

Investigation of the radiation fields inside the accelerator tunnel during operation of the NanoTerasu



NanoTerasu

Title: NanoTerasu with an aerobatic flight overhead
Date Taken: June 8, 2024



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Radsynch2025, 26 June 2025

1. Introduction

- a) NanoTerasu
- b) Background and Aim
- c) Comparison Between Shielding Design and Operational Status

2. Method for investigating Beam Loss

- a) Beam Loss Overview
- b) Method Overview

3. Beam Loss Investigation Experiment

- a) Full-Ring Radiation Dose Mapping
- b) Full-Ring Activation Survey
- c) Dose Measurement under Varied Beam Conditions

4. Summary



Taken in Spring

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Taken in Spring

1-a) NanoTerasu

- The 10th synchrotron facility built in Japan
- Managed under a public-private partnership framework
- Operating since 2024



Design parameters

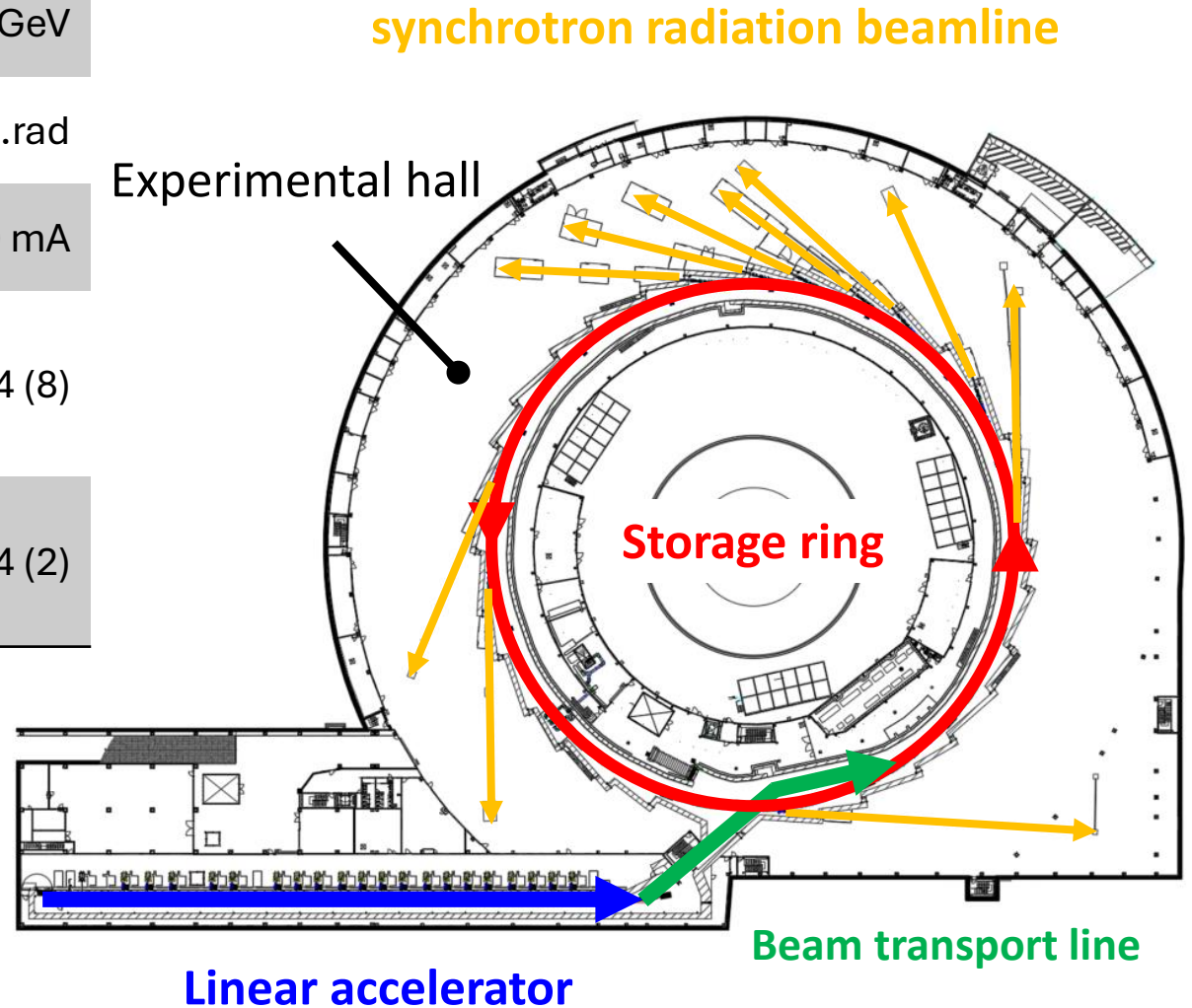
Beam energy	3 GeV
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Normalized emittance	1.14 nm.rad
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Beam current	400 mA
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Max (Beginning). number of undulators	14 (8)
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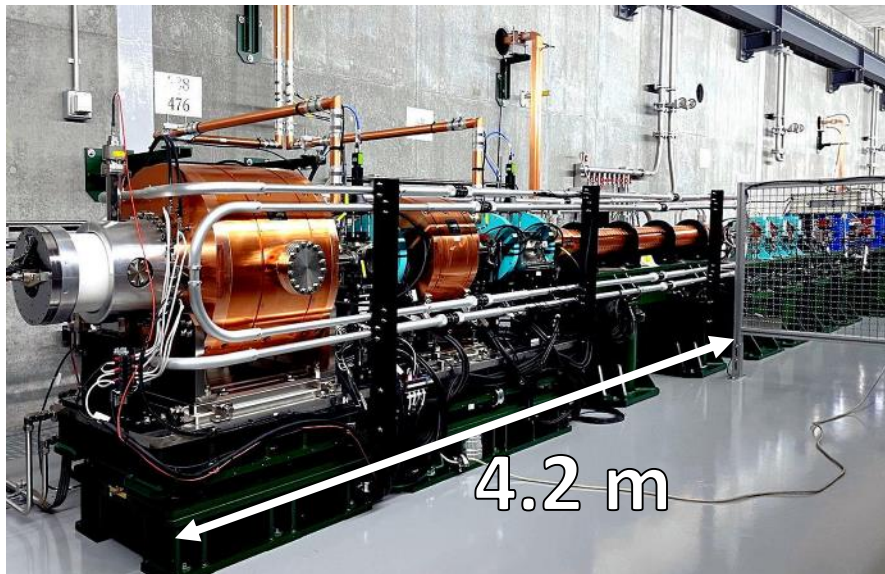
Max (Beginning). number of multi-pole wigglers	14 (2)
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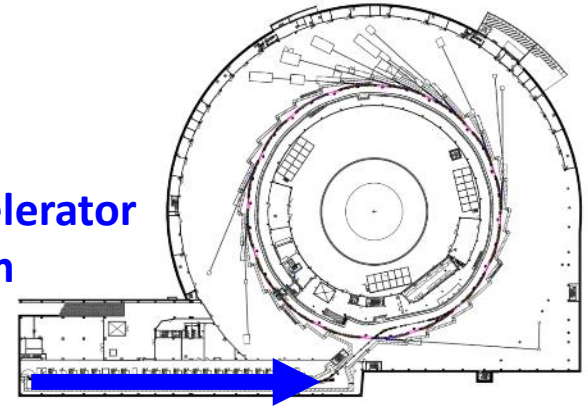
Compact and high performance

3GeV Linear accelerator	length
NanoTerasu	110 m
MAX IV (Sweden)	300 m

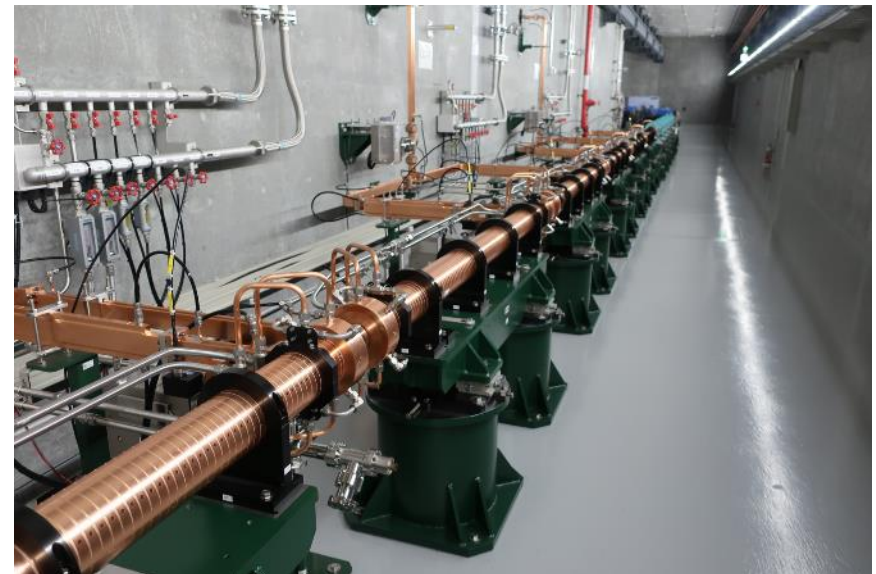
New compact electron gun system using a commercial grid thermal cathode



Linear accelerator
110m

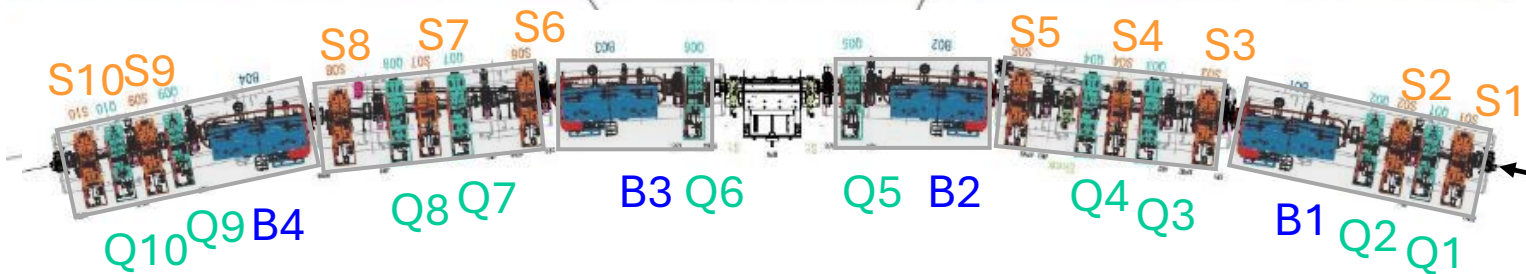
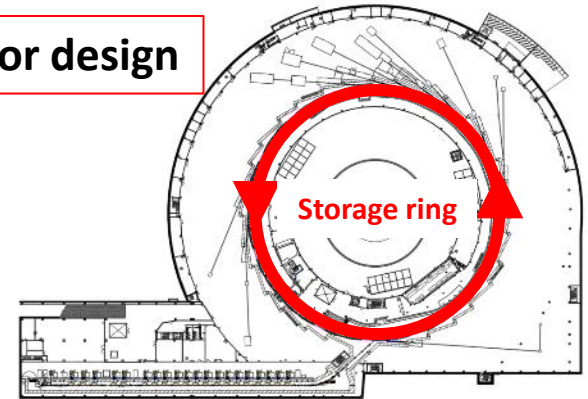


