

PMQ Radiation Testing at the NSLSII IFE

NAPAC 2025

T. Roff, Brookhaven National
Laboratory

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“The research described herein is Fundamental Research as defined in the ITAR (22 CFR §120.34(a)(8)), EAR (15 CFR §734.8), or Part 810 (10 CFR §810.3), as applicable, and as described in the USD (AT&L) memoranda on Fundamental Research, dated May 24, 2010, and on Contracted Fundamental Research, dated June 26, 2008.”

NSLSIIU Motivation

NSLSII is a 3rd generation double bend achromat light source. It is one of the last built with first light in 2014.

NSLSII, with 800pm-rad horizontal emittance, is being surpassed now by many modern light sources employing multi-bend achromat technology.

MAX-4 (Sweden, 2016), ESRF-EBS (France, 2019), and SIRIUS (Brazil, 2020). Two upgrade projects, APS-U and ALS-U, are being developed in the US and several other projects worldwide including IHEP LS (China), Elettra-2 (Italy), Diamond-2 (UK), Soleil-2 (France), and CLS-2 (Canada) have entered the design stage.

In the next decade, we expect approximately ten synchrotrons and X-ray FELs with an emittance lower than that of NSLS-II by a factor of 10-20 (and, consequently, with brightness at 10 keV of photon energy that's higher by a factor 10-100) to begin their operations, which will put NSLS-II at a significant disadvantage.

These specifications require more compact configurations of the synchrotron magnets with precise dipole fields tailored to the lattice functions, as well as high gradients with tight field tolerances. In the past few years new configurations of Permanent Magnet element designs have emerged featuring small apertures required for high field strengths.

In collaboration with the accelerator community, we have been investigating novel Complex-Bend technology to realize ~20pm-rad (40x) reduced emittance for NSLSII-U. These new designs require small aperture magnets of demanding specifications in terms of field and gradient strengths, field quality, vacuum chamber integration and x-ray extraction.

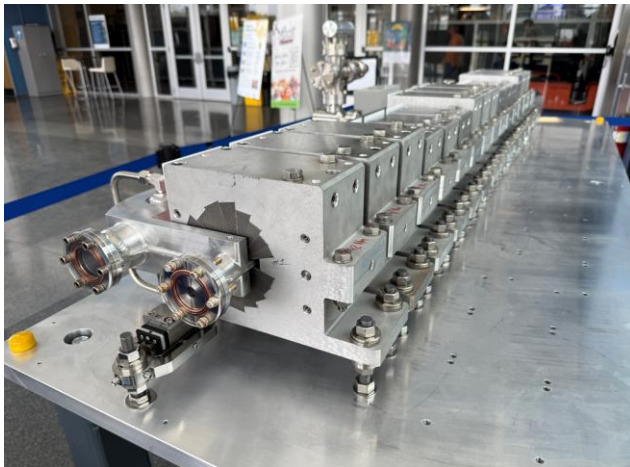


NSLSII-U Lattice

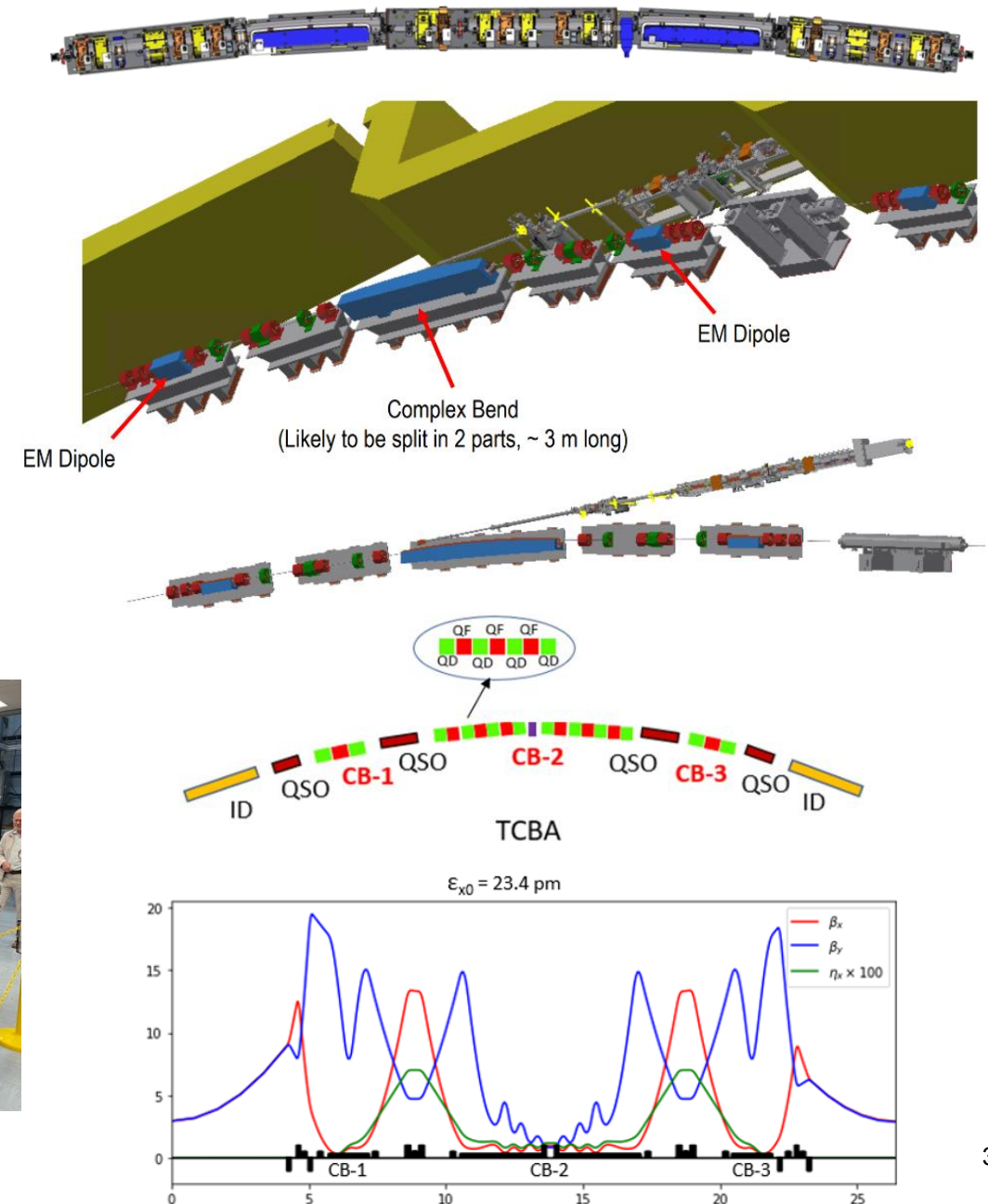
NSLSII-U TCBA (triple complex-bend achromat) lattice.

CB-2 will have a smaller aperture (11mm vacuum ID) than CB1 and CB3.

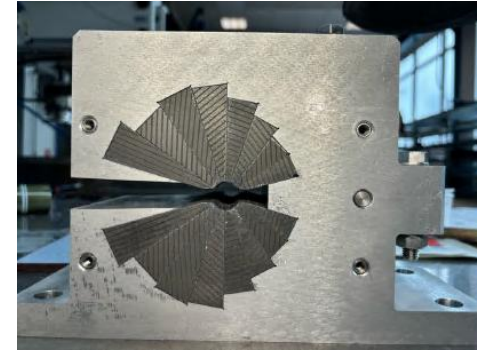
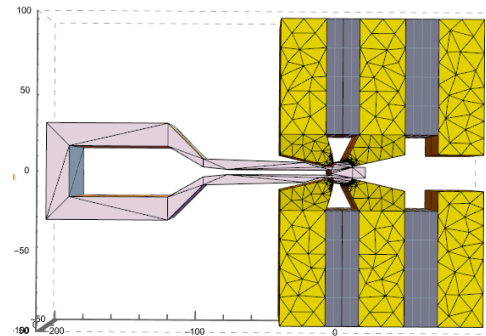
PMQ and vacuum chamber were prototyped under a recently completed LDRD.



National Synchrotron Light Source II



Halbach design selected for prototyping.

