ☑ Remote handling high radioactive equip.

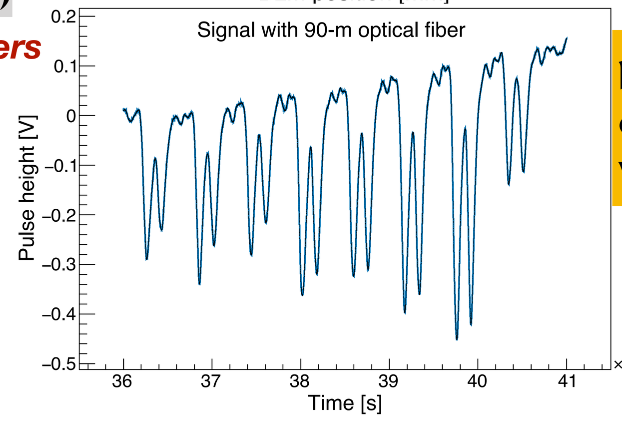


Current beam loss level along beamline

R&D: Optical-based Beam Loss Monitor (O-BLM)

Cherenkov light generated & guided by optical fibers



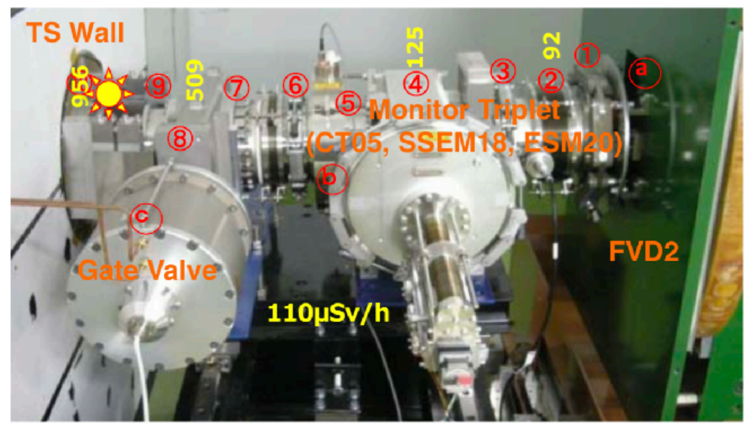


beam loss observed w/ O-BLM

Key features: fast response, portable, economical

Remote Handling Scheme for Highly Radioactive Equipments

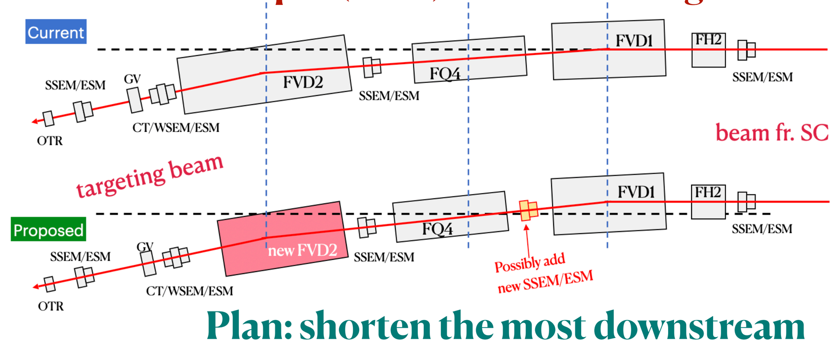
High residual dose due to beam back scattering fr. beam window, target station



Four months after the beam stop.