3 GeV C-band (5.7 GHz) accelerator
(40 of 2m-long-cavities)



MBA (Multi-bend achromat) lattice with the latest accelerator design

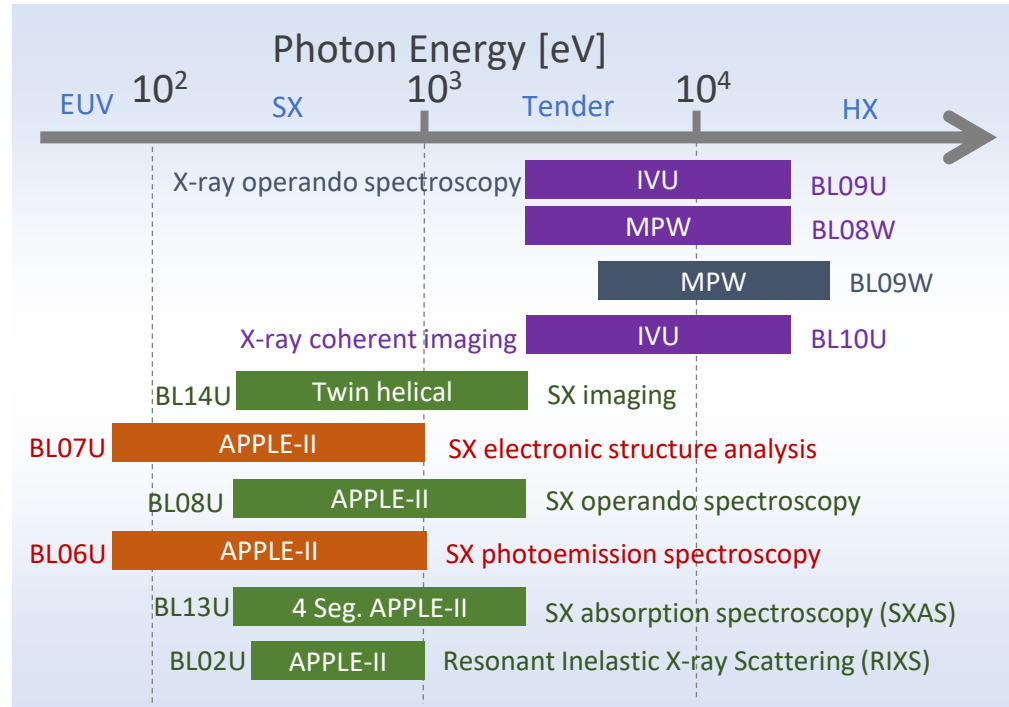
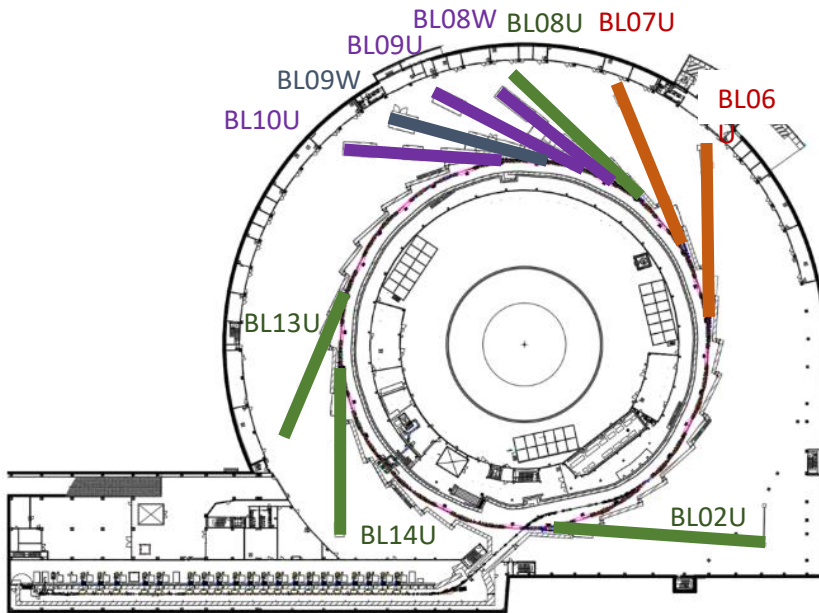
3GeV Storage Ring	circumference
NanoTerasu	349 m
TPS (Taiwan Photon Source)	518 m



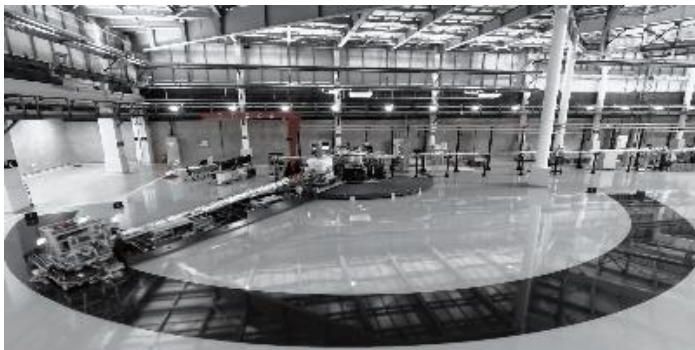
B : Bending magnet 4
 Q : Quadrupole magnet 10
 S : Sextupole magnet 10

× 16 Cells

All the beamlines use insertion devices Undulator or Multipole Wiggler



BL02U (RIXS)



Undulator

APPLE-II

4 Seg. APPLE-II

Twin helical

IVU



May 2023

Presented shielding design at RadSynch 23, Grenoble (ESRF)



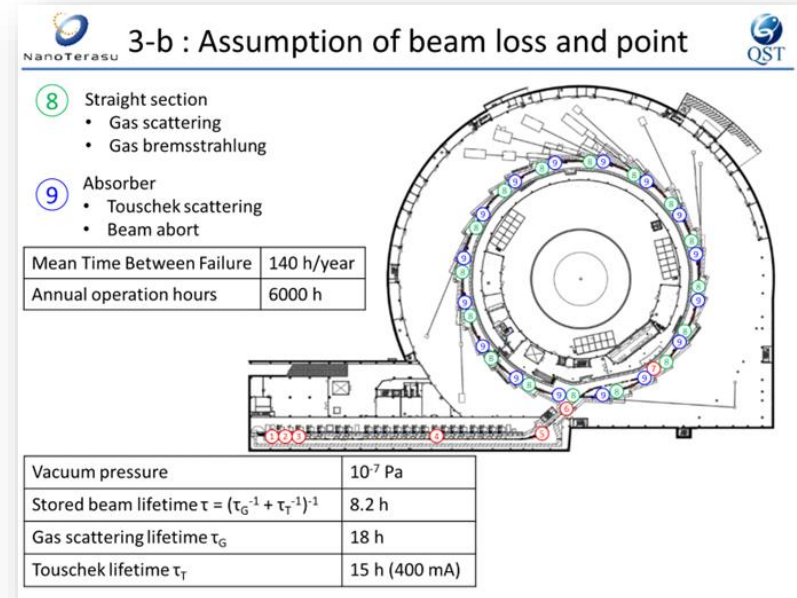
Accelerator commissioning began in 2023

User operation started in April 2024

As of June 2025

One year of user operation completed

No major issues observed



Aim:

1. To compare the shielding design assumptions with actual conditions after the start of operation
2. To investigate radiation doses resulting beam losses in the accelerator tunnel during actual operation

May 2023

Presented shielding design at RadSynch 23, Grenoble (ESRF)



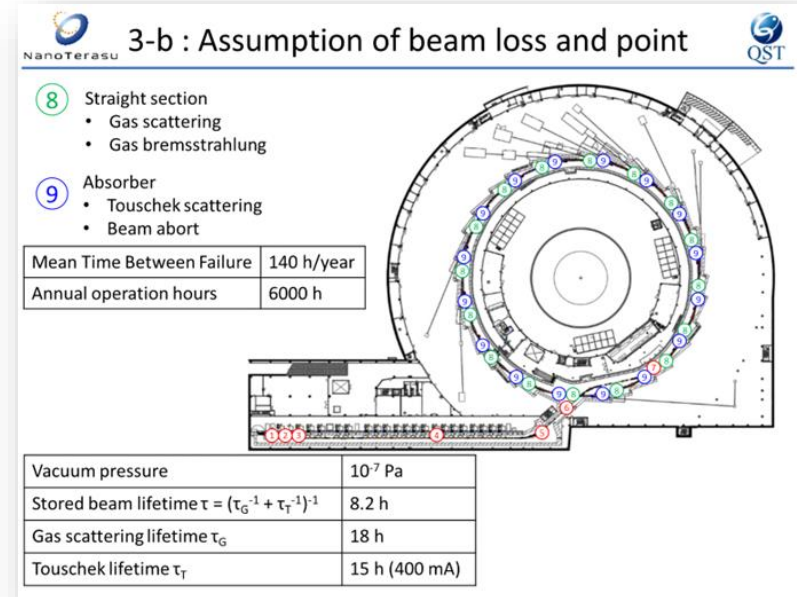
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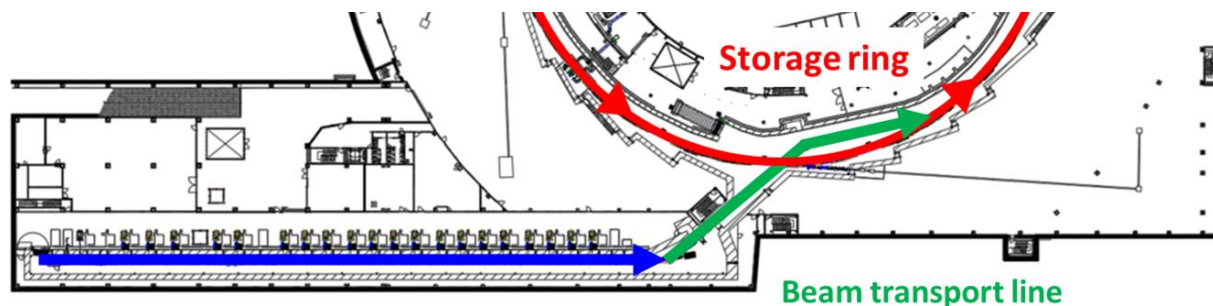
Aim:

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1-c) Facility Status

	Design	2024FY (First year)
Operating Current	400 mA	Up to 200 mA
Operation hours	6000 hours (goal)	3568.5 hours (scheduled) Downtime: 13 hours Availability: 99.63 %
Mean Times Between Failure	140 hours	323.2 hours
Abnormal beam dump	43 times/year	11 times/year

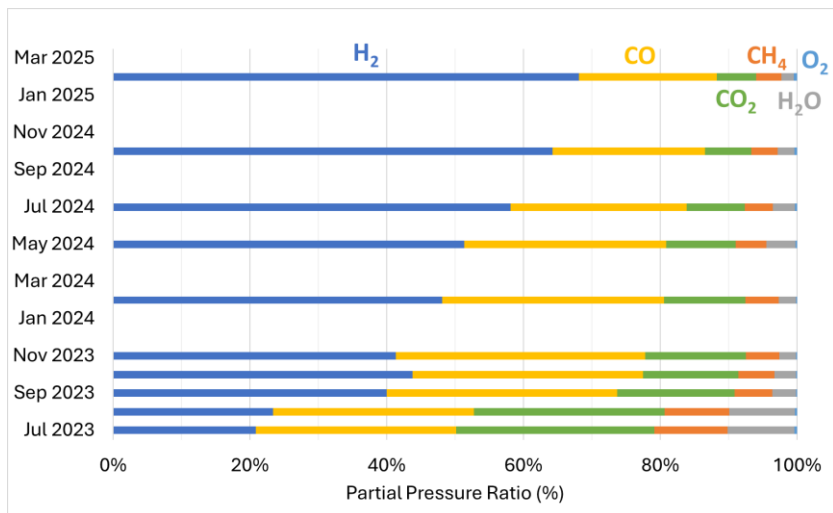
	Design	Current Status
Maximum Linac Output	1.8 W (3 GeV, 0.6 nC/s)	1.1 W (3 GeV, 0.38 nC/s)
Maximum injected charge into the Storage Ring	4.8E+05 nC/3 months (1.9E+06 nC/year)	1.8E+05 nC/year (2024FY)
Beam transport efficiency (Linac → Beam transport line)	99 %	80 %
Beam loss output in the beam transport line	0.018 W	0.22 W
Beam injection efficiency (Beam transport line → Storage Ring)	95 %	90 %
Beam loss output in the injection	0.09 W	0.088 W



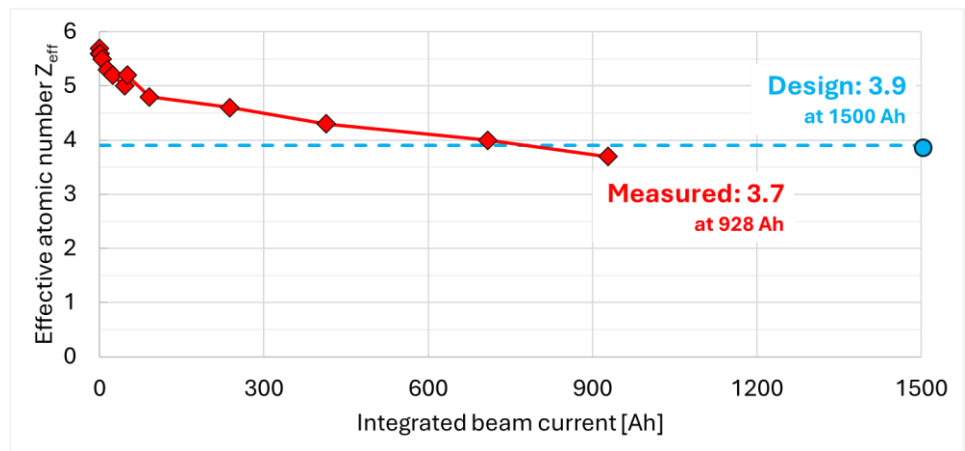
Linear accelerator

	Design	Current Status
Vacuum pressure at Storage Ring	2.75E-07 Pa	1.00E-07 Pa
H ₂ ratio in the vacuum	51 %	68 %
Effective atomic number	3.9	3.7
Stored beam lifetime	8.2 hours (400 mA)	10 hours (200 mA)
Number of electrons lost due to beam lifetime decay	1.0E+08 electrons/s (400 mA)	4.0E+07 electrons/s (200 mA)

Change in Composition of Residual Gas



Change in Effective Atomic Number



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Taken in Summer

Regular losses:

- Touschek Scattering

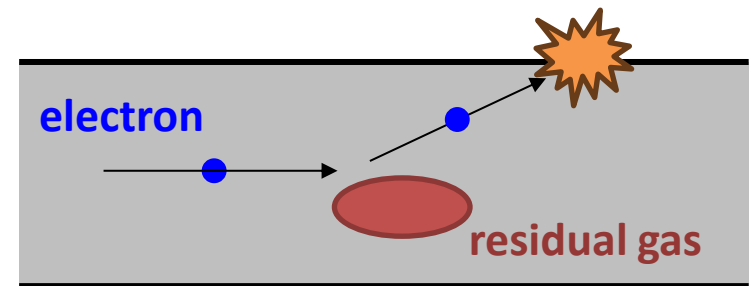
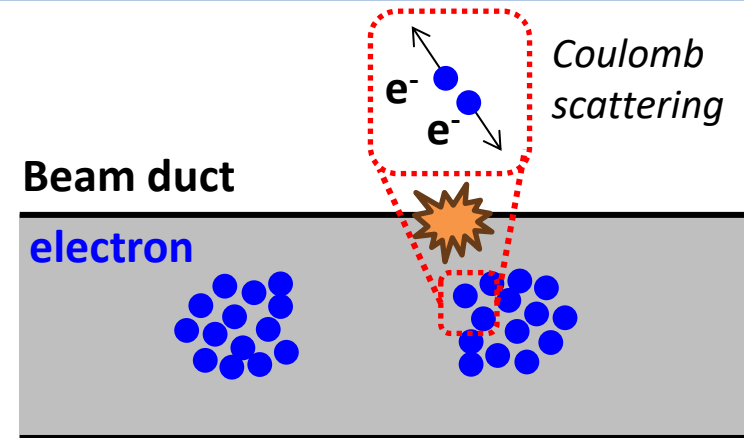
Dependence of beam current, beam size

- Residual Gas Scattering

Dependence of vacuum pressure

Irregular losses:

- Equipment abnormality, etc.



(1) Full-Ring Radiation Dose Mapping

Installed passive dosimeters throughout the entire storage ring tunnel to measure accumulated dose during user operation

(2) Full-Ring Activation Survey

After operation, conducted gamma surveys of accelerator components to identify activated areas

(3) Dose Measurement under Varied Beam Conditions

During machine study periods, used active dosimeters at suspected loss points to monitor dose changes in response to varying beam conditions

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Luminess badge dosimeter

Optically Stimulated Luminescence (OSL) and CR-39



Radiation Type	Dose Measurement Range	Energy Range
X-rays / Gamma rays	0.01 mSv – 10 Sv	5 keV – 10 MeV
Thermal neutrons	0.1 mSv – 6 mSv	0.025 eV – 0.5 eV
Fast neutrons	0.1 mSv – 50 mSv	24 keV – 15 MeV

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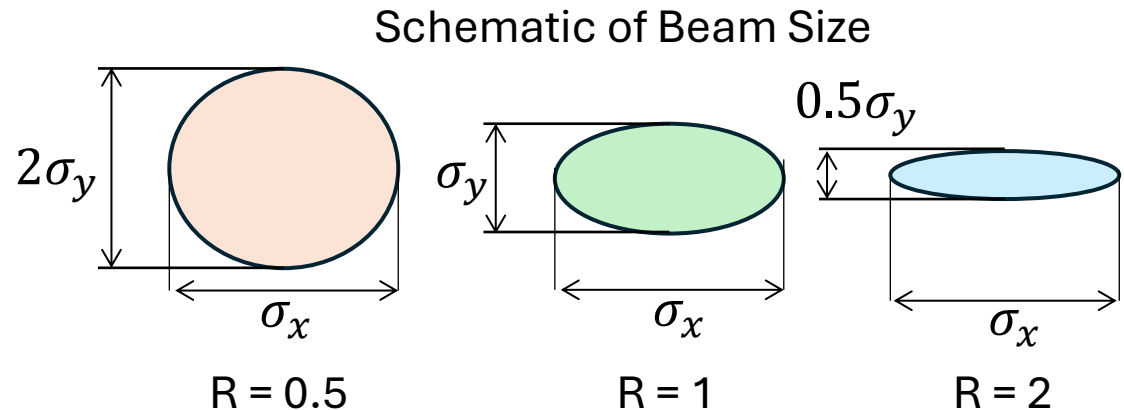
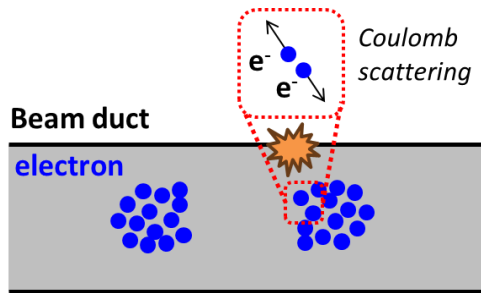
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Changes in vertical beam size affect the radiation dose through variations in Touschek scattering