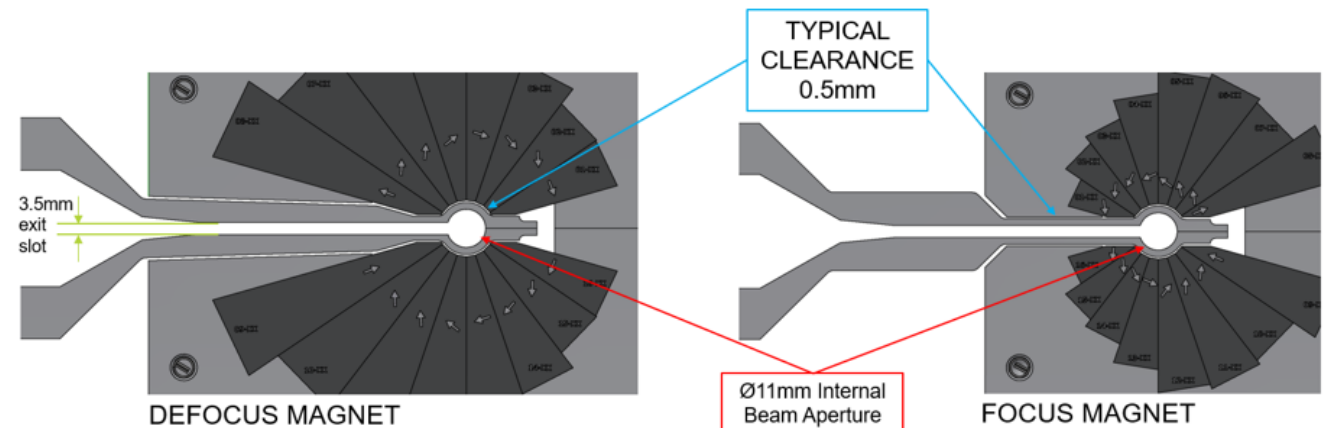
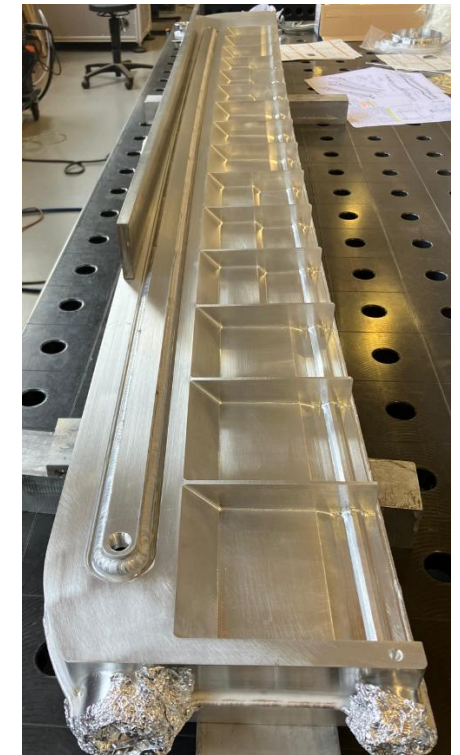
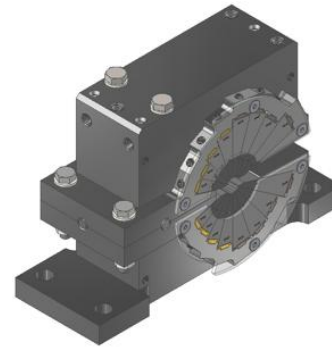
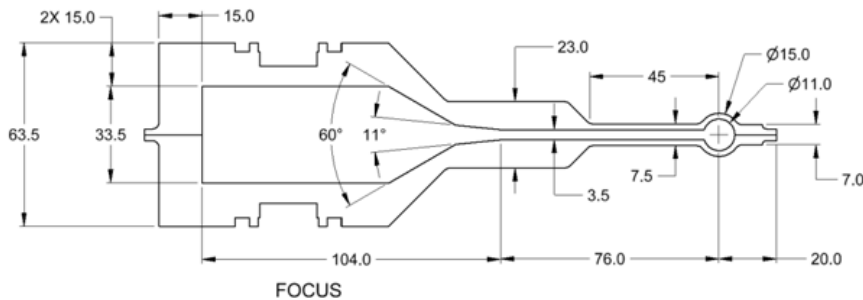
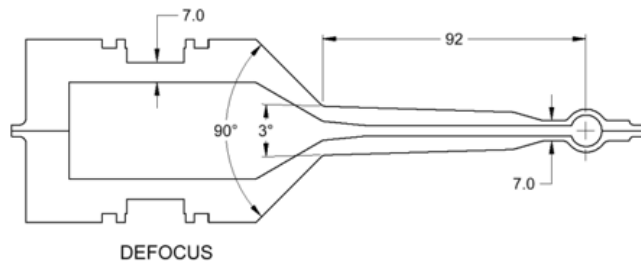


	Hybrid magnet	Halbach magnet
Pros	- Compact - Low sensitivity to PM errors - Low risk of PM demagnetization - Proven design	- Most compact - Unique design - Use less PM material - Linear (no saturation, no <u>cross-talk</u>)
Cons	- Use more PM material - Pole material saturation - <u>Cross-talk</u> between magnets - Limited field tuning	- High radiation damage risk - Sensitivity to PM errors - Field errors correction - Field tuning

Complex Bend Dimensions

Magnet aperture (16mm) puts beam very close to magnets

Thin wall (2mm) aluminum chamber provides little shielding



Permanent magnet sensitivity to radiation and temperature

Rare earth magnets are extensively used on light source insertion devices and with emerging PMQ designs for future machines.

Demagnetization of Nd-Fe-B magnets used for insertion devices have led to ID failures being observed at APS.

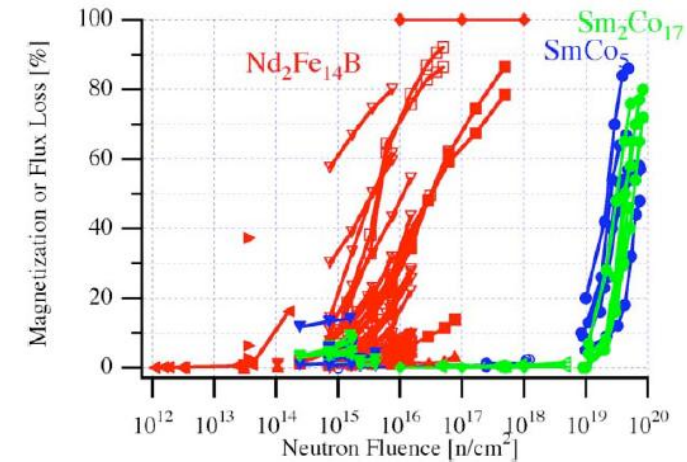
Radiation damage of rare earth magnets, both Nd-Fe-B and Sm-Co, have been studied and measured at numerous facilities under various conditions using a variety of radiation sources and energies.

Results show:

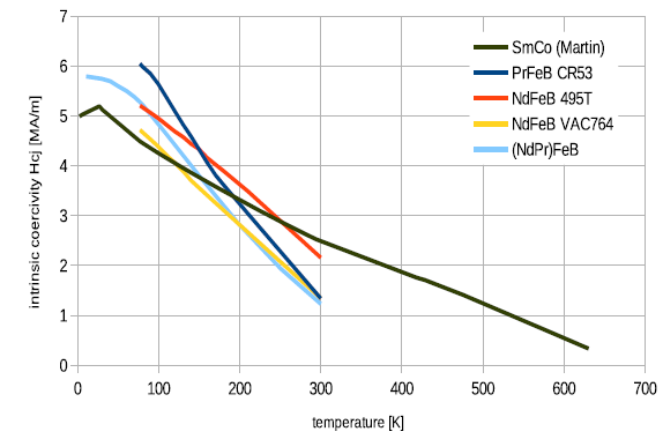
Sm-Co is more radiation resistant than Nd-Fe-B, even when Coercivity is the same. (Sm-Co likely benefits from a higher Curie temperature and superior thermal properties).

The type and energy of radiation may also play a role in radiation damage.

The PMQ technology expected for NSLSIIU needs to be validated for this criteria. The IFE instrument will be used for this radiation testing.



