

Design of a, J-PARC inspired, IR-Camera measurement for a rotating graphite target at HIPA

BRIDGE 2025

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Outline



- 1. Purpose, constraints and requirements
- 2. J-PARC infrared camera system
- 3. Thermal lab tests
- 4. HIMB Target H design
- 5. Summary and Outlook

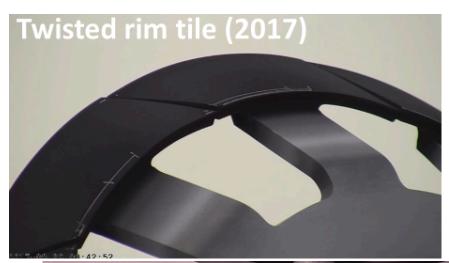


1. Purpose, constraints and requirements

Purpose

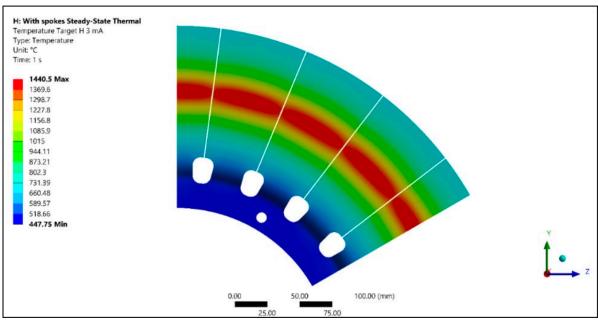


- 1. Monitoring of the target's integrity
 - Target E failures only seen during target exchange
- 2. Investigation of radiation damage and the loss of thermal conductivity
- 3. Validation of the numerical simulations





Maximum Temperature 1440.5°C



Simulation Target H for 3 mA 590 MeV proton beam

Constraints



CONSTRAINT	DEFINITION	
Vacuum compliance	Minimize the impact on the vacuum (limit openings and leakage points).	
Existing design limitations	Limit the impact on the existing shielding, and component layout/design.	
Thermal load	Account for potential power depositions.	
Radiation tolerance	Account for the radiation effect on surfaces and electronics.	
Target sublimation	get sublimation The target sublimates and can create graphite layers on surfaces.	
Target rotation	Use non-contact temperature measurement techniques.	

Requirements



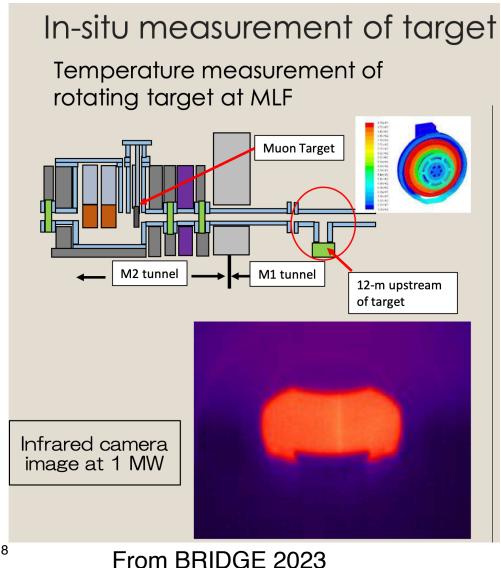
	Requirement	Value	
Infrared (IR) Camera System	Temperature range Camera must be capable of capturing temperatures over the expected thermal range during operation.	300 °C - 1700 °C	
	Temperature Accuracy The camera must provide a temperature accuracy of the true temperature.	± 5%	
	Spatial resolution Must have a minimum spatial resolution to accurately capture temperature gradients.	1 mm / pixel	
	Minimum frame rate Must provide a smooth monitoring of the rotating target.	> 24 Hz	
	Field of view Must cover the area of the target interacting with the beam.	100 mm diameter disk area centred on the beam/target impact point	
	Radiation hardening Electronics must be capable of operating under radiation exposure at service level.	Beam level: 10 kSv/h Service level: 1 Sv/h	
Ontical	Mirror material Must have high reflectance in the IR range and radiation compliant.	R _{IR} > 95 %	
Optical system	Lens material Must have high transmittance in the IR range and radiation compliant.	T _{IR} > 75 %	
Mechanical design	Maintenance Stable, adjustable, and maintenance-friendly mounts		
Data system	Data acquisition Real-time data streaming. No integration with safety system		