Touschek scattering



$$R \propto \frac{I^2}{\sigma_x \sigma_y}$$

R : Touschek scattering rate

I : Stored current

σ_x : Horizontal beam size

σ_y : Vertical beam size

Predicted trends:

- **Larger vertical beam size**

→ Dose **decreased** due to reduced Touschek scattering

- **Smaller vertical beam size**

→ Dose **increased** due to increased Touschek scattering



MIRION
TECHNOLOGIES

Personal Electronic Dosimeter DMC3000N (Neutron Module)



Neutron Module

	Photon	Neutron
Detector	Silicon diode	Li-6, PE + Silicon diode
Energy range	15 keV ~ 7 MeV	0.025 eV ~ 15 MeV
Dose range	1 uSv ~ 10 Sv	1 uSv ~ 10 Sv
accuracy	< ± 10%	< ± 10%

- Easy to set up
- Battery: standard AAA
(3,000 h battery life in continuous mode)

Size : 13cm × 6cm × 2cm

Weight : 140g

- **Time series data can be acquired
(settable intervals 10 s, 60 s, 10 m, 1 h, 24 h)**

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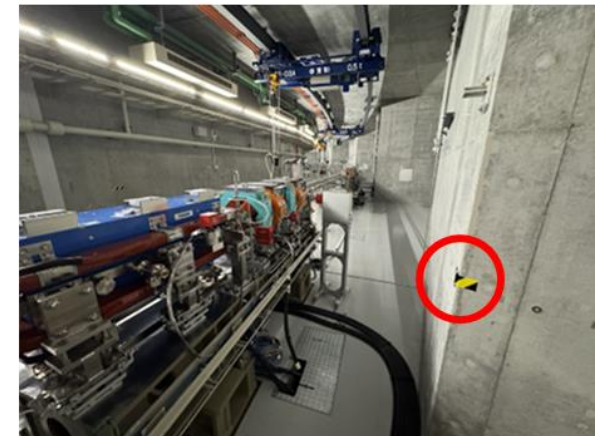
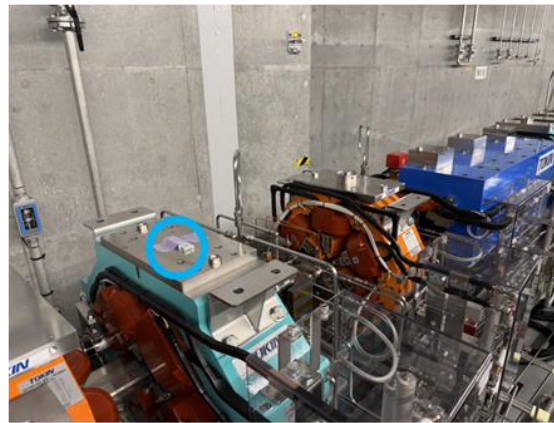
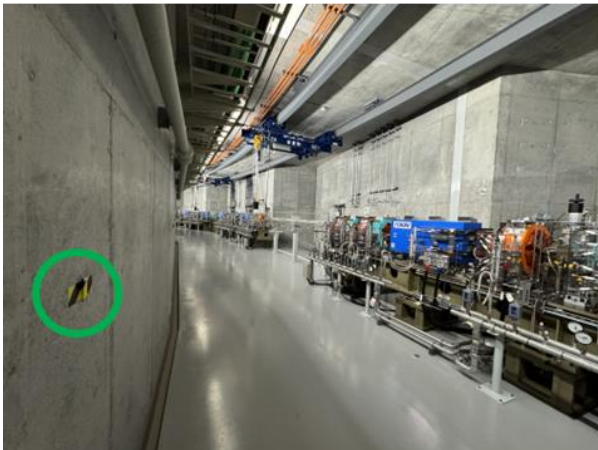
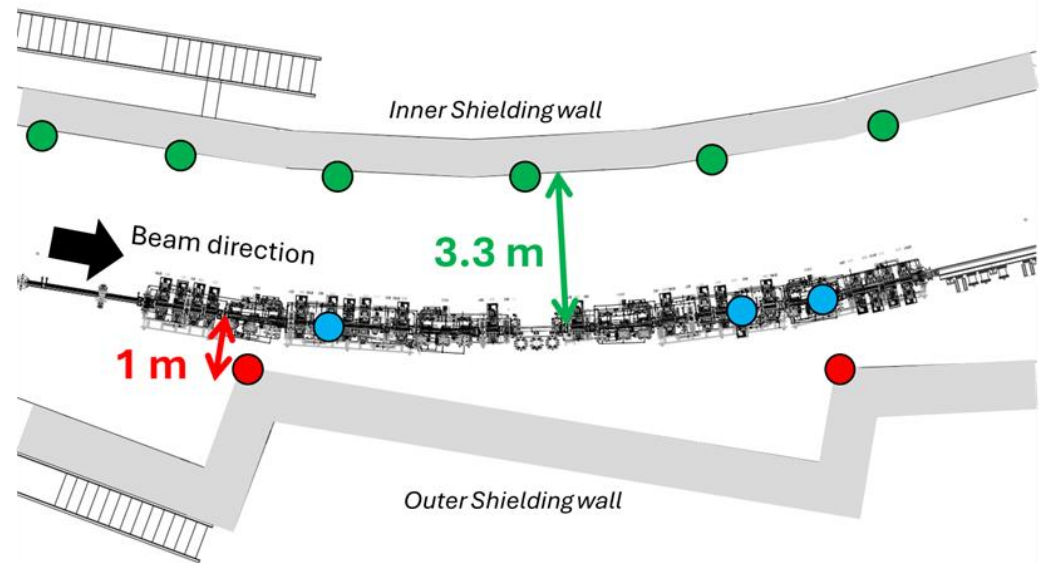
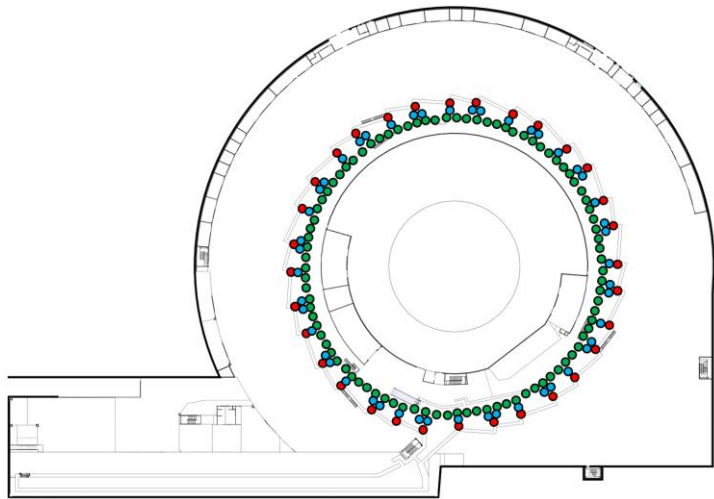
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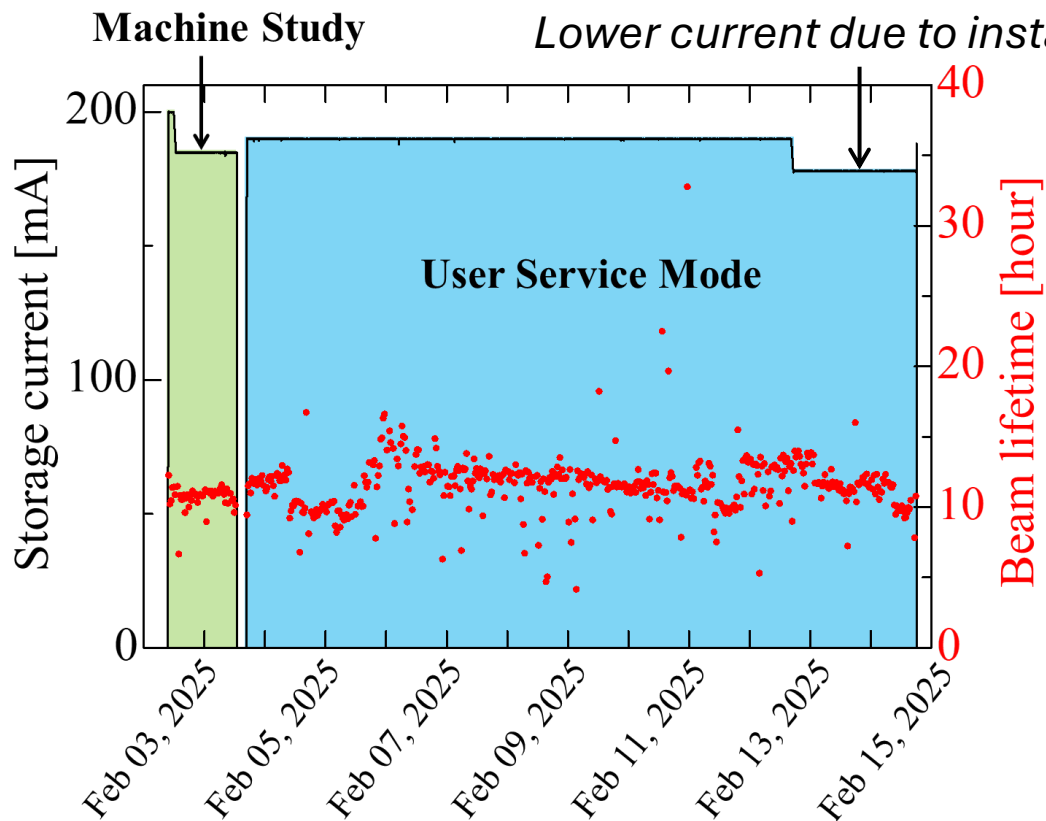


Taken in Fall

A total of 176 dosimeters were installed — 11 per cell across all 16 cells

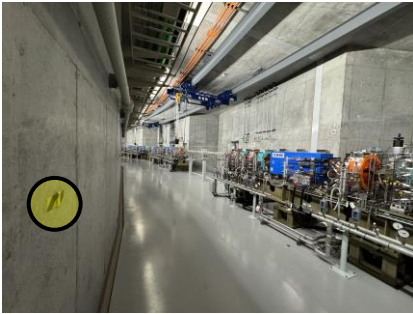


Storage current		Operation time
Machine Study	200 mA	2 hours
	185 mA	24 hours
User Service Mode	190 mA	216 hours
	178 mA	48 hours