Remanence loss as a function of neutron fluence
Courtesy: X.-M Marechal, Proceedings of EPAC 2006



SmCo higher intrinsic coercivity
Courtesy: B. Shepherd, CLIC note 1079

NSLSII IFE (Instrumentation Front End)

Principal Investigator: Sushil Sharma

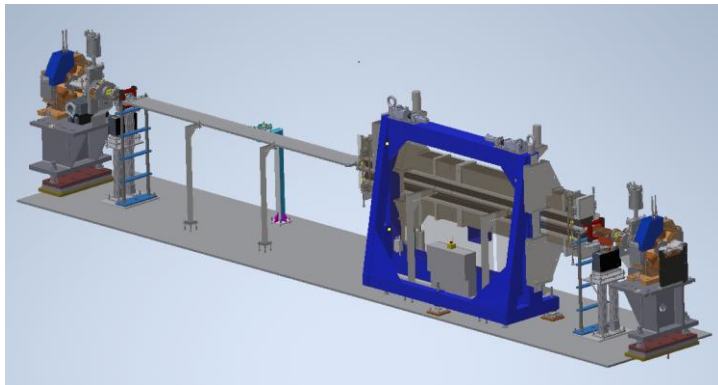
Dedicated to the study of accelerator materials and components

Open for collaboration with internal and external investigations

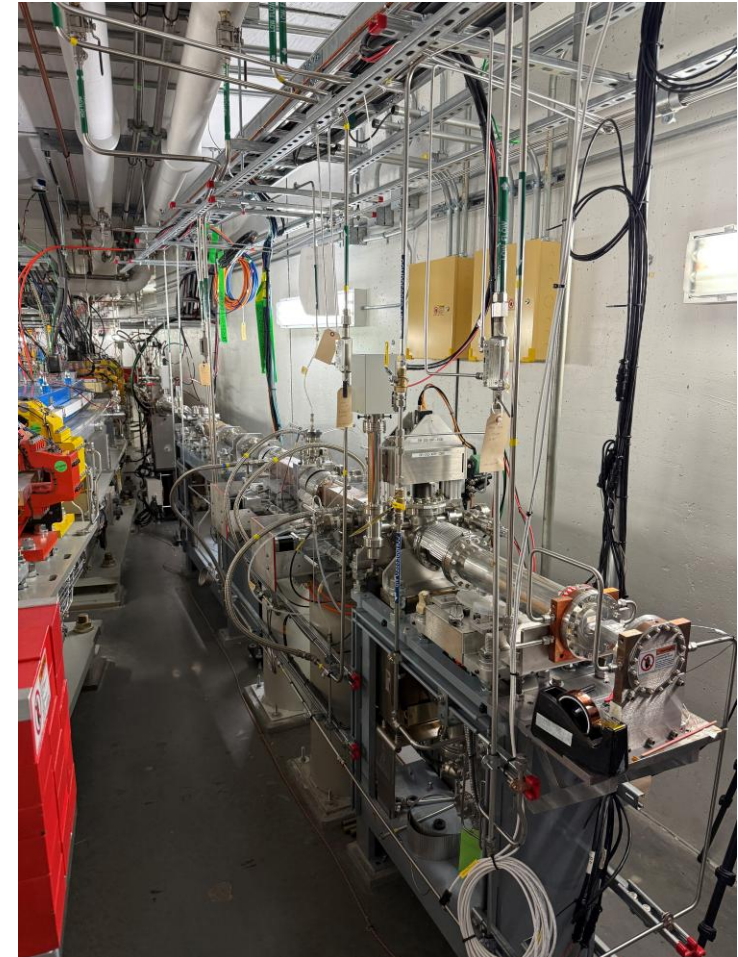
Commissioned in 2024

Source:

U68 Undulator: total radiation 5.1kW



National Synchrotron Light Source II

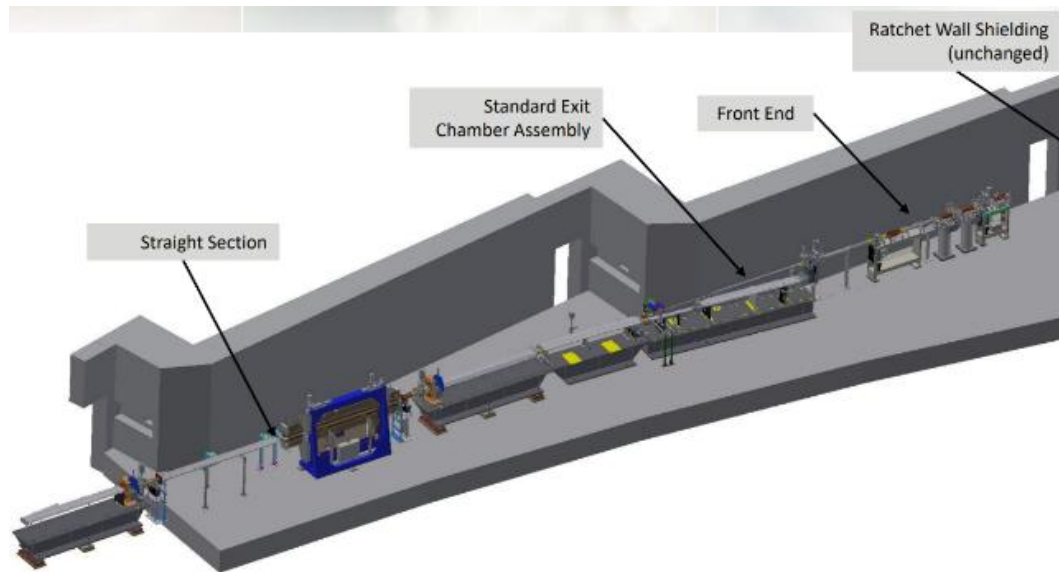


IFE Location

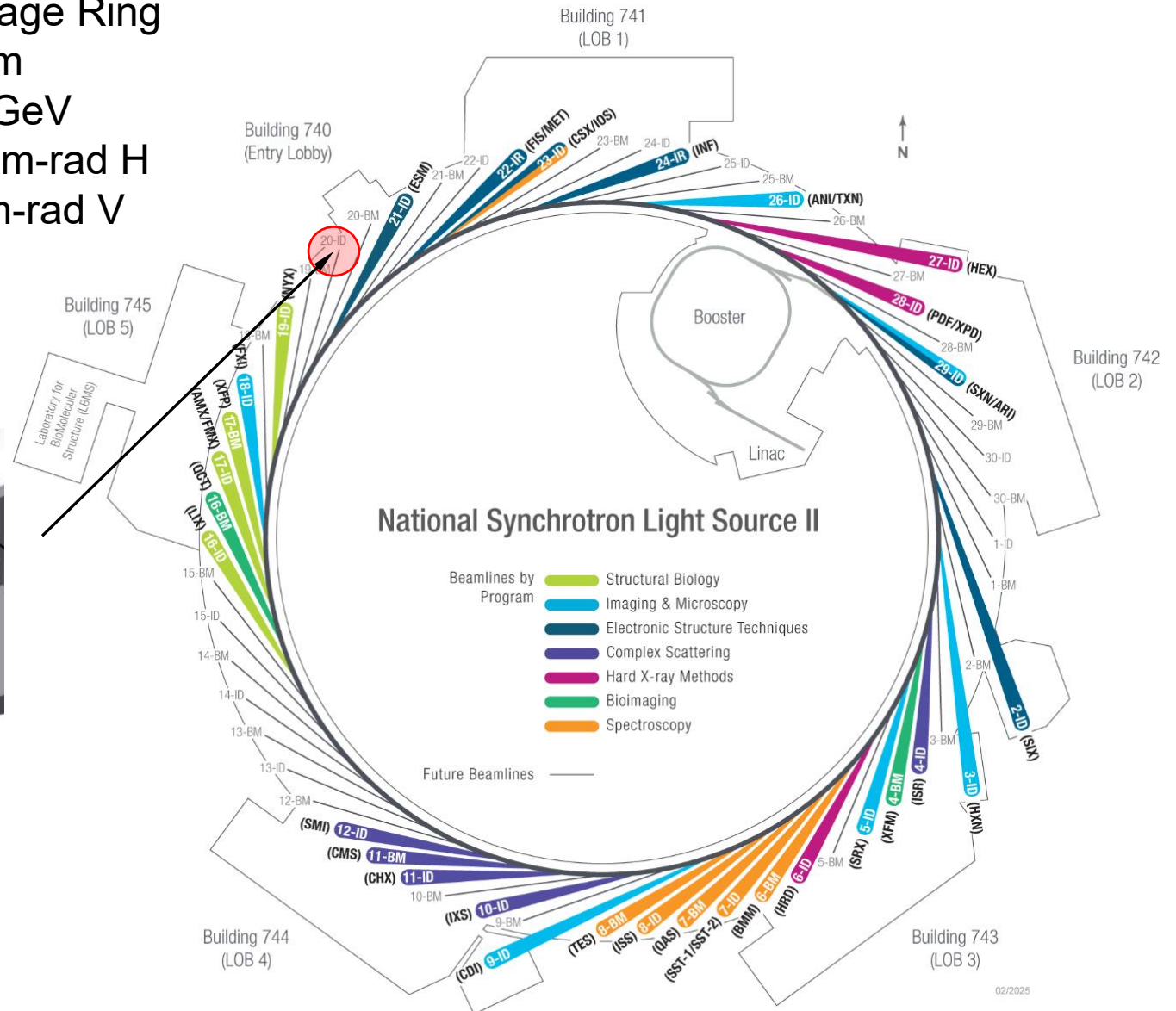
Convenient location in pendant 4

- Not closed for RF or injector studies
- No sources or FEs in the area

Storage Ring
792m
3.0 GeV
0.5nm-rad H
8 pm-rad V



National Synchrotron Light Source II



U68 Source

Original manufacturer Danfysik

BNL inherited from Wisconsin SRC
(Synchrotron Radiation Center)

