QSK (CXRS on NBI) - Detailed Design Review OP2

(Ladungsaustauschspektroskopie am Neutralheizstrahl)

DDR 28.01.2020

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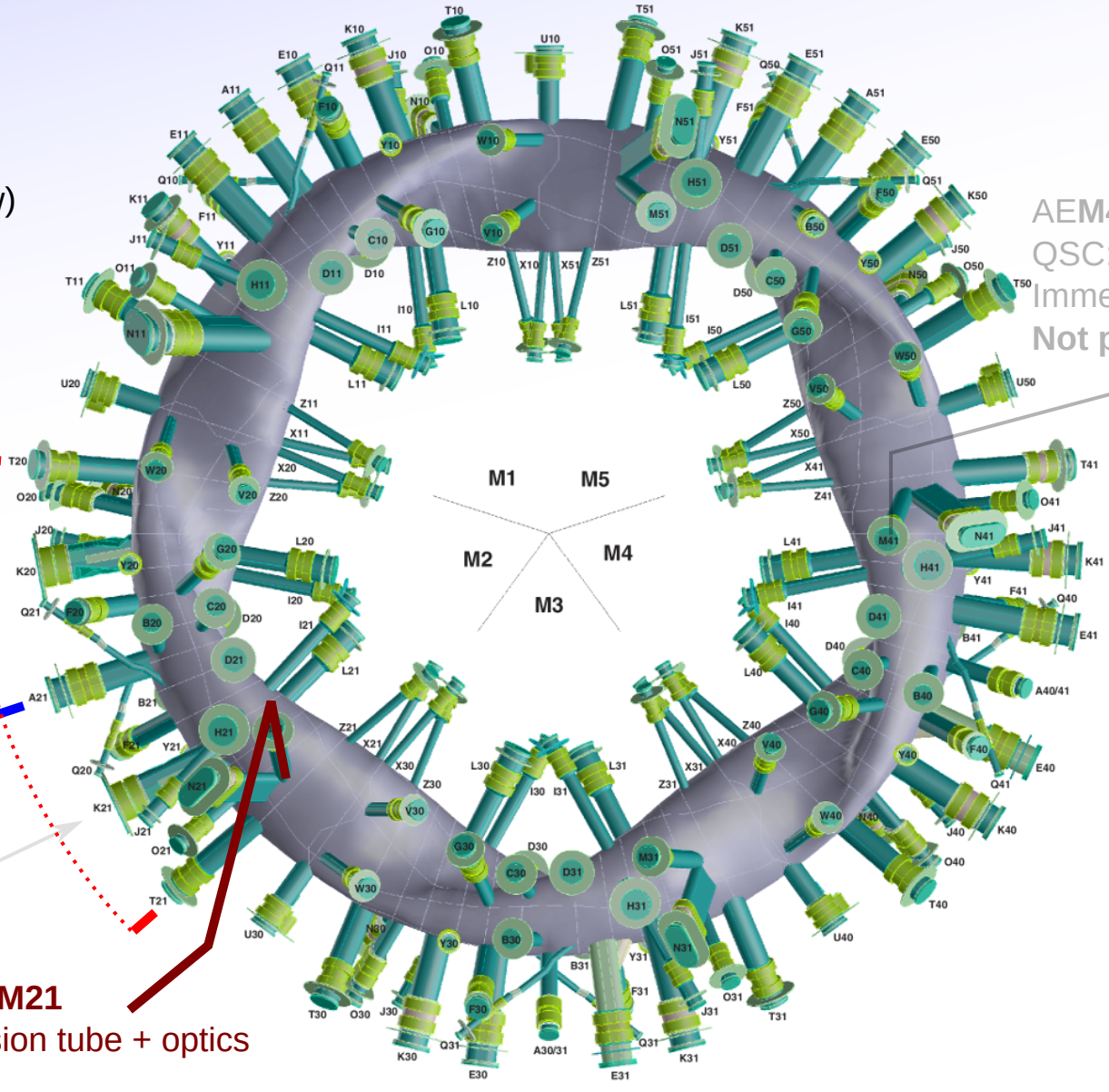
Component Overview

Outline:
1) AEM21: - Port protection
- Immersion Tube
2) AEA21: - Front plate
- Immersion tube
- Lower tube (new)
3) AET21: - Fibres
4) Documentation etc.