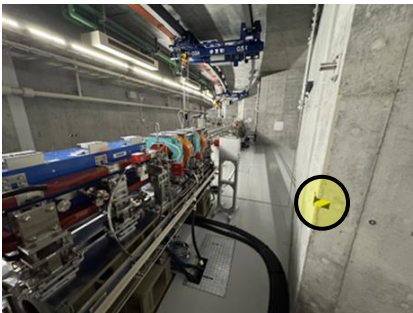


**Total:
290 hours
(12 days)**

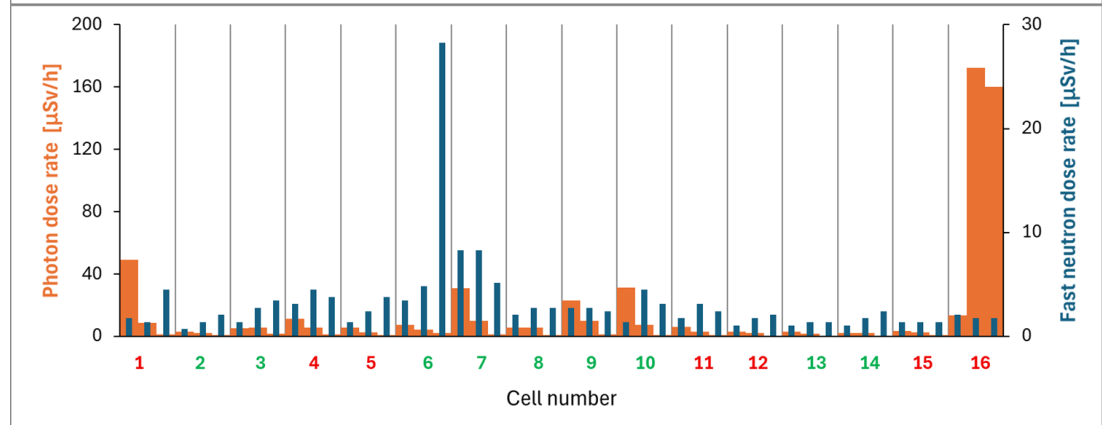
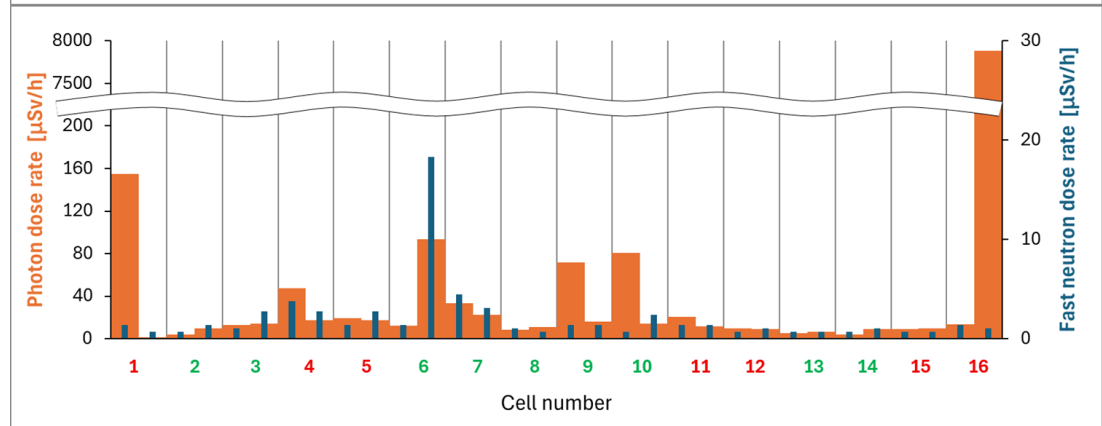
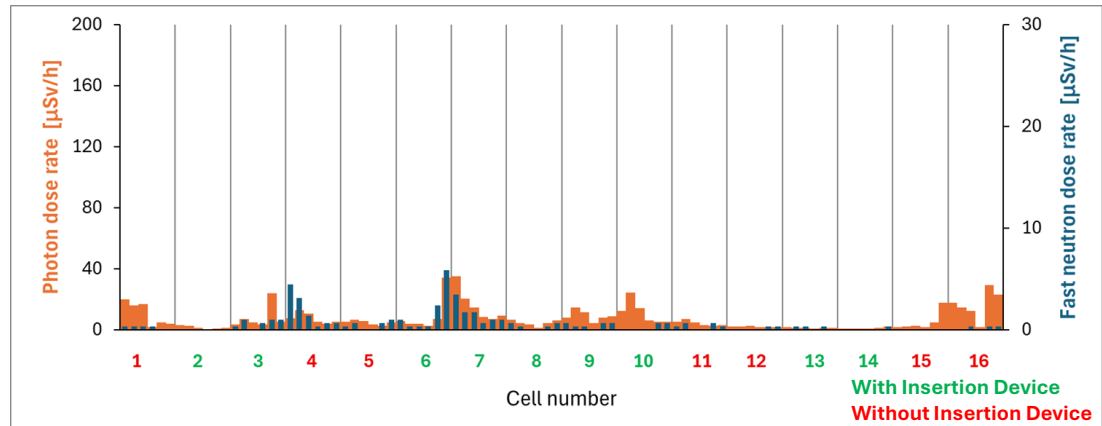
Inner shielding wall



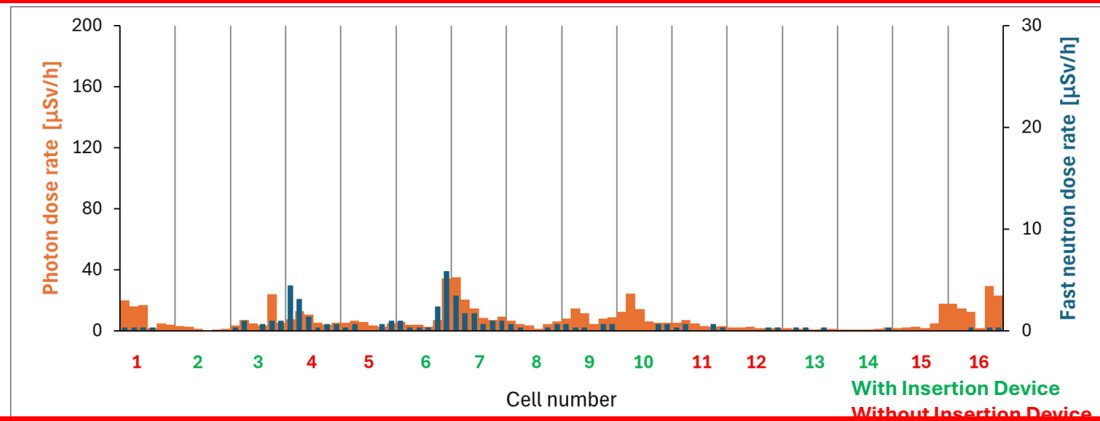
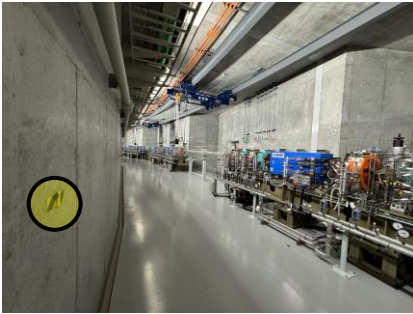
Outer shielding wall



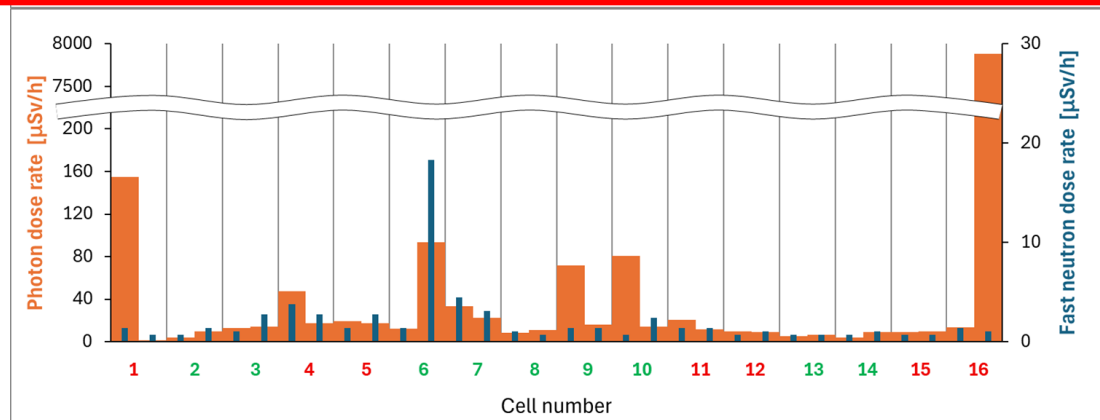
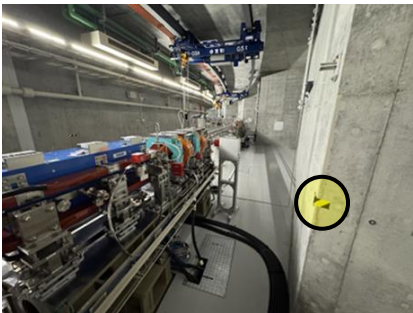
On magnets