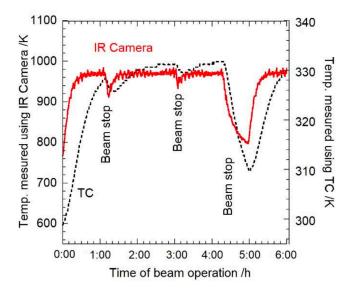
2. J-PARC Infrared Camera System

J-PARC

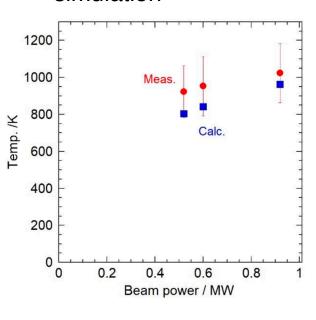




Fast response of camera compared to thermocouple



Good agreement with simulation



S. Matoba, N. Kawamura, S. Makimura,

https://iopscience.iop.org/article/10.1088/1742-6596/2462/1/012031

S. Makimura and S. Matoba, BRIDGE Workshop 2023 https://indico.psi.ch/event/14832/contributions/44589/attachments/26163/48607/ Struggle target.pdf

[&]quot;Development of monitoring system for the muon rotating target at J-PARC using an infrared camera"

Main Parameters - Optical system



	Brand	ULVVIPS-04171SL, Vision Sensing
Infrared camera	Shielding	boron-containing polyethylene blocks and lead bloc
	Spatial resolution	2.5 mm
	Lens material	Germanium
	Focal length	150 mm
	Resolution	640 x 480
	Accumulated admissible dose	5 Gy (Cobalt-60 tests)
	Operating time	30% due to SEUs
	Transmission rate	10 frames per second
Mirror	Material	gold-deposited mirror on a stainless-steel substrate
	Location	11 m upstream of the target in the proton beam duct at an angle of 45° to the beam axis at 141 mm from the beam center
Vacuum window	Material	ZnSe



3. Thermal Lab Tests

Components



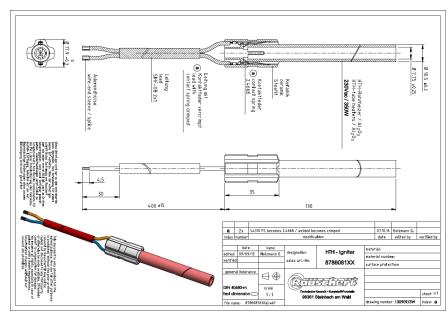


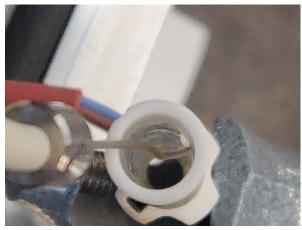


PFE20-M01 - 2" Protected Gold Elliptical Mirror, H45E2 - 45° Mount for 2" Elliptical Optics