K3: AE**T20/21**
Immersion tubes + optics
(In QYB/P0008)

NI20

K1: AE**A21**
Immersion tube
+ optics

NI21

K2: AE**M21**
Immersion tube + optics

AE**M41**
QSC: CXRS am RuDIX
Immersion tube
Not part of QSK!

RuDIX

AE**K41**
K6: Passive
CXRS

K4: Fibre optic transfer to lab.
K5: Spectrometers and components in lab

Complete in OP1.2b, no changes for OP2 - not covered in this CDR!

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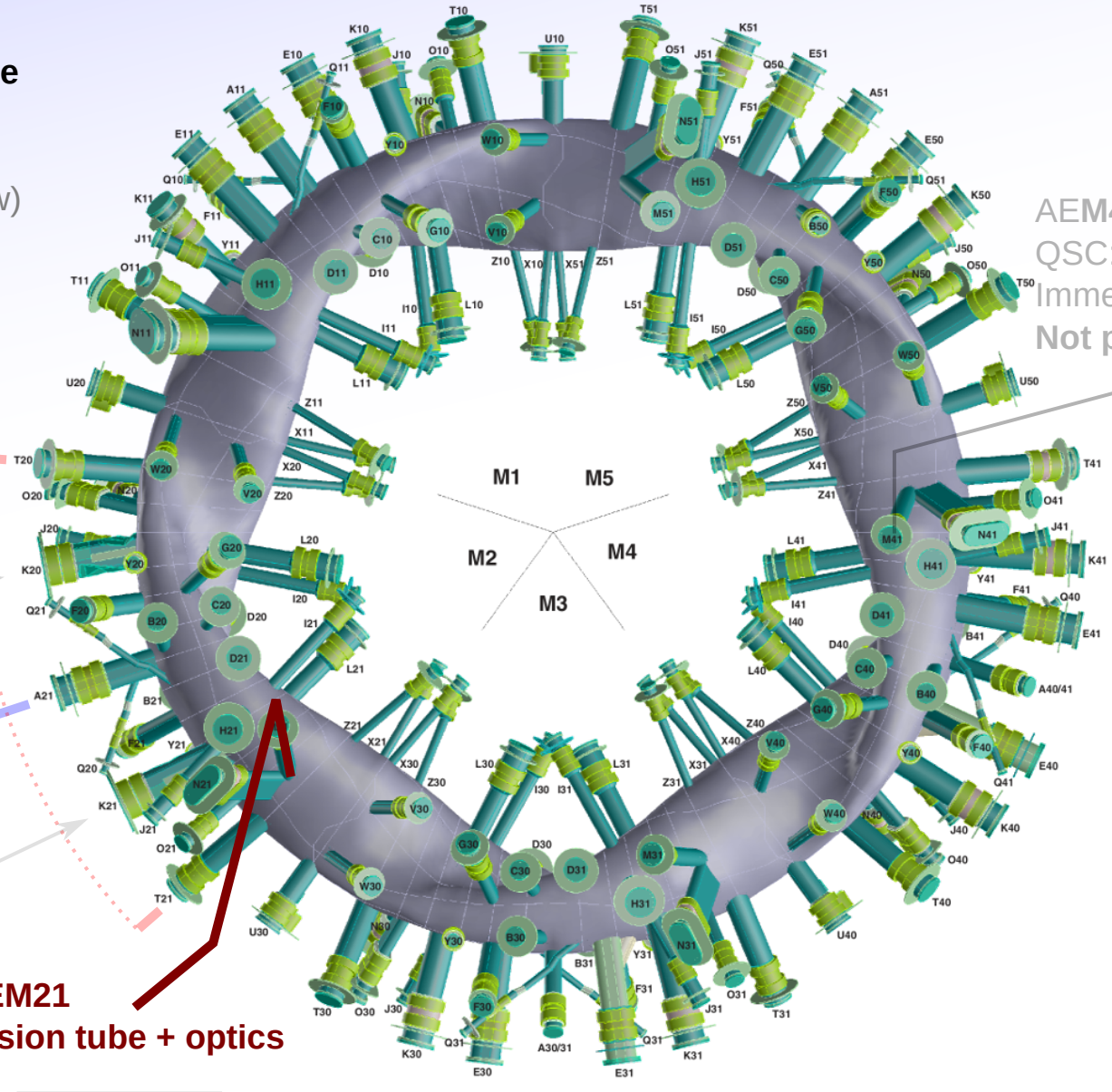