20 years in LS operation. Last
light 2014

Significant upgrades:

Drive train

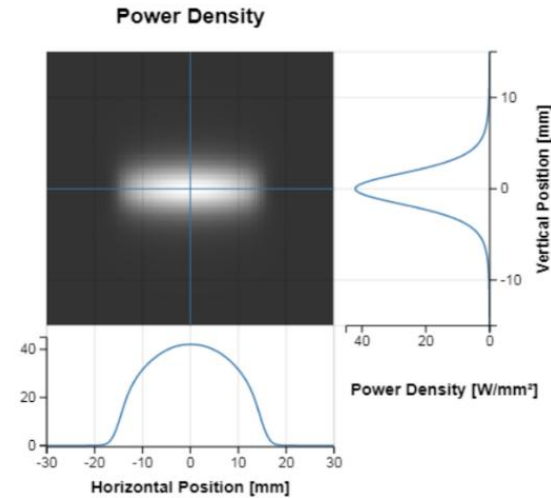
Added field correction (magic
fingers and window frame
correctors)

Position switches

Kinematic floor plates

Safety guards

Control system



Beamline	IFE
Type	IVU
Source	U68 Undulator
Device envelope length	3.52 m
Magnetic Length	3.50 m
Canted	N/A
Canting angle	N/A
Magnetic Period	68 mm
# of Periods	51
Nominal (minimum) gap *	23.93mm
Peak field: nominal (maximum)	0.719 T nominal
Keff: nominal (maximum)	4.567
Energy Range: nominal (minimum)	110 eV – 1800 eV
Total Radiation Power	5.1 kW
Spatial Power Density (at 20m from the source)	42 W/mm ²
Angular Power Density	16.05 kW/mr ²
Location	20-ID (long, high beta)
Device center ^{*2}	1890.725 mm d/s of straight center
Fan angle ^{*1} (mrad H): nominal / maximum	2.0 / 2.7
Fan angle ^{*1} (mrad V): nominal / maximum	0.83 / 1.32



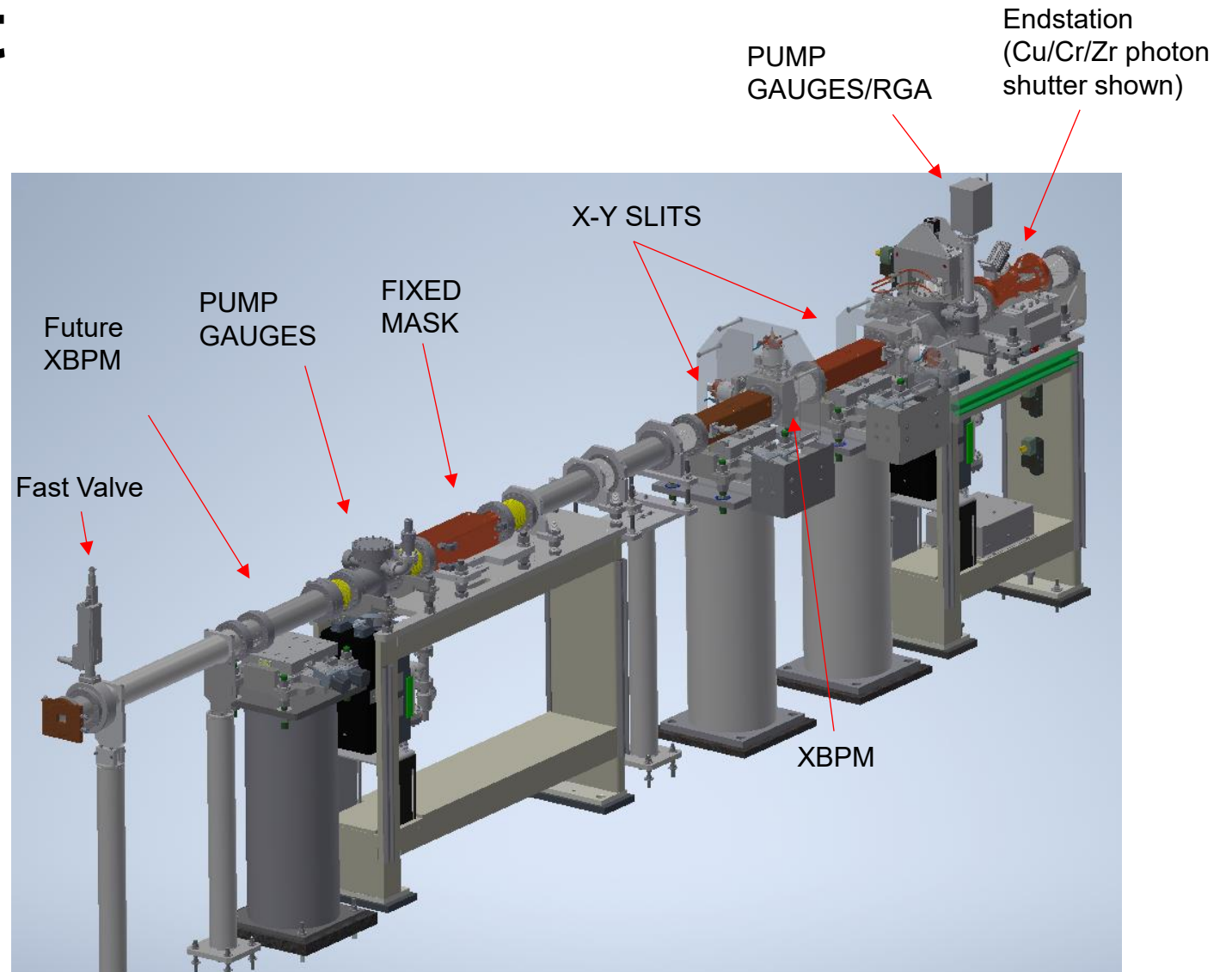
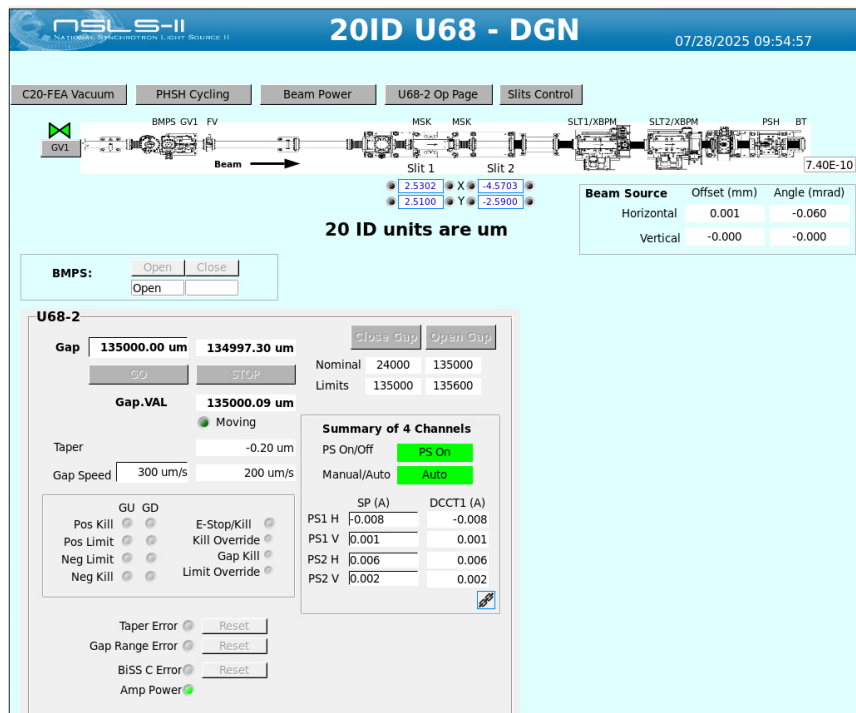
U68 Installed at SRC