Higher beam power makes human operation challenging

☞ **Need to adopt a (semi-)remote handling scheme**

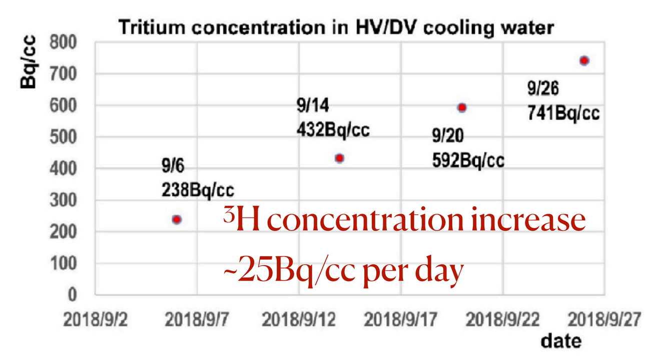


Plan: shorten the most downstream magnet (FVD2) to get more space

Radioactive Water Disposal System

New disposal tank is proposed & approved for construction. Disposal capability: $100m^3 \rightarrow 500m^3$

Most critical issue is to dispose of ^3H, which **may come fr. steel wall** even after beam stop



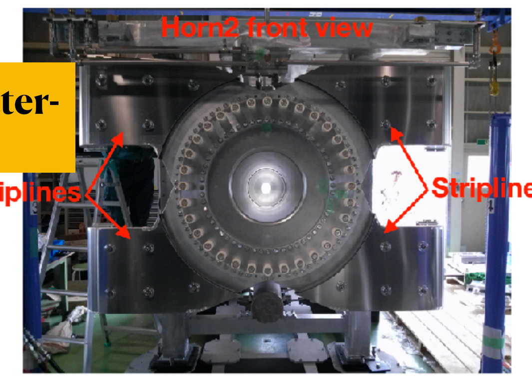
For maintenance ^3H concentration < 60 Bq/cc

Improving Machine Robustness against High Intensity

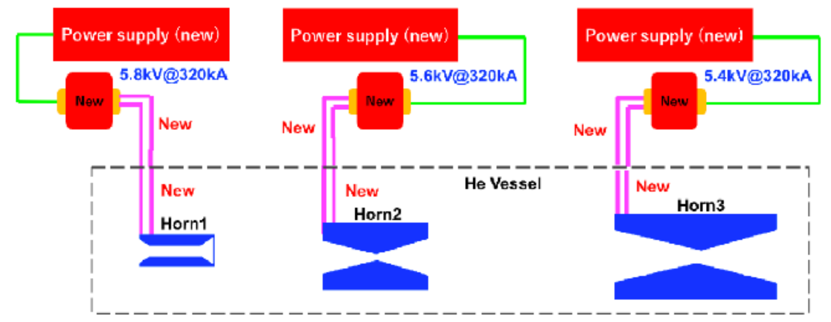
System of 3 magnetic horns, *which focus the produced mesons*, currently operate at 250kA.

Plan: have 320kA operation to gain 10% in flux

New water-cooled



Upgrading Horn power supply (PS)



All upgrades inside of target station will be done in 2021; one more PS will be included after that

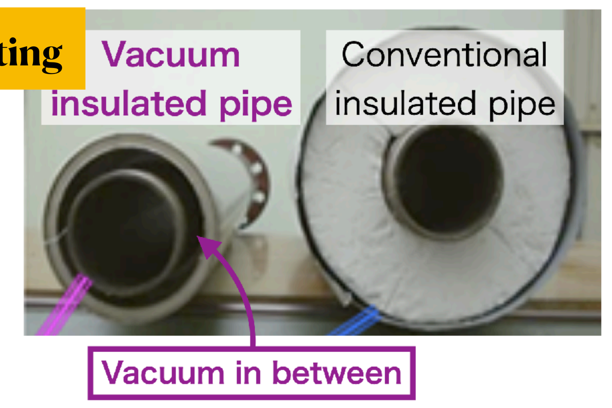
Production target, *made of a graphite rod and placed inside of 1st horn*

- To test **new 750kW target** in Jan. 2020
- To manufacture a 1.3MW target prototype