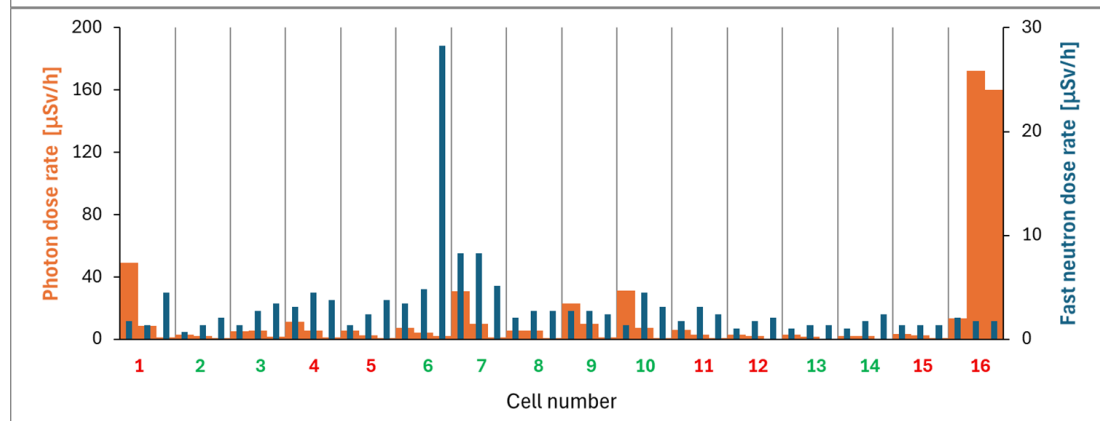
Inner shielding wall



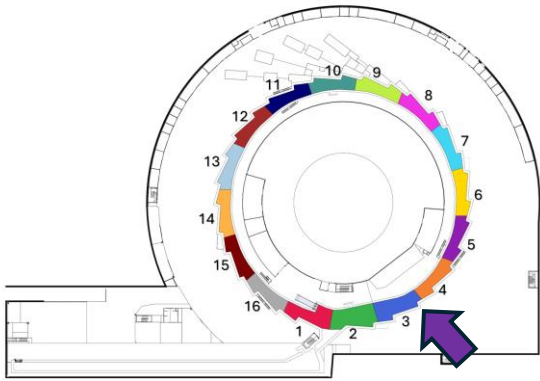
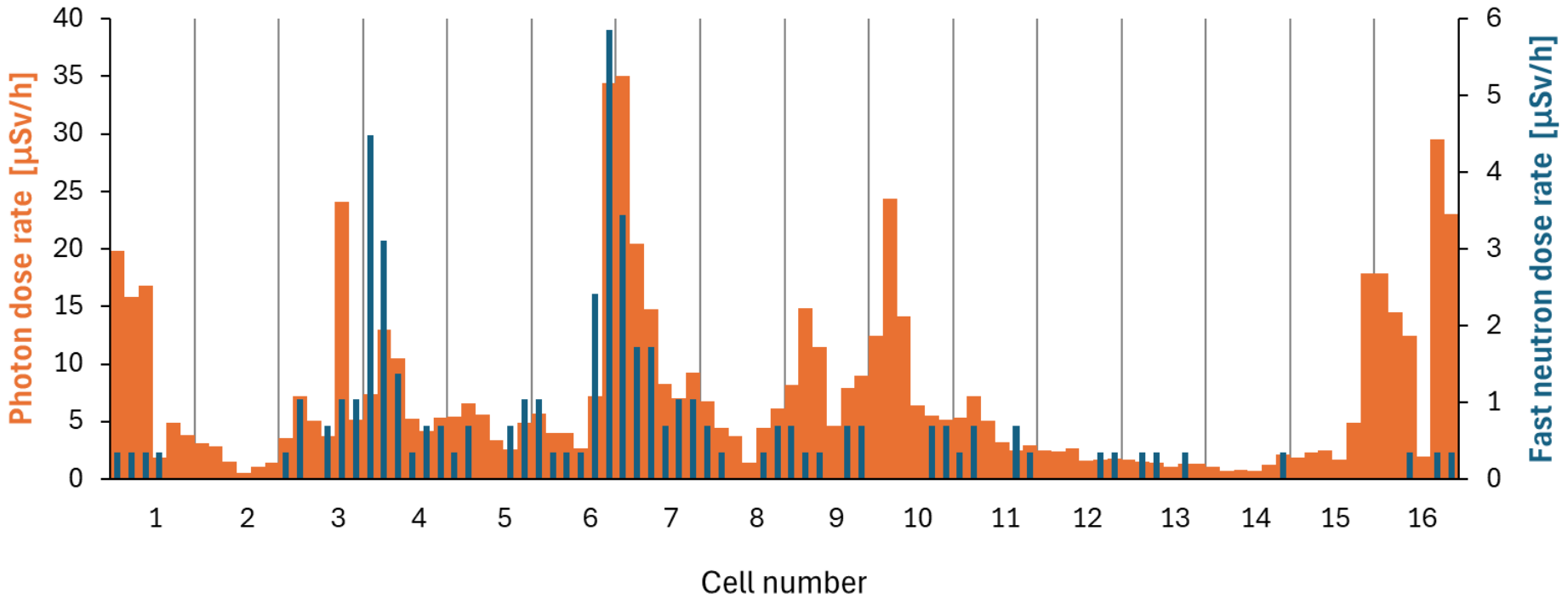
Outer shielding wall



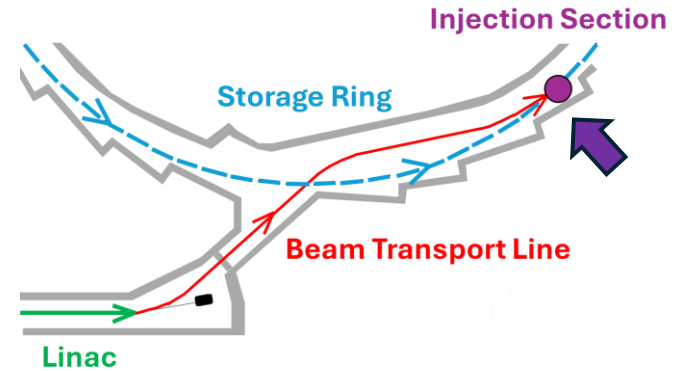
On magnets



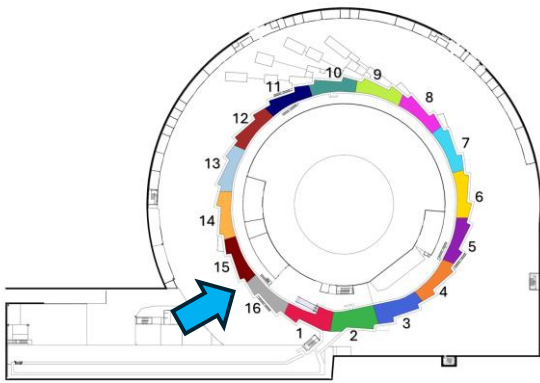
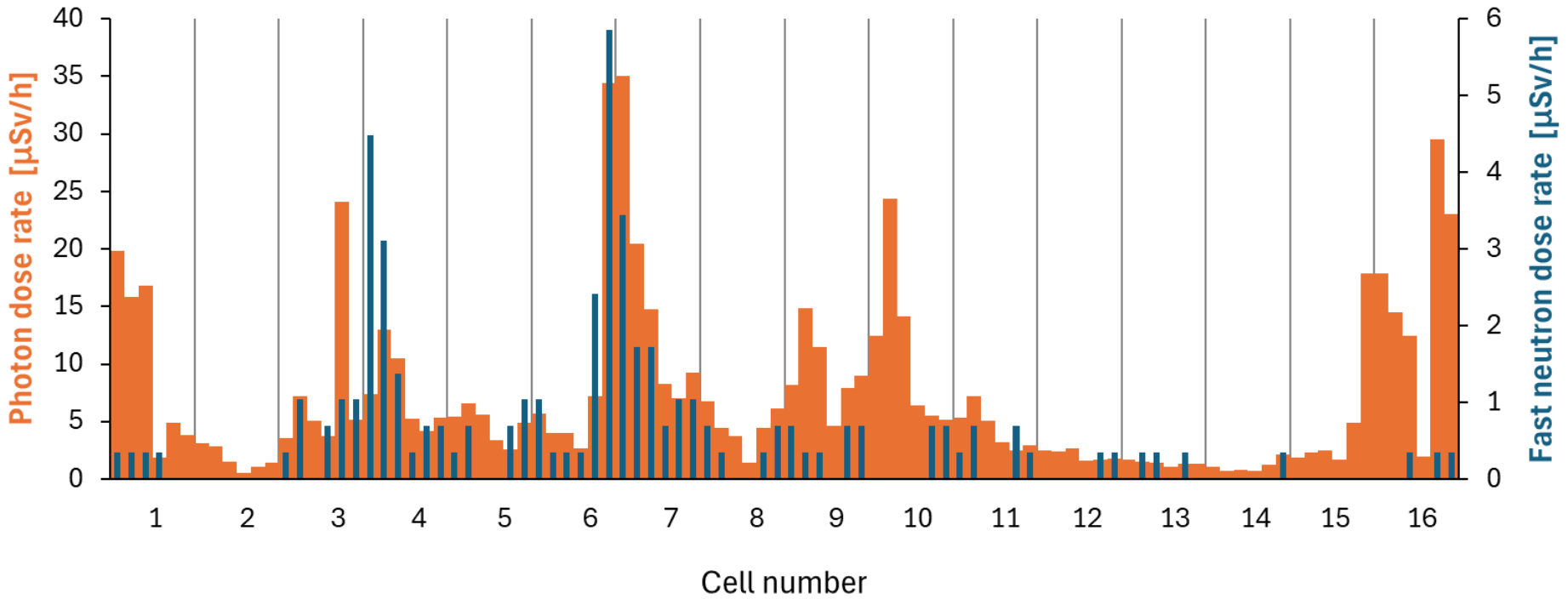
Injection Section



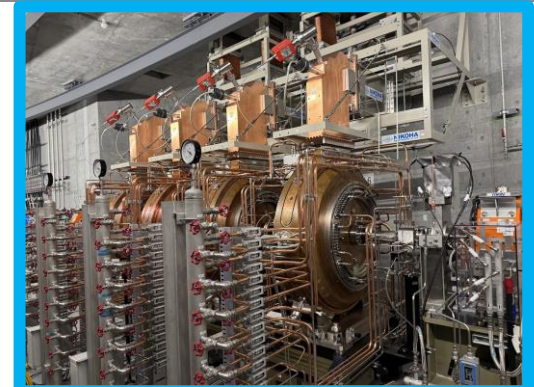
Electron losses during transfer to storage ring