U68 Installed at NSLSII

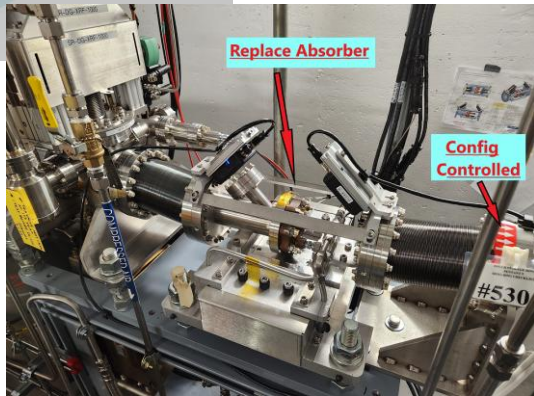
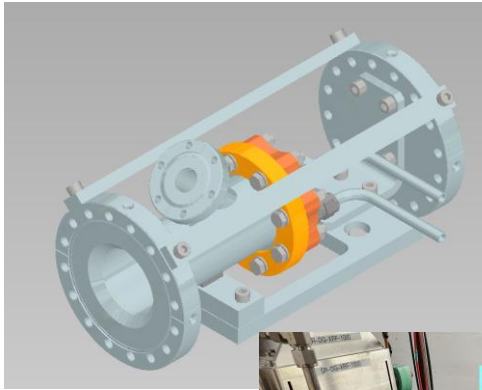
IFE General Layout

Max power delivered to
endstation: 1697W

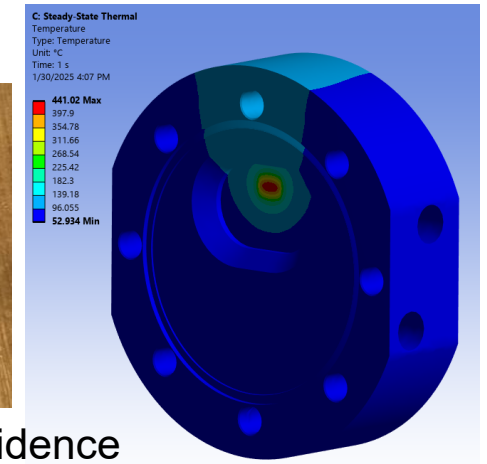


Recent Testing of Absorbers

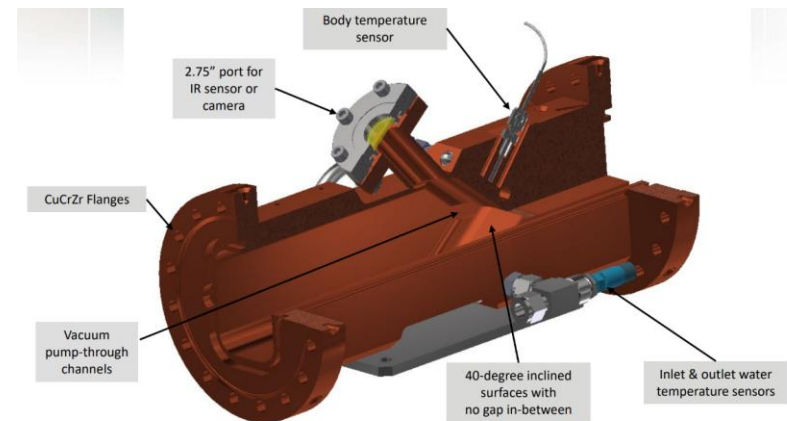
* Results to be presented: S. Sharma, MEDSI '25, Lund Sweden



2 Soleil 3D printed CuCrZr abs



High temp CuCrZr normal incidence
test thermal fatigue life at approximately 450°C



Note: This device functions as the synchrotron beam stop (EPS)

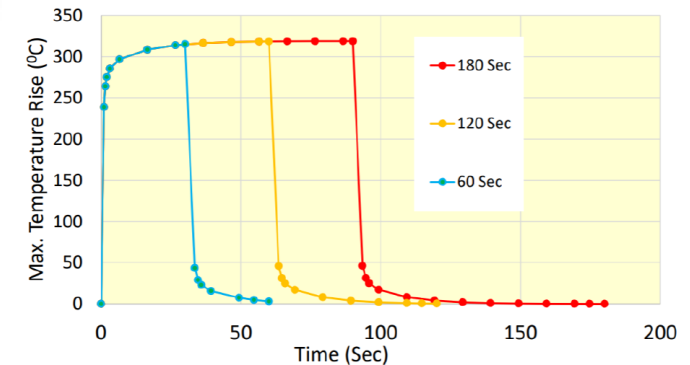
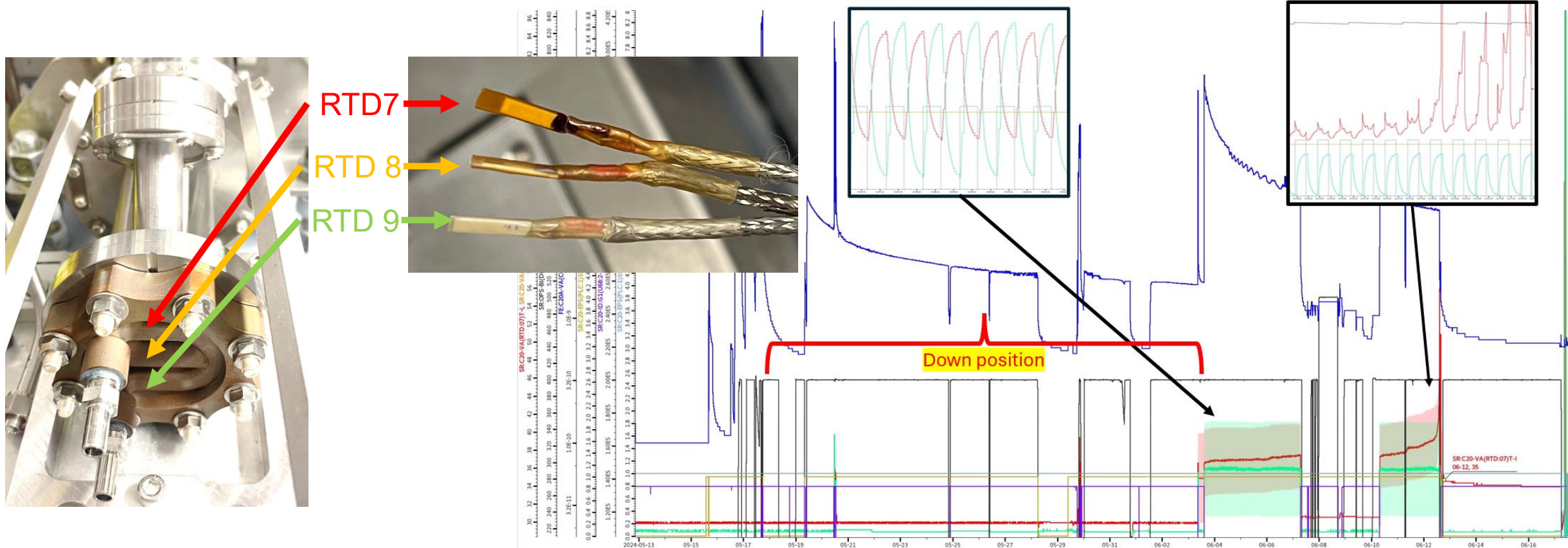