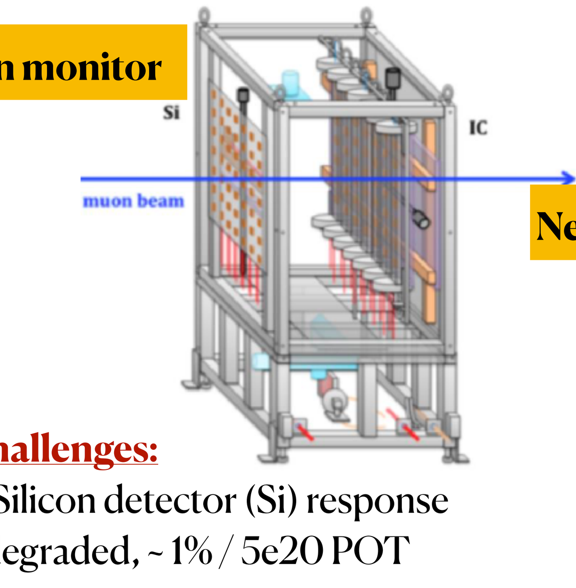
New 750kW target

Upgrade the target cooling system

Testing



Muon monitor



Challenges:

- Silicon detector (Si) response degraded, ~1% / 5e20 POT
- Ionization Chamber (IC) experiences non-linearity at high intensity

EMT as Future Muon Detector

Muons are by-product of a neutrino beam. Monitoring muon is helpful to characterize ν beam

New candidate

EMT[1]: kind of PMT w/ bare aluminum plate (NO photocathode) to suppress the *space-charge effect* which may lead non-linear response

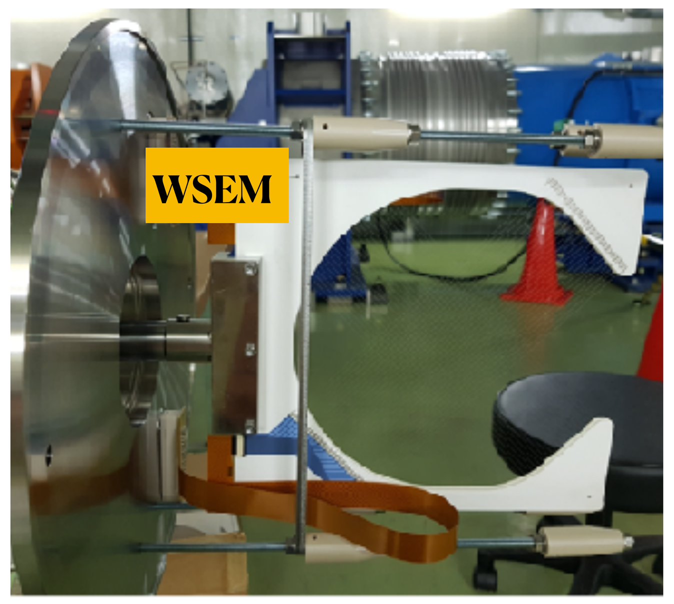
[1]PTEP, 2018 vol. 10

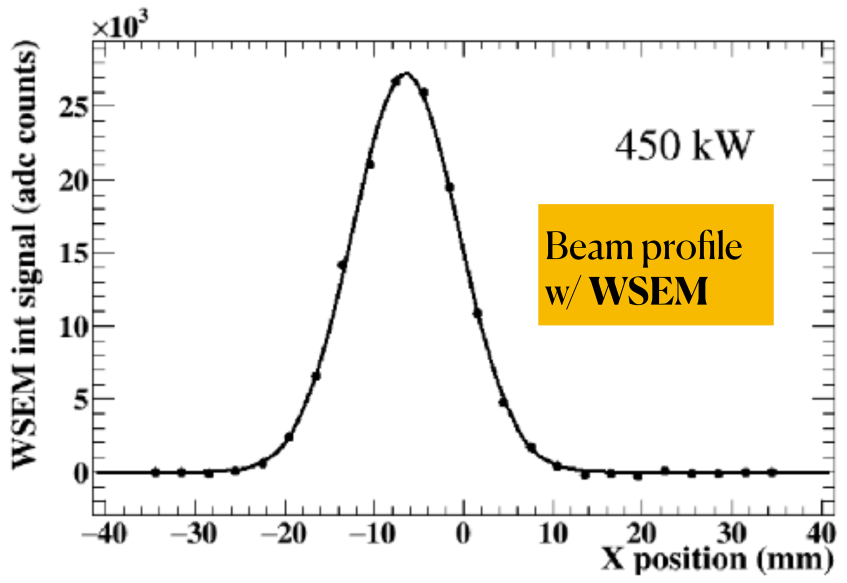
Intercepting Beam Profile Monitors

Signal obtained by intercepting beam w/ material inserted into beamline.