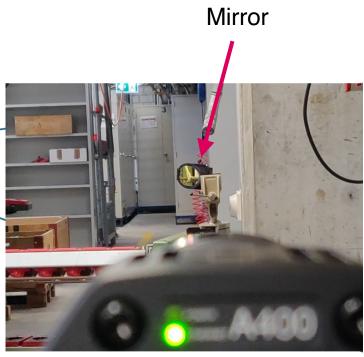




Setup

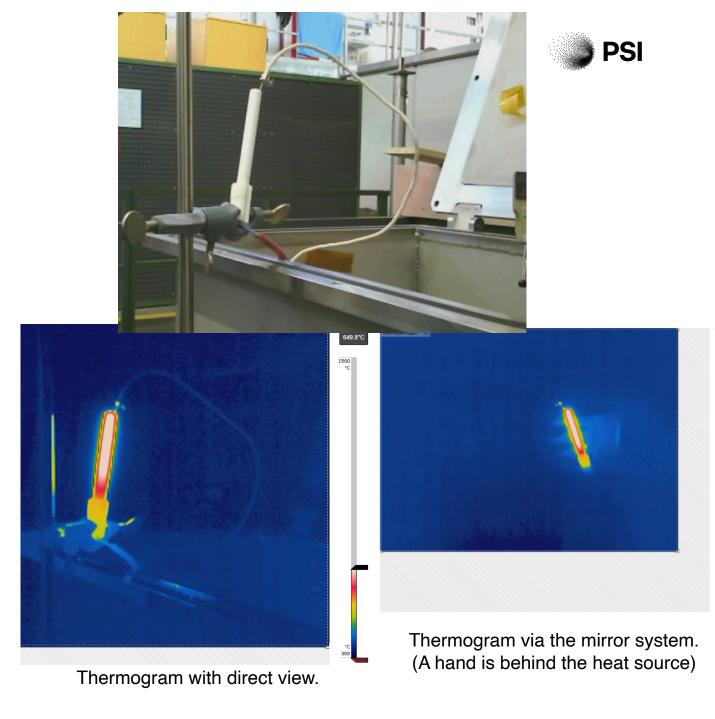






Results

- Probe from Alumina with a thermocouple heated up to 650 degrees
- Temperature measured through mirror shows error below 2%
- Spatial resolution of 1.76 mm / pixel allows to capture features of muon target
- Camera reading corrected with emissivity of probe
- Conclusion:
 System feasible for muon target H



Requirements



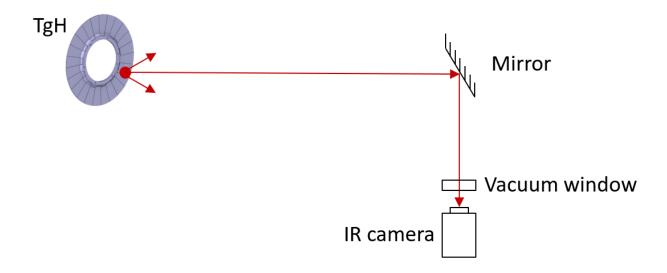
	Requirement	Value	FLIR A400 + 6°
Infrared (IR) Camera System	Temperature range Camera must be capable of capturing temperatures over the expected thermal range during operation.	300 °C - 1700 °C	300-1500 °C
	Temperature Accuracy The camera must provide a temperature accuracy of the true temperature.	± 5%	± 2%
	Spatial resolution Must have a minimum spatial resolution to accurately capture temperature gradients.	1 mm / pixel	1.76 mm / pixel @5m distance
	Minimum frame rate Must provide a smooth monitoring of the rotating target.	> 24 Hz	30 Hz
	Field of view Must cover the area of the target interacting with the beam.	100 mm diameter disk area centred on the beam / target impact point	About 150 mm
	Radiation hardening Electronics must be capable of operating under radiation exposure at service level.	Beam level: 10 kSv/h Service level: 1 Sv/h	Not radiation hard
Optical system	Mirror material Must have high reflectance in the IR range and radiation compliant.	R _{IR} > 95 %	Gold coated R _{IR} = 96%
	Lens material Must have high transmittance in the IR range and radiation compliant.	T _{IR} > 75 %	Integrated to the camera



4. HIMB design

Concept - Measurement





General: $T_{apparent} = \epsilon * T_{surface} + (1-\epsilon) * T_{reflected/passed}$

$$T_{\text{measured, IR Camera}} = \\ \epsilon_{\text{window}} * T_{\text{window}} + (1 - \epsilon_{\text{window}}) * (\epsilon_{\text{mirror}} * T_{\text{mirror}} + (1 - \epsilon_{\text{mirror}}) * (\epsilon_{\text{target}} * T_{\text{target}} + (1 - \epsilon_{\text{target}}) * T_{\text{target chamber}})))$$

Ideal case: $\varepsilon_{target} \sim 1 \ \varepsilon_{mirror} = 0 \ \varepsilon_{window} = 0$