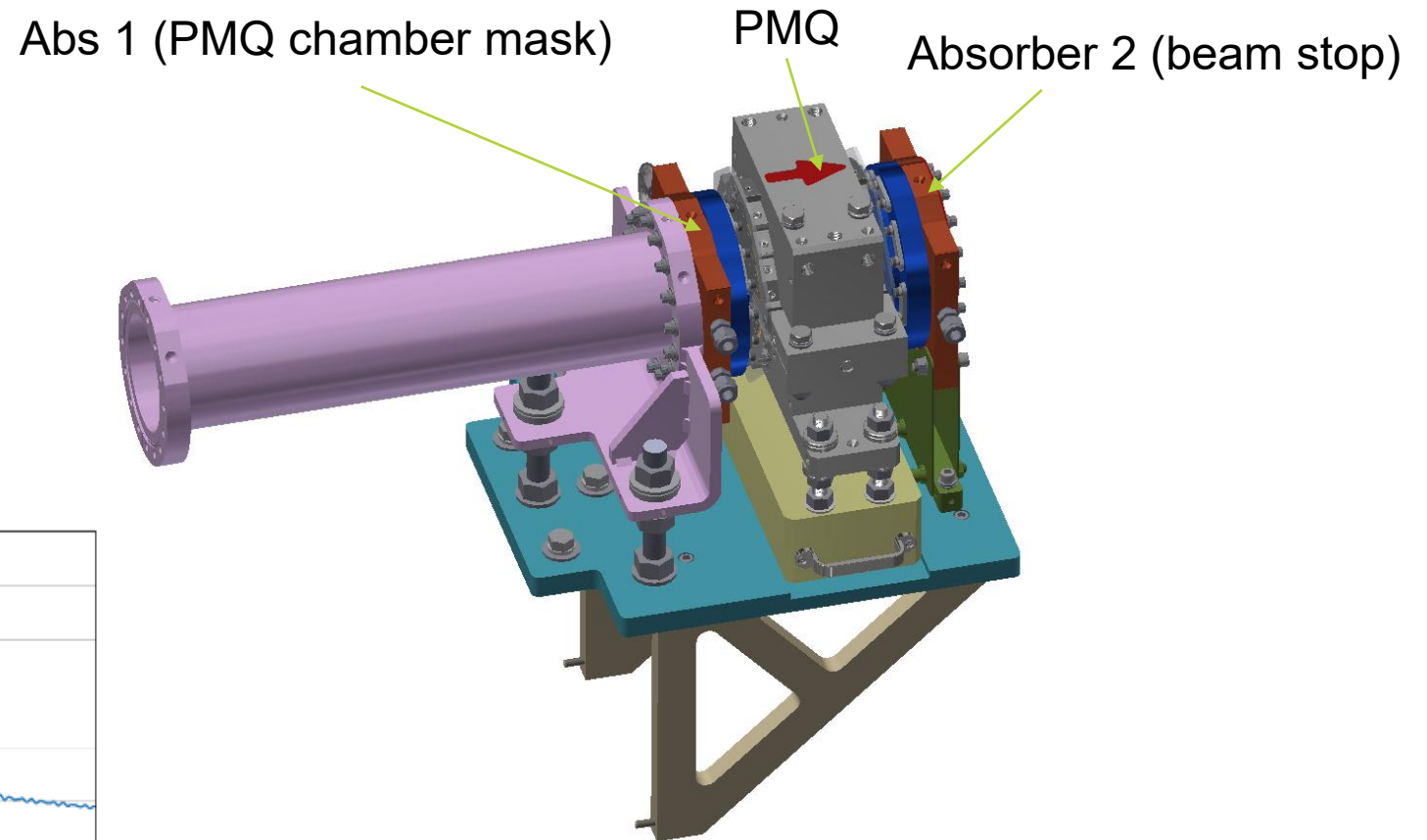
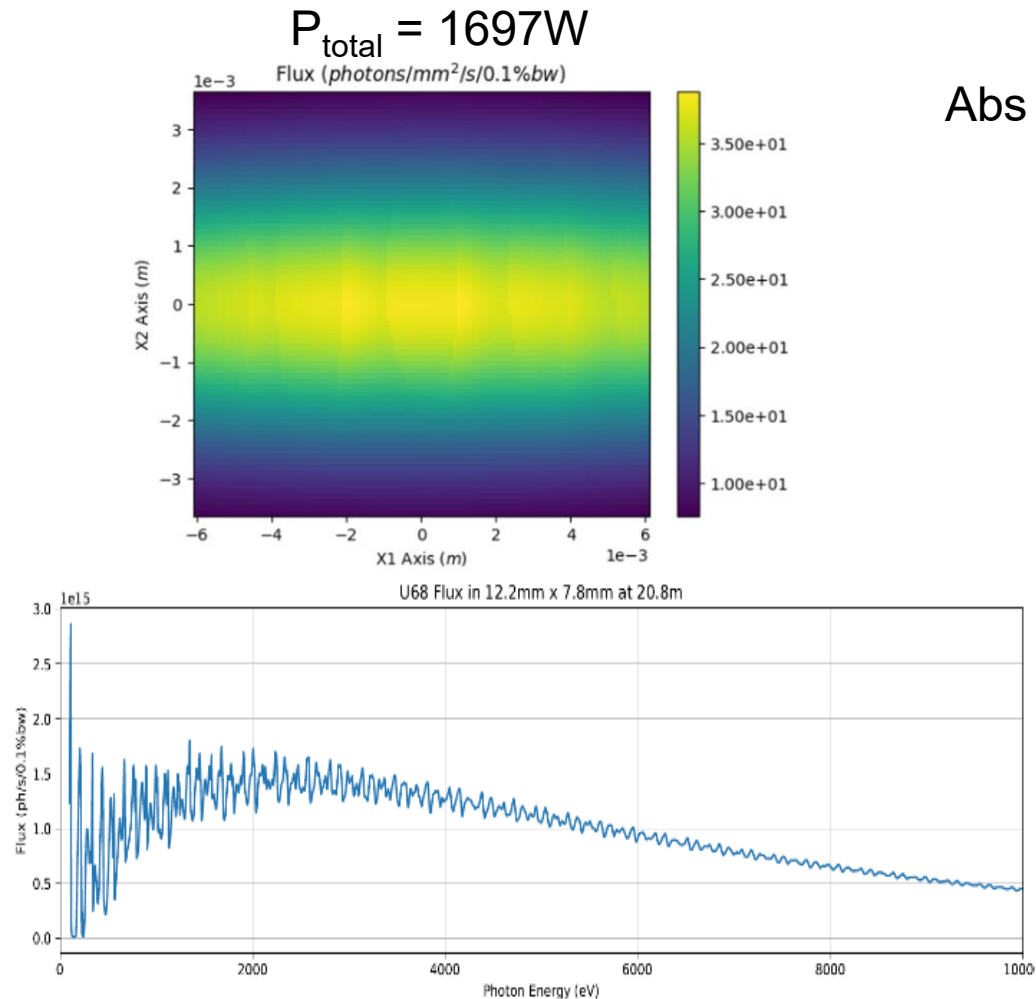
Figure 3: Photon Shutter Thermal Response Cycle at 400 mA

CuCrZr material (40° incidence): Confirm design criteria of 300°C

Radiation damage to an RTD at IFE placed at beam center with ID gap open, exposed for a short duration only to BM!



PMQ Radiation Test Configuration



Radiation striking PMQ assembly

Incident power:

ABS1 (565 W)

ABS2 (1132 W)

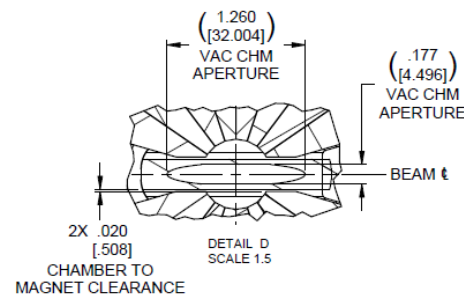
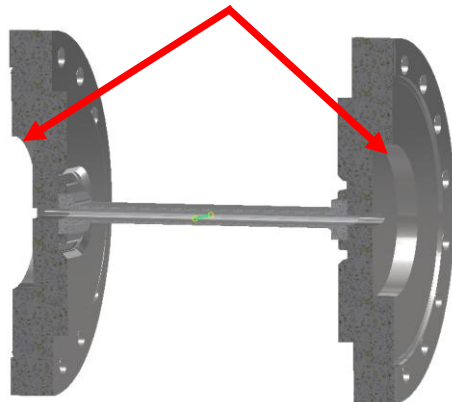
Aluminum vacuum chamber:

Thin wall (1mm top and bottom)