Downside: can't operate continuously due to high beam loss ☞ motivated for non-destructive monitor

- **SSEM**: Three 5-μm-thick Ti foils, two stripped (2-5mm) vertically and horizontally → cause 0.005% beam loss
- **WSEM[1]**: Like SSEM but 25-$\mu m\phi$ Ti wire, **beam loss is reduced by factor of 10: stable operation, consider carbon nano-tube as more-robust option**





[1]arXiv: 1908.05141

Non-Destructive Beam-Induced Fluorescence (BIF) monitor

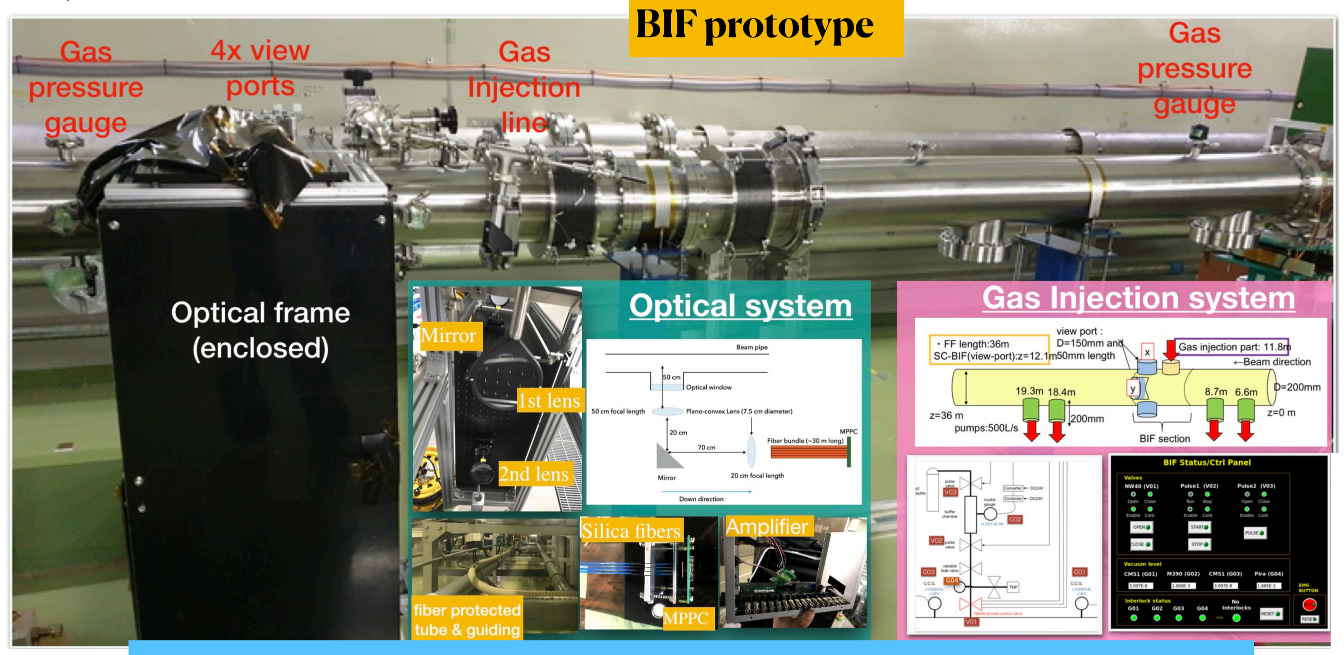
Fluorescence induced by proton interactions w/ gas injected into beamline, is captured and fitted to extract the beam profile.