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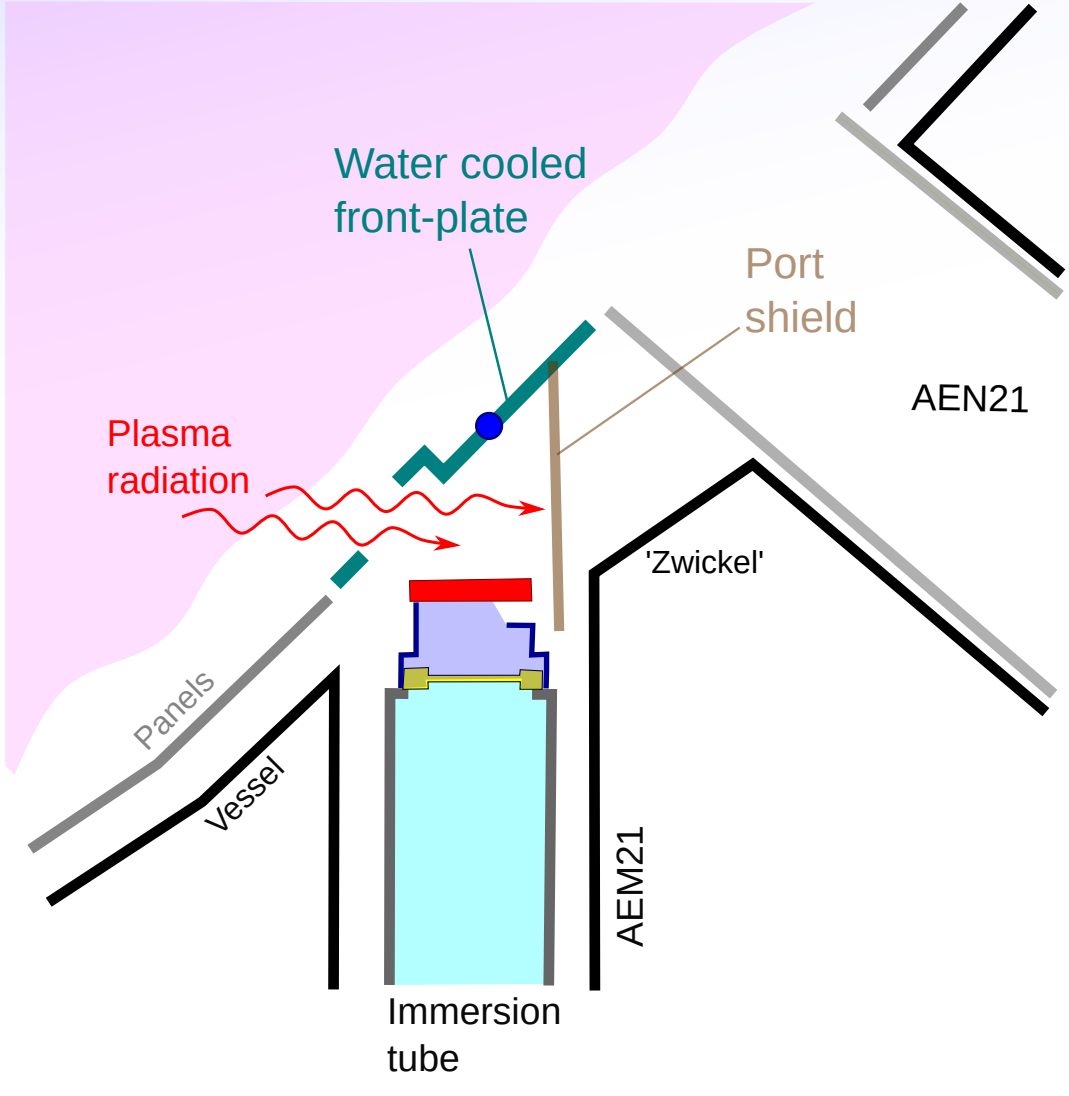
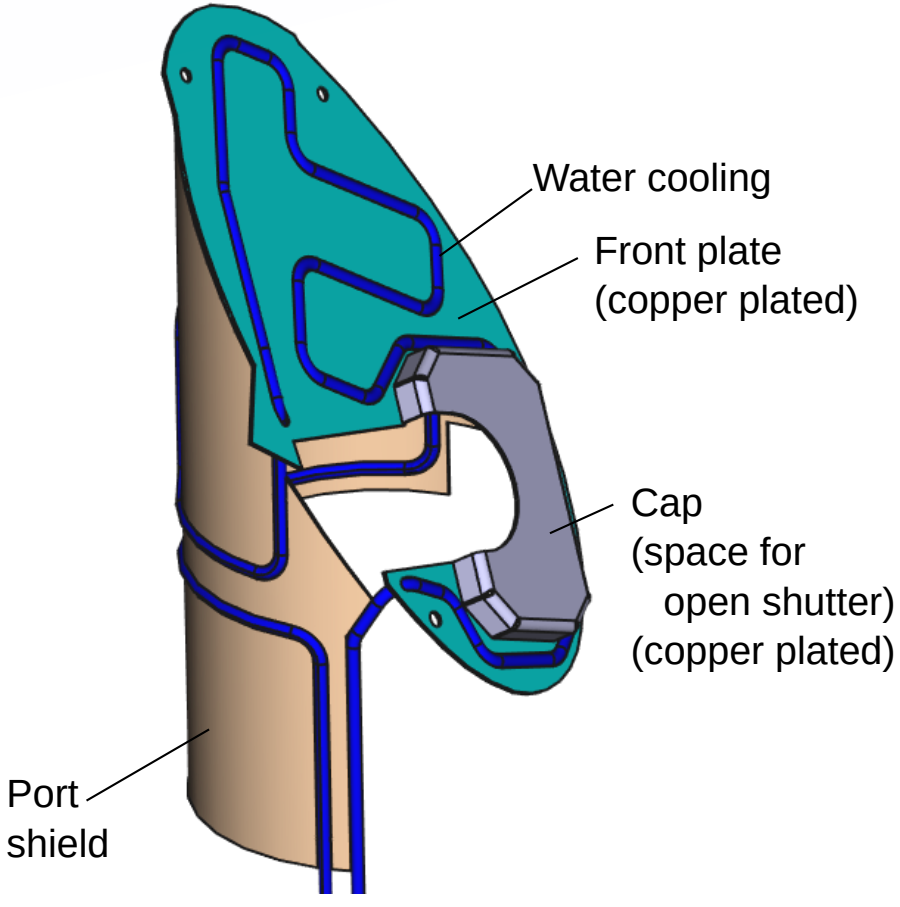
AEM21 port protection - port shield