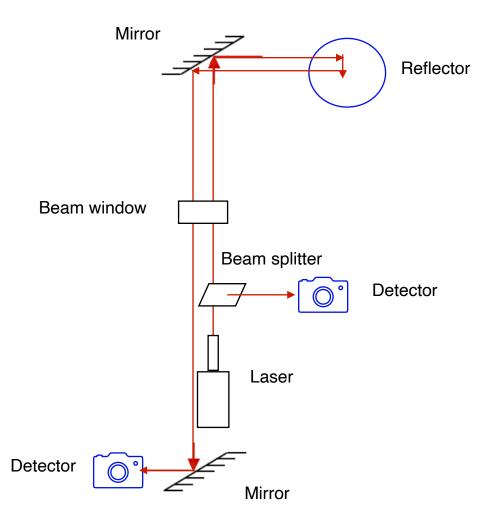
 $T_{measured, IR Camera} = T_{target}$

Emittances can be calibrated in advance, but

Worry: Emirror might change over time: graphite deposition, radiation damage

Concept - Mirror reflectivity measurement

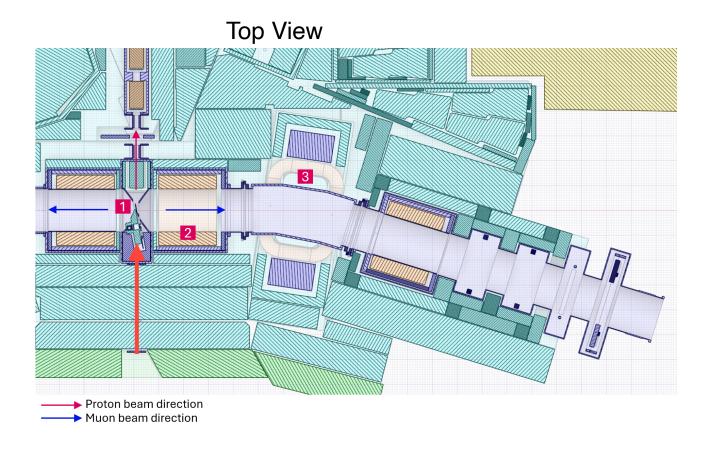




- Calibration of mirror reflectivity with laser on service level
- Ratio of the laser intensity at 2 detectors will determine mirror reflectivity
 - 1 for direct path
 - 1 for path reflected by mirror

Location



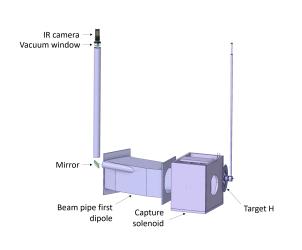


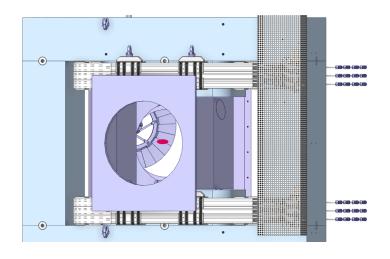
Location	Advantages	Drawbacks
1 – Target Station	Proximity to the target (easy to collect light)	 Very limited space High radiation levels at both service and beam levels Power deposition in the forward direction Limited field of view via the proton beamline (small apertures of both protection collimator and KHHO) Highest concentration of sublimated graphite
2 – Capture solenoid	Clear view of the target tiles	 Possible graphite deposition Critical component for HIMB Adding another function complexifies an already challenging component
3 – 1 st Dipole	Clear view of the target tiles Available space Less graphite deposition	- Far from the target (4m)