RF Cavities



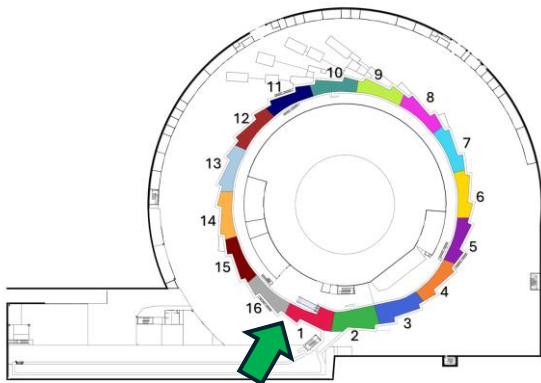
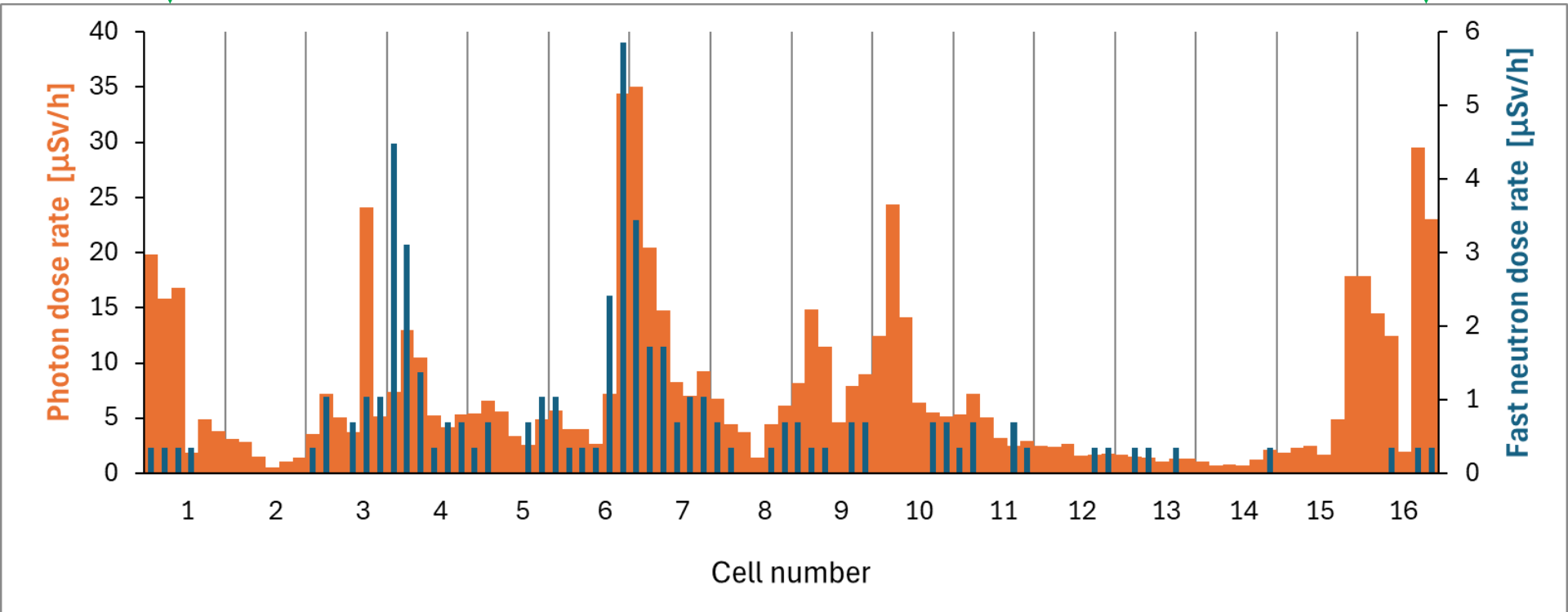
X-ray generation by dark current



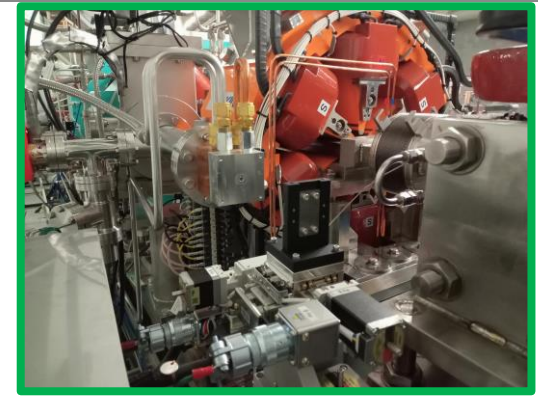
X-ray pinhole camera (forward)



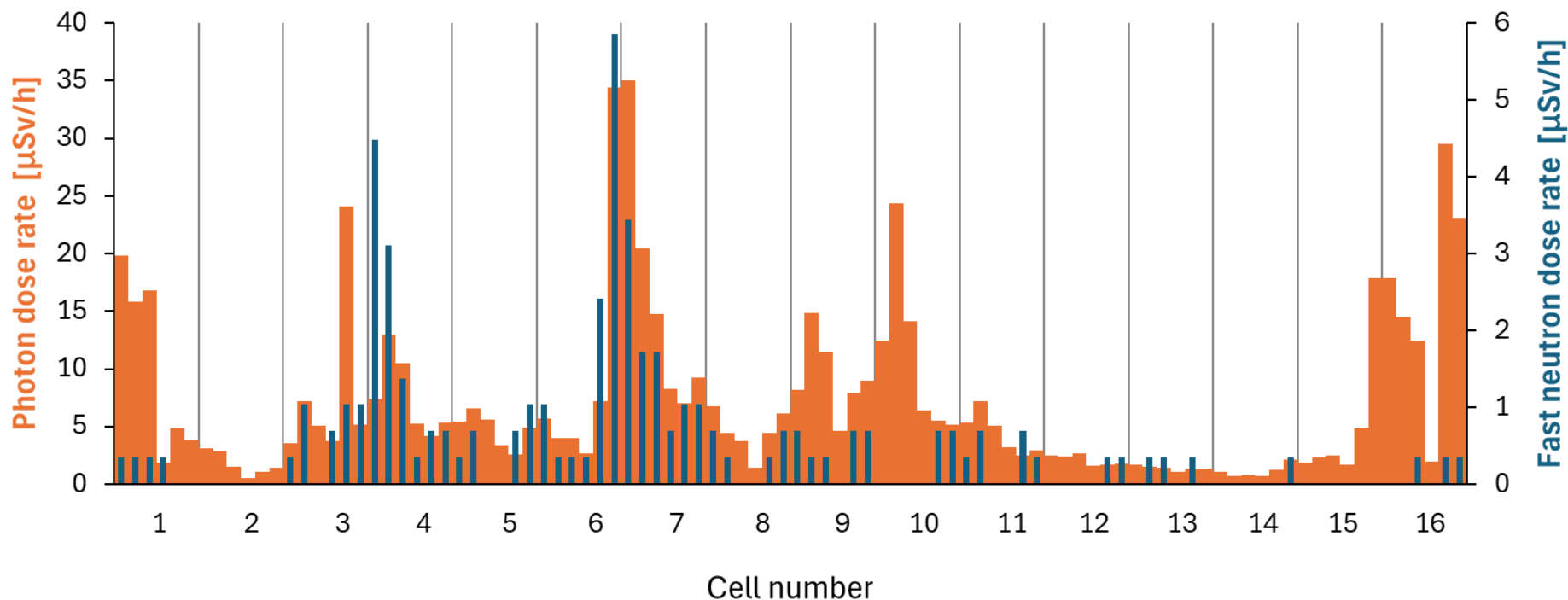
X-ray pinhole camera (lateral)

X-ray extraction into **air** for electron beam diagnostics



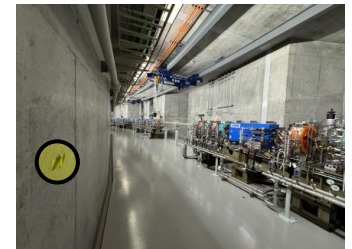
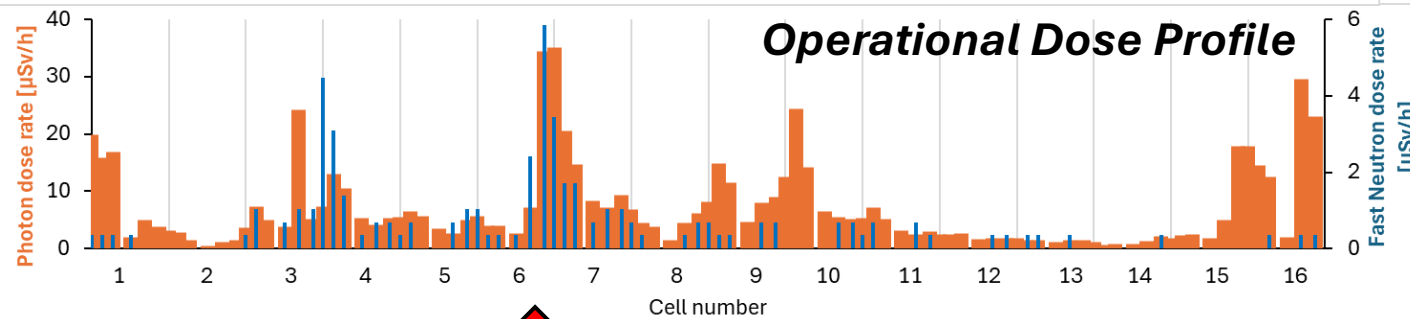
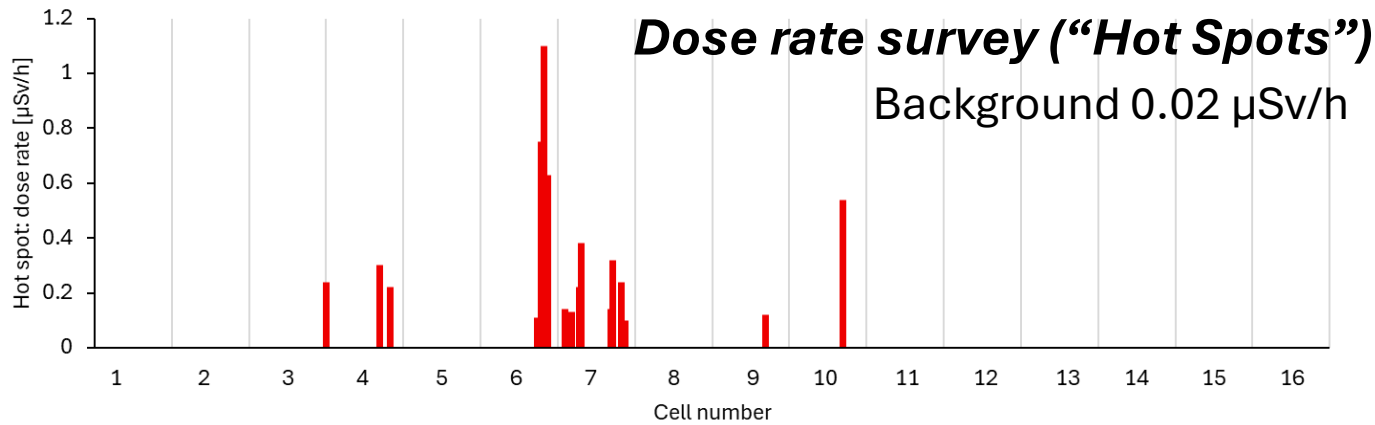
High Dose