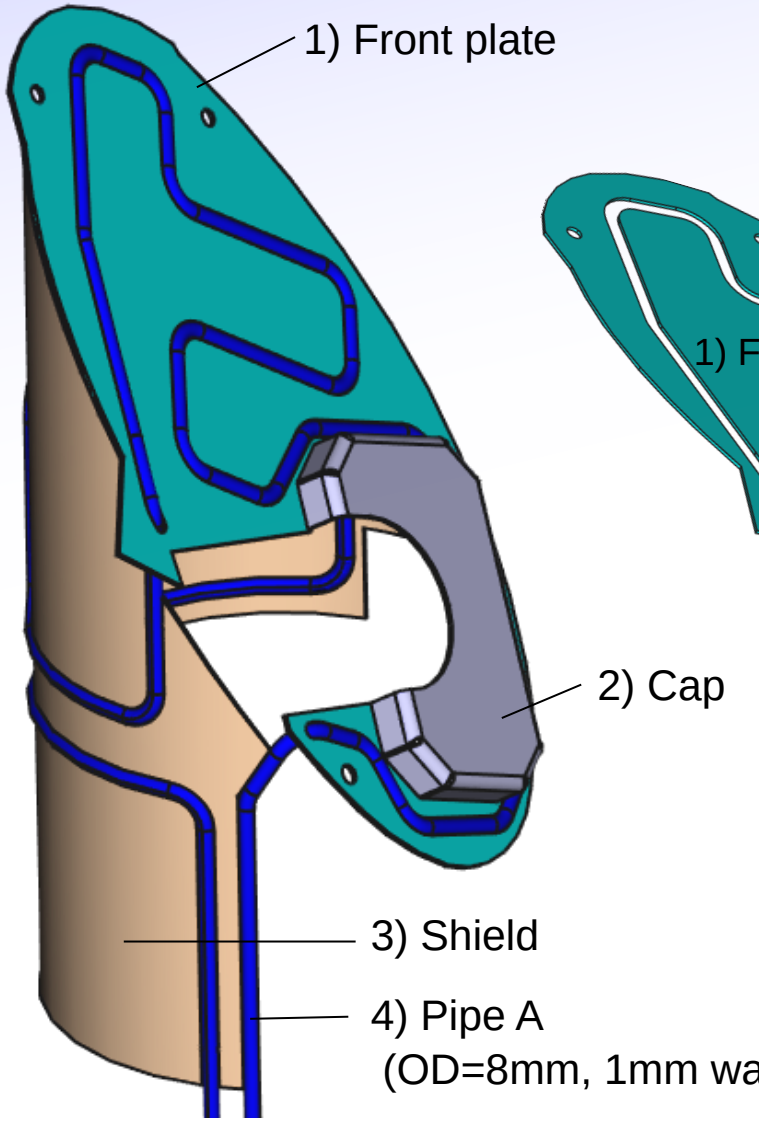
Back surface 'port shield' to protect port wall, 'zwickel' and welding seams together with AEN21 port-liner.