Key feature: continuous operation, minimal beam loss

BIF is under development[1,2,3] w/ required specifications:

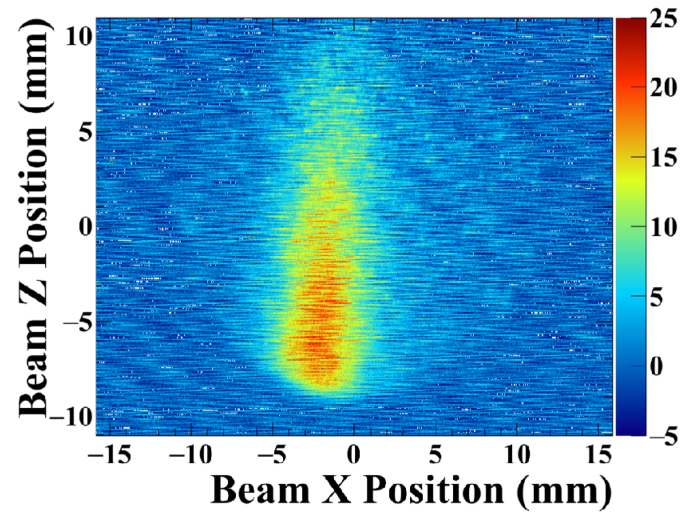
- **Gas needs to be injected in the beamline**: gas normally at ~10^{-6} Pa, not enough to see BIF signal
- **Method to deal with space charge effect**: need fast readout ☞ use e.g Multi-Pixel Photon Counters (MPPC)
- **High radiation environment**: MPPCs are not rad-hard ☞ must operate at sub-tunnel, need rad-hard optical fibers to guide light from beamline to sub-tunnel

BIF prototype

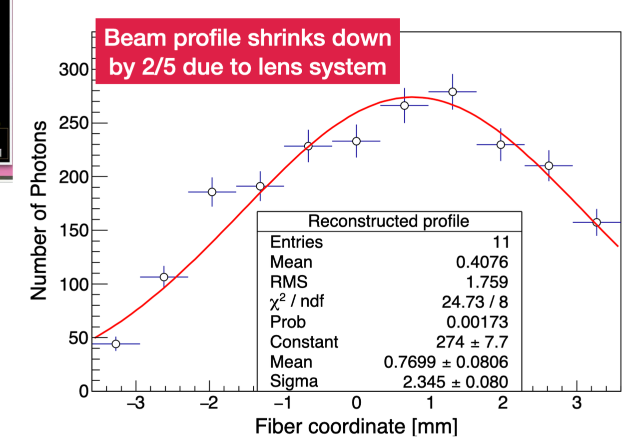


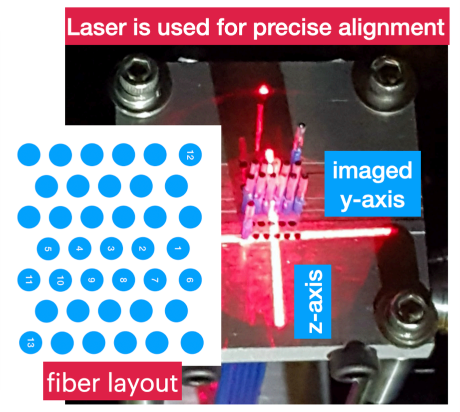
A BIF prototype, including a gas injection system & two readout systems:
(i) Gateable Image Intensifier coupled to CID camera , (ii) MPPC w/ optical fibers

The complete BIF prototype was commissioned during 515kW proton beam operation on Jan. 2019 and we made the first observation of beam-induced fluorescence. There are on-going efforts to improve both gas injection system and readout system to realize BIF as a continuous non-destructive beam monitor toward MW beam



BIF light captured by CID camera. Reconstructed profile agrees w/ the beam optics





BIF light guided by 30-m optical fiber & captured by MPPC. Reconstructed profile agrees w/ the beam optics

[1]IBIC2016-WEPG66 [2]IBIC2018-WEPC08 [3]IBIC2019-TUPP024

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