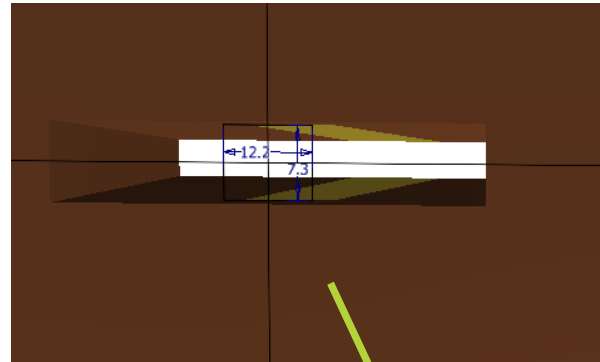
0.5mm clearance to PMQ

No direct light strikes vacuum chamber walls

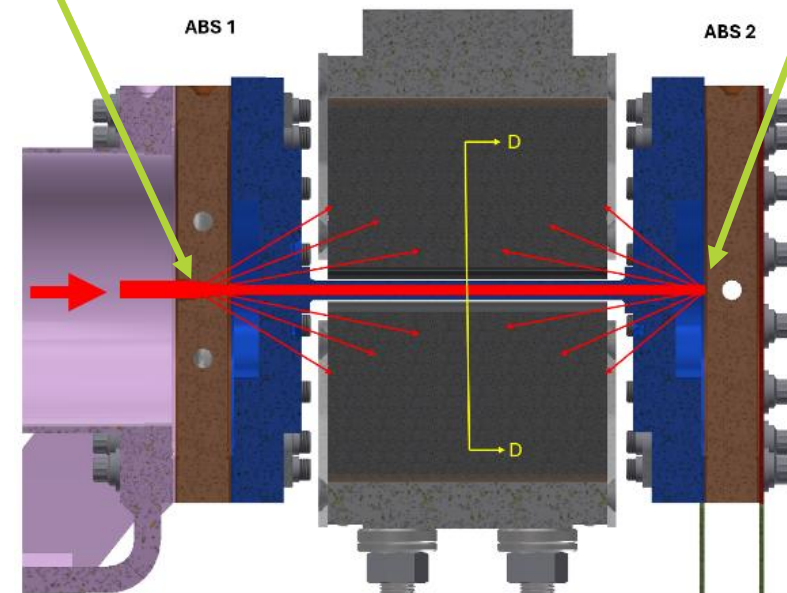
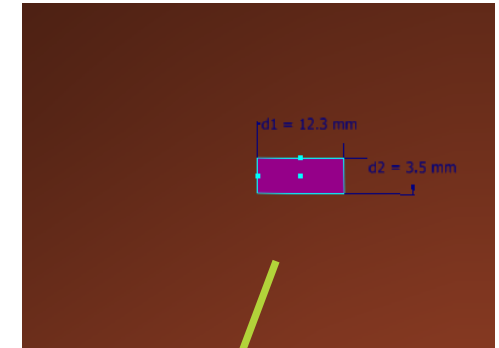
Stainless steel material removed from bi-metallic flanges to prevent shielding of cosine distributed scattered light



ABS 1
12.2mm wide x 7.3mm high on 7.34-degree inclined surfaces
(Subtracting aperture)



ABS 2
12.3mm wide x 3.5mm high at normal incidence



Dosimetry Options

The anticipated source of radiation is some smaller fraction of GB (Gas Bremsstrahlung), and a more significant dose of scattered SR (synchrotron radiation) of <100keV energies.

Two options (usable for 100-150KGy) considered:

1) Alanine dosimeters (4.2mm disc/vial)

Alanine selected for SIRIUS investigation. (F. N. Moura)

*Insufficient room between PMQ and chamber.

*indeterminate for X-ray application below 200keV.

2) Film type dosimetry (advantage: fits between vacuum chamber and PMQ)

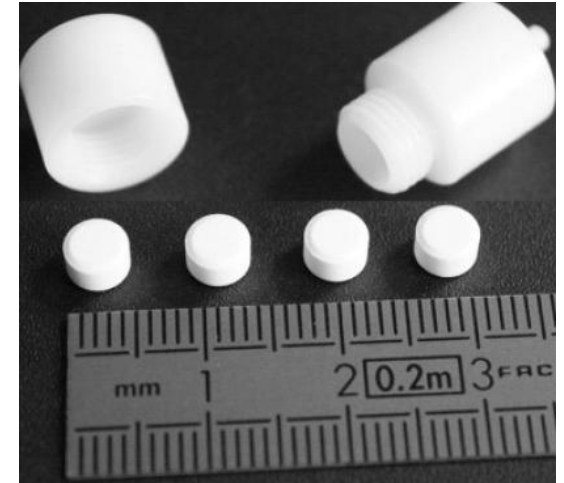
Two types investigated:

FWT Radiochromic film from Far West Technology

Gafchromic HD-V2 film from Ashland

Gafchromic film: capped at 1000Gy with a high energy range of >100keV.

FWT film: range up to 200kGy with broader energy range; lower than 80keV up to 25MeV.



Film Sensitivity to Temp and Humidity



Pergamon

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TEMPERATURE, HUMIDITY AND TIME. COMBINED EFFECTS ON RADIOCHROMIC FILM DOSIMETERS

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(Received 15 February 1995)

Abstract—The effects of both relative humidity and temperature during irradiation on the dose response of FWT-60-00 and Risø B3 radiochromic film dosimeters have been investigated in the relative humidity (RH) range 11–94% and temperature range 20–60°C for irradiation by ⁶⁰Co photons and 10-MeV electrons. The results show that humidity and temperature cannot be treated as independent variables, rather there appears to be interdependence between absorbed dose, temperature, and humidity. Dose rate does not seem to play a significant role. The dependence of temperature during irradiation is $+0.25 \pm 0.1\%$ per °C for the FWT-60-00 dosimeters and $+0.5 \pm 0.1\%$ per °C for Risø B3 dosimeters at temperatures between 20 and 50°C and at relative humidities between 20 and 53%. At extreme conditions both with respect to temperature and to humidity, the dosimeters show much stronger dependences. Whenever possible one should use dosimeters sealed in pouches under controlled intermediate humidity conditions (30–50%) or, if that is impractical, one should maintain conditions of calibration as close as possible to the conditions of use. Without that precaution, severe dosimetry errors may result.

*Storage Ring tunnel Temp and RH well controlled
Maintain film temperature 20-50°C and RH 20-53%

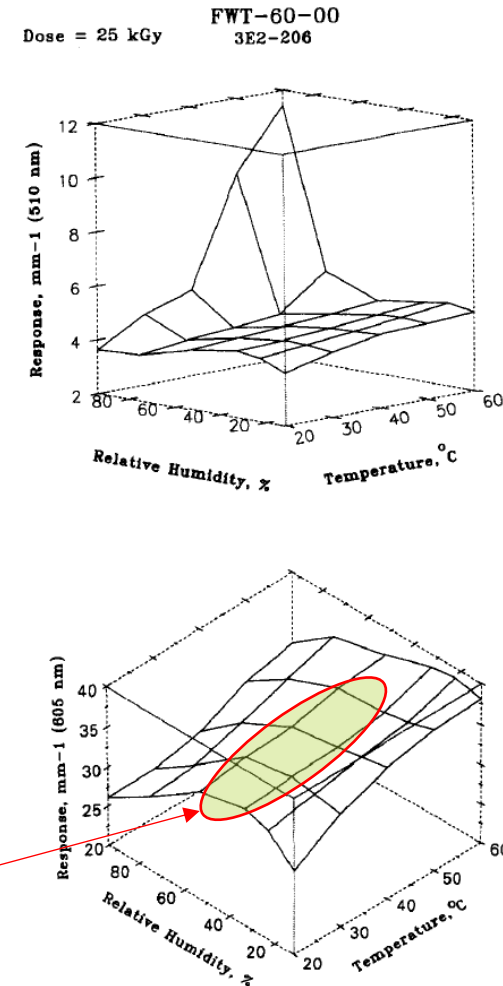


Fig. 4. Tridimensional diagram representing response of FWT-60-00 as a function of relative humidity and temperature during irradiation. Dose 25 kGy.