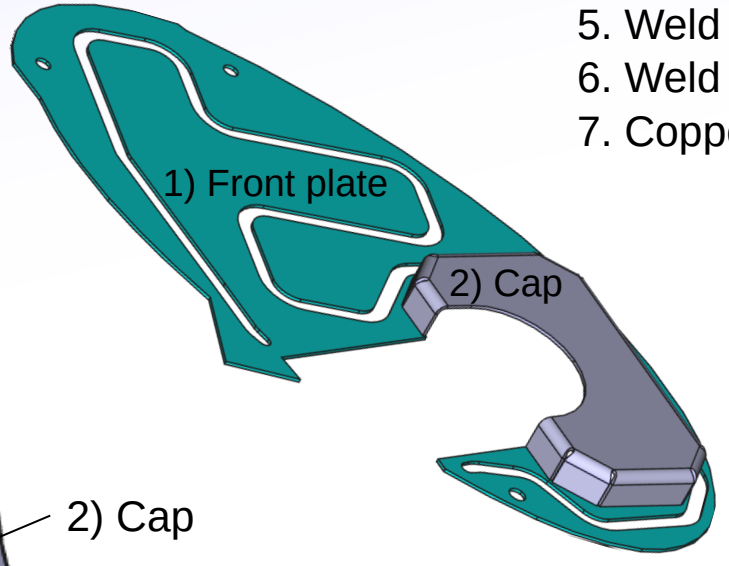


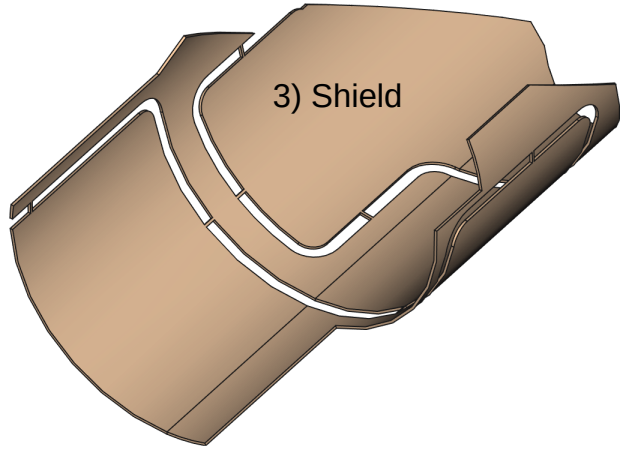


AEM21 port protection - construction

Port protection assembled from 3 distinct parts:







1. Manufacture front plate, cap, shield
   (+ Manufacture aluminium dummy FP)
2. Weld cap to front plate
3. Bend pipe sections
4. Weld together pipe sections
5. Weld pipe into front plate
6. Weld shield parts to pipe
7. Copper plating

Tolerances:

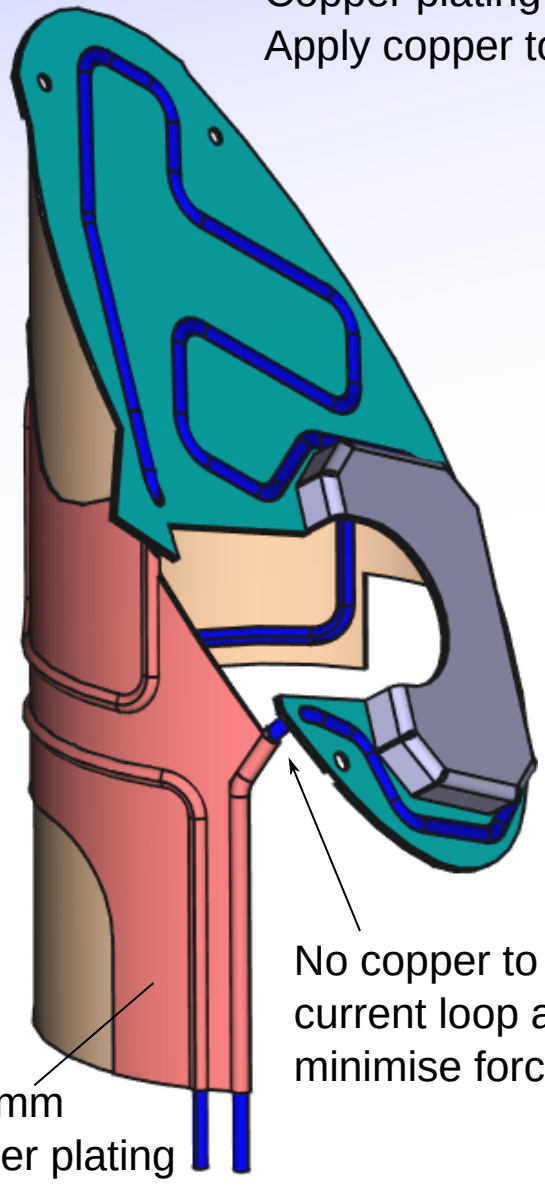
Manufacturing tolerances will not be high, but only need to be sufficient to fit shield in port without stress.

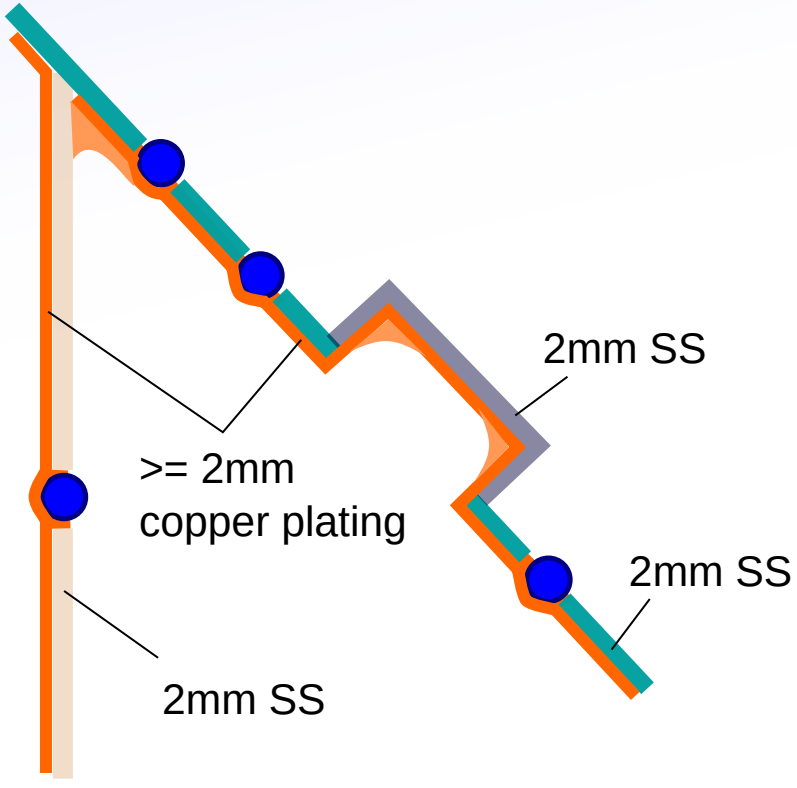
- Panel adjusted to other panels during installation
- CXRS optics require only ~ +/- 5mm.