*No unique reason identified;
same lattice structure applies across all 16 cells.*

Next Step: Activation Survey of Accelerator Components

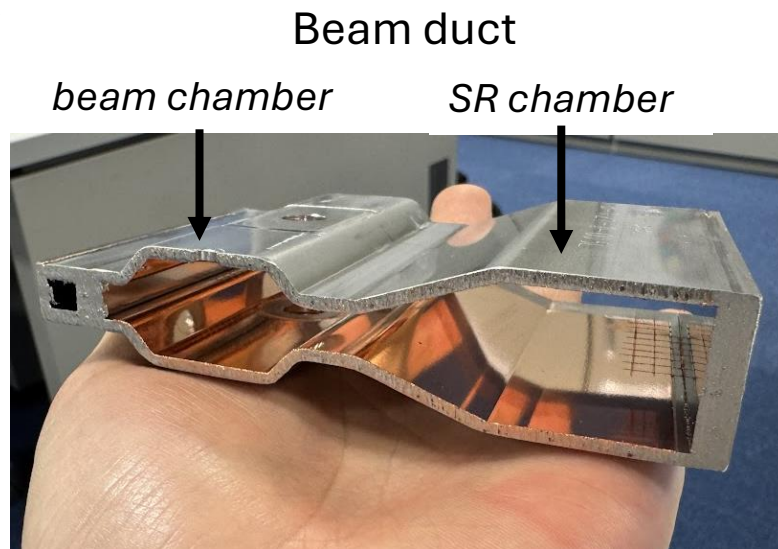
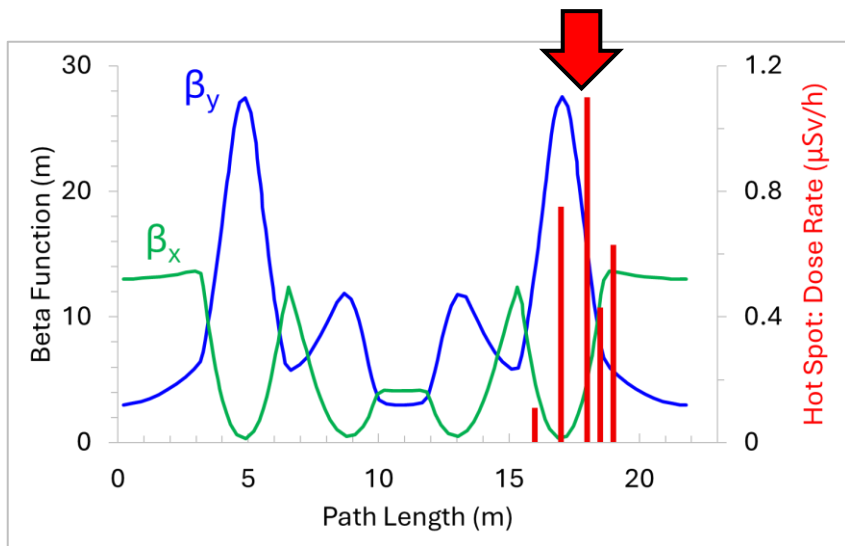
Indication of unidentified local beam loss



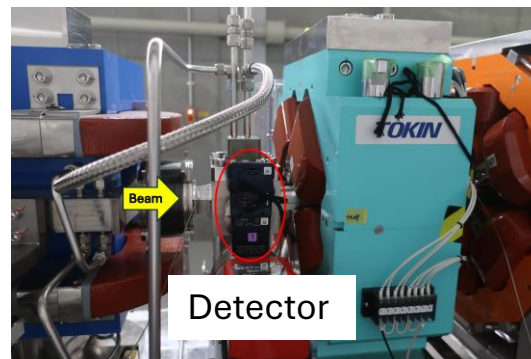
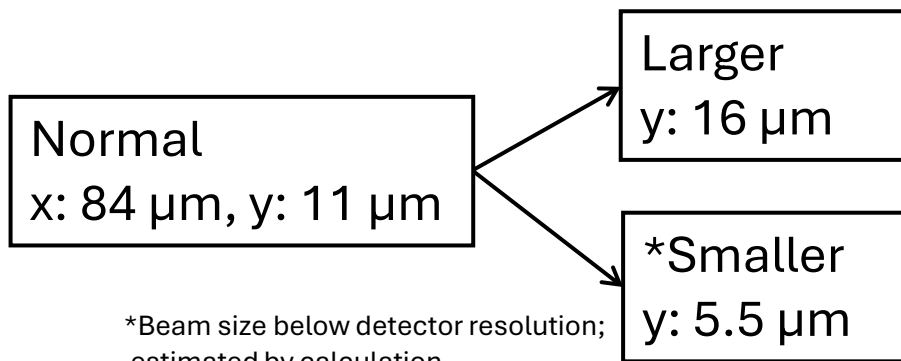
Next Step: Detailed Investigation at the Loss Point

High dose observed near the vertical beta function maximum suggests possible vertical beam loss inside the chamber.

Distribution of lattice functions along the unit cell

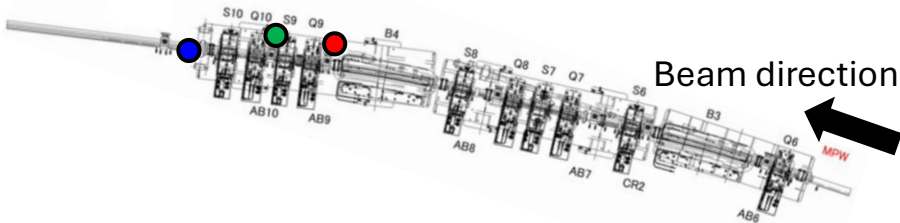


Radiation dose measured while changing vertical beam size in a machine study.



Effect of Vertical Beam Size on Normalized Radiation Dose

Detector Locations (Cell 6)



Smaller vertical beam size

→ **Dose increased**

Due to increased Touschek scattering

Larger vertical beam size

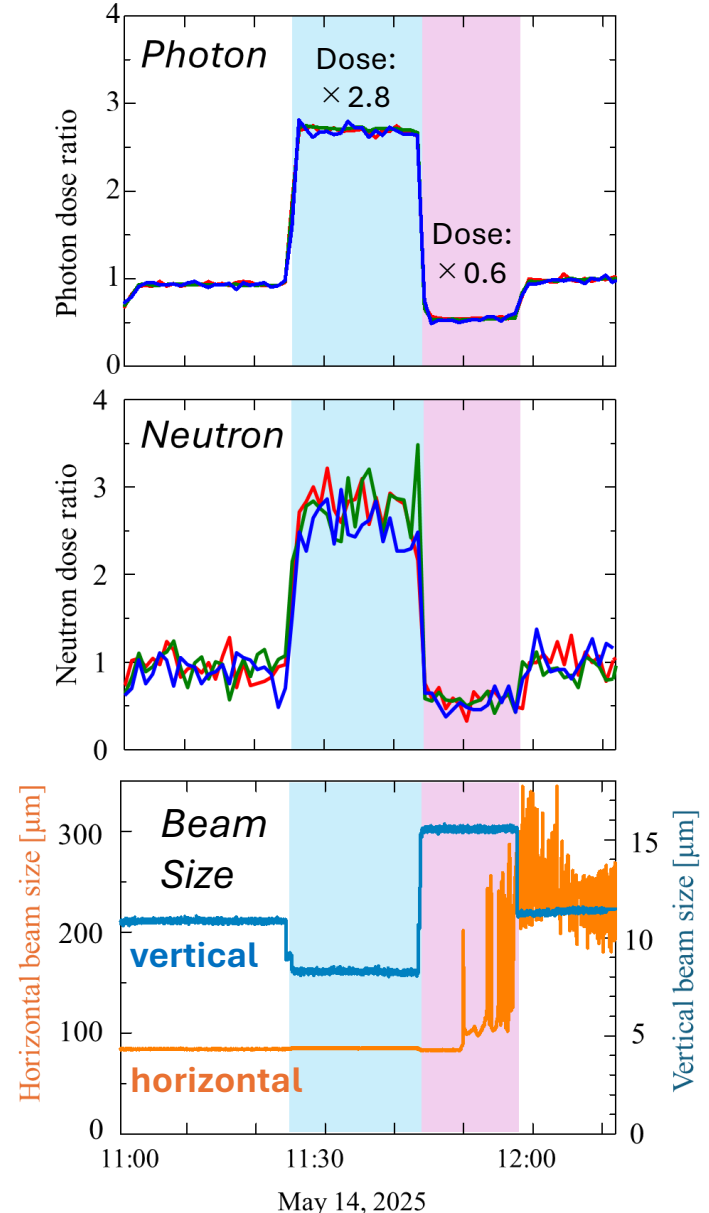
→ **Dose decreased**

Touschek scattering reduced

*No additional beam loss observed;
Contrary to expectation, vertical beam
spread did not lead to increased loss*

This study eliminated one possible cause of the beam loss.

Further studies are planned to identify the origin.



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Taken in Winter

- ✓ **Comparison of shielding design and operational conditions:**
Confirmed overall agreement with design parameters

- ✓ **Dose mapping in the tunnel during user operation:**
Identified localized high-dose areas in several cells

- ✓ **Unexplained dose distribution:**
Survey following accelerator run revealed activation, confirming actual beam loss

- ✓ **Investigation of vertical beam spread as a loss cause:**
Beam size variation experiment showed that vertical expansion did not cause beam loss — further investigation underway

Thank you

Acknowledgement:

- NanoTerasu Center Accelerator Group



NanoTerasu



Title: A view of NanoTerasu with Comet
C/2023 A3 (Tsuchinshan-ATLAS)
Date Taken: October 20, 2024