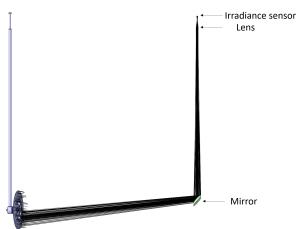
ANSYS simulations

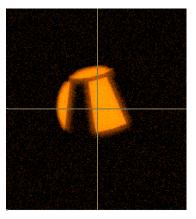


Simulations with ANSYS SPEOS confirm feasibility







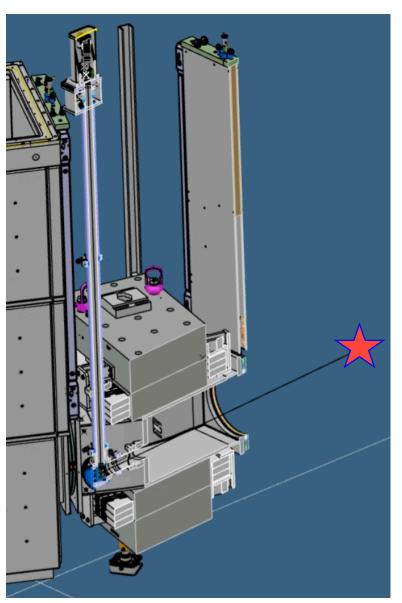


CAD Design - Overview

) PSI

Camera

Cut out view from side



Target

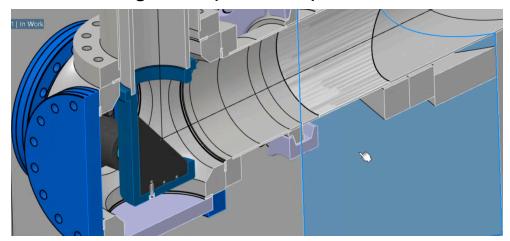
Mirror

CAD design - Mirror - beam level

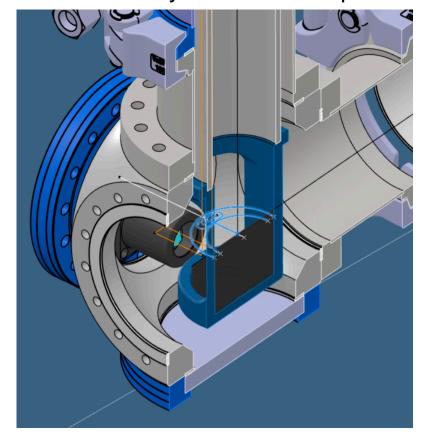


- Mirror can be rotated
 - Alignment adjustment
- 3 positions:
 - 1. Target temperature
 - 2. Mirror reflectivity
 - 3. Parking position (mirror turned away from target, not shown)

Target temperature position

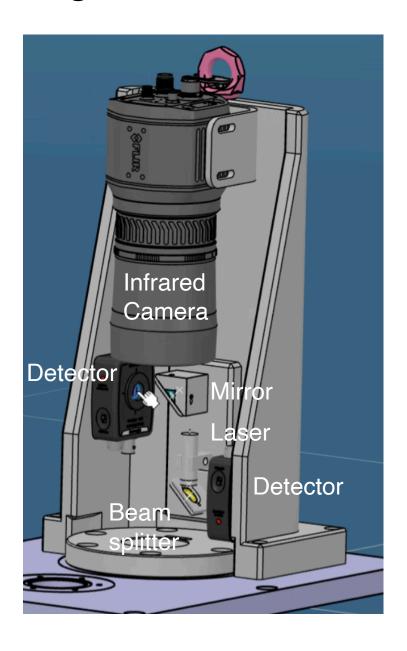


Mirror reflectivity measurement position

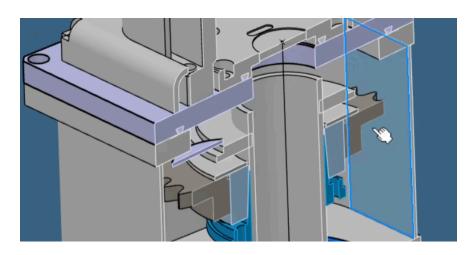


CAD design - IR Camera - service level





- Single piece with 4 screws for easy and quick dismounting at service level
- Mirror rotation from top
 - Mirror can be pulled out from top
- Camera shielding foreseen



Mirror rotation drive (ongoing design)

Components



Alignment laser:

100 mW – 635 nm - 3.5 mm diameter – divergence < 1 mrad TTL-Modulation bis 10 kHz https://www.edmundoptics.de/p/100mw-635nm-alignment-laser-diode/46627/



Diameter 9.8 mm. https://www.thorlabs.com/thorproduct.cfm?partnumber=DET100A2

Beam splitter:

10:90 400 - 700 nm > 0.5" diameter optimised for 45° https://www.thorlabs.com/thorproduct.cfm?partnumber=BSN04

Reflector:

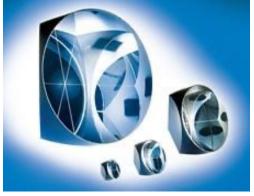
Fused Silica https://www.edmundoptics.de/f/uv-fused-silica-corner-cube-retroreflectors/ 13435/

Vacuum window: ZnSe beam window











5. Summary and Outlook

Conclusions



- Need for online temperature measurement of graphite target
- J-PARC work provided inspiration and motivation: ありがとう ございま!
- Initial lab tests successful
- Presented IR-camera design for HIMB
 - Maintainable system
 - Only reflector cannot be replaced
 - Not meant for continuous measurement
 - Parking position and mirror calibration for longevity
 - First measurements planned in 2028

(our) Questions?



- Camera: Radiation-hard or cheap? suggestion?
- How can thermal conductivity measurement be done best?
- Operational experience?
 - Broken parts / maintenance?
- Future plans?

Comments / Questions?





Backup

Zn-Se window transmission