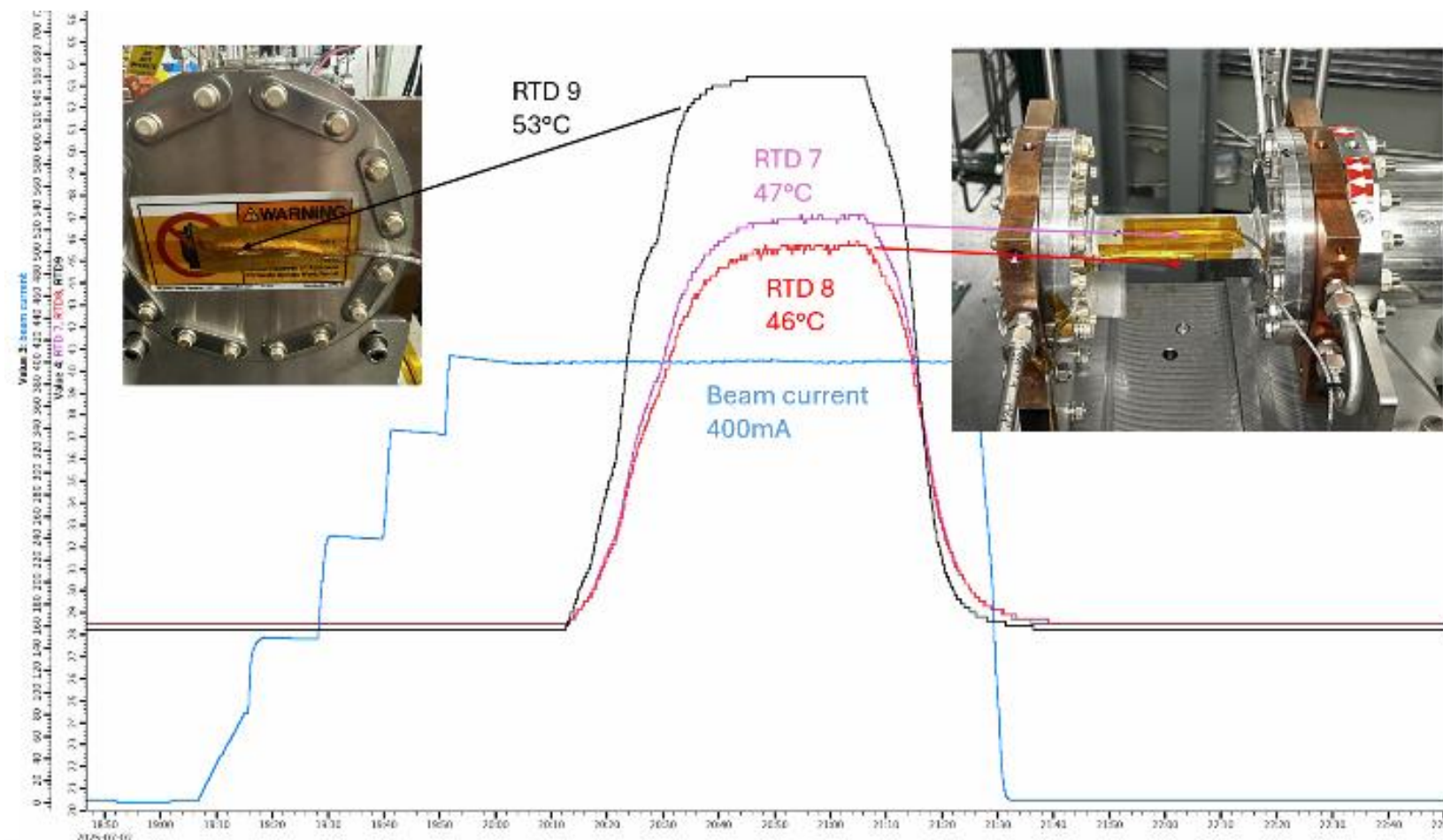
Temperature Testing

Initial temperature measurement of vacuum chamber:

47°C (@ 400mA)

Temperature expected to be higher at 500mA. This temperature is too high and film can't be placed directly on the vacuum chamber.

Also, with the PMQ installed, the temperature between the chamber and magnet will be higher due to the loss of free convection.



Radiation Testing Plan

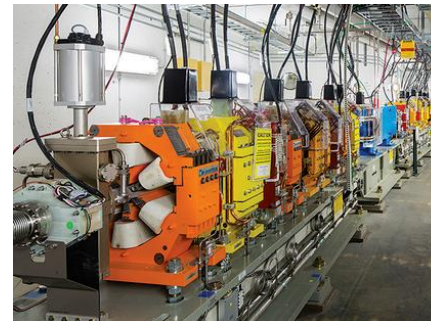
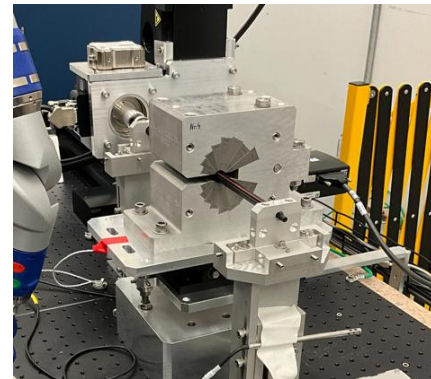
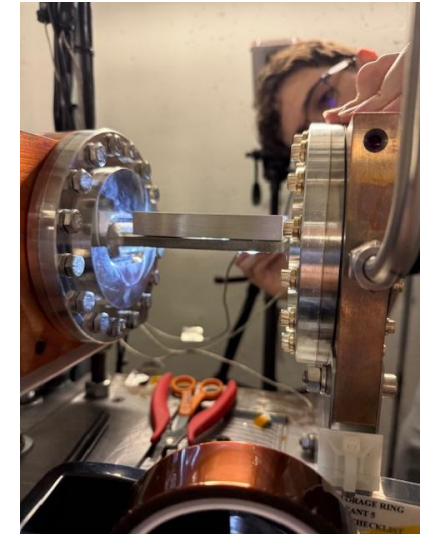
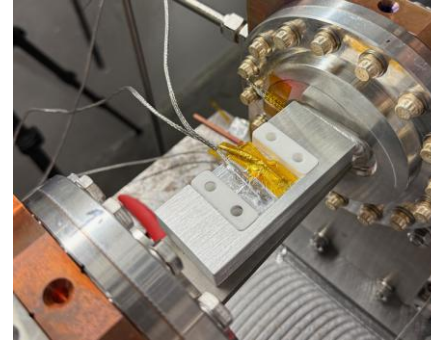
Dose rates will be measured without the PMQ installed.

Multiple films will be placed close to the chamber in a holder (pictured to the right). Each film can only be removed and measured once.

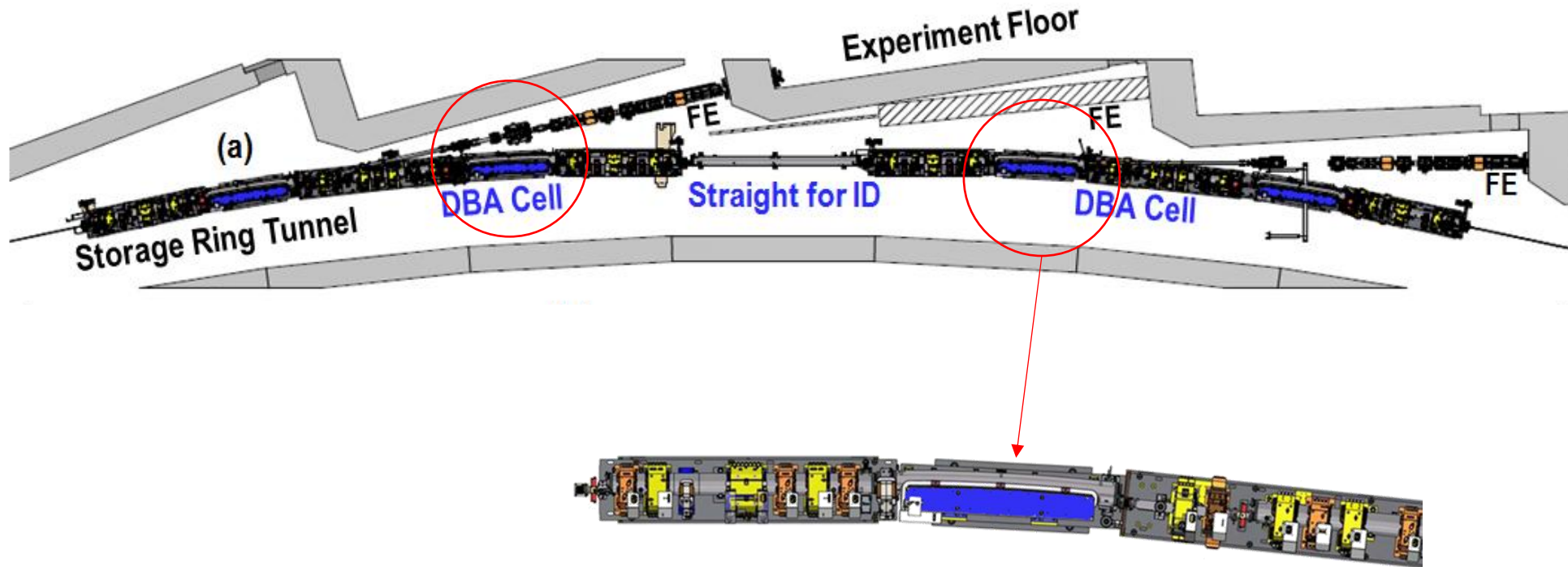
The dose rate will be accurately established as a function of machine current and will be extrapolated in time allowing integrated doses to be measured on the PMQ.

The PMQ will be installed and then periodically removed for magnetic measurements as a function of total dose. (rotating PCB coil shown to the right)

Part of the study will also include measuring dose at various locations in the storage ring. In particular, regions in close proximity to the electron beam channel, the RF region as well as the superconducting wiggler supplying very hard x-ray beams.



Future R&D: Install two full scale CB in storage ring bracketing a straight section.



~3m long / 6 deg radius

END. Thank you.

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Survey Group: R. Hubbard