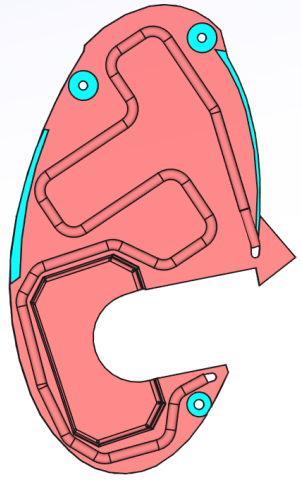
TD Auftrag - Manufacturing company found - 6k€

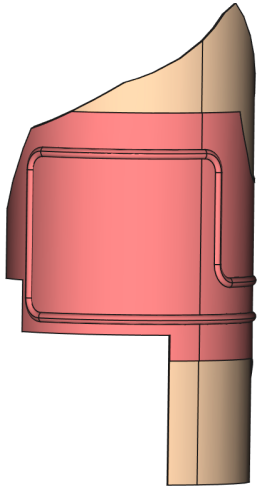
AEM21 port protection - copper plating

Copper plating to increase thermal conductivity to SS cooling pipes.
Apply copper to back of front plate and cap and back side of shield.





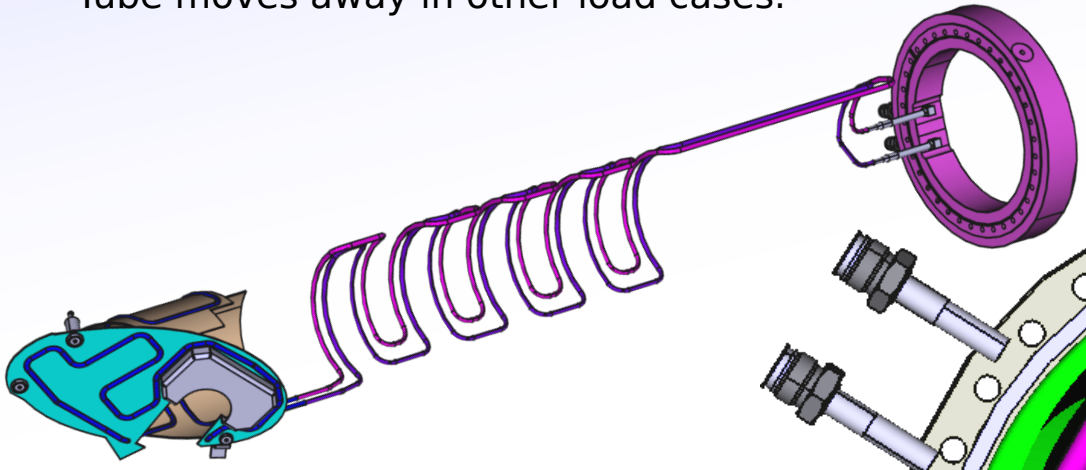


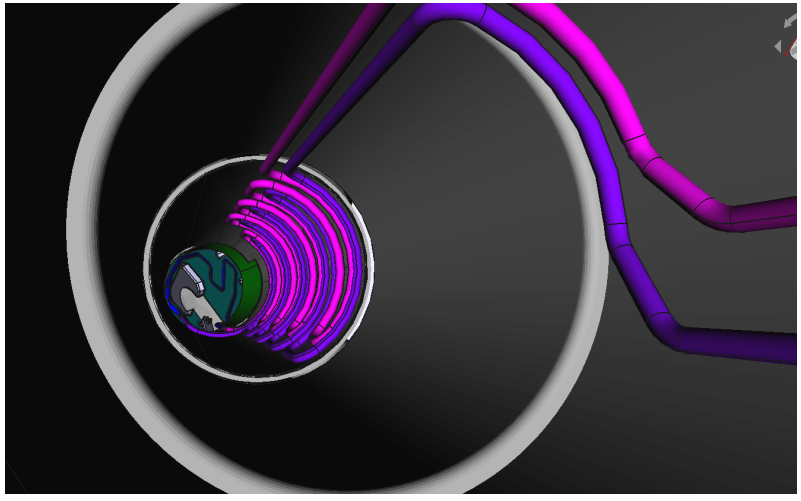


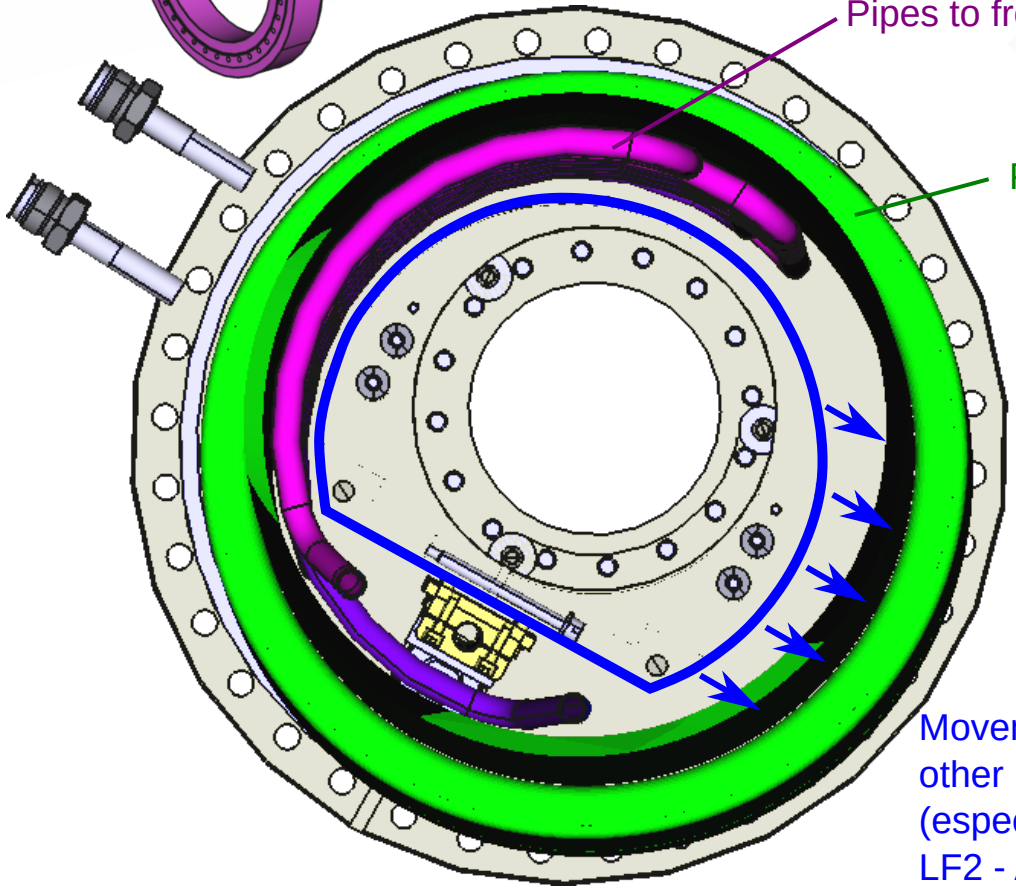
Copper plating expertise by Galvano-T.
- CTS Plugin for ECRH - (Delivered)
- AEA21 front plate (In discussion)
- Initial assement by Galvano-T as feasible but copper thickness may vary signifcantly as difficult to work in corners.

AEM21 port protection - pipes

- Space for water cooling pipes very limited.
- Contact of immersion tube with pipes in LC2 (Ausheizen) --> stress on pipes join to panel.
- Solution:
  1) Use narrower pipes than usual (8mm, 1mm wall).
  2) Pipes on side of tube with narrowest as-built gap.
     Tube moves away in other load cases.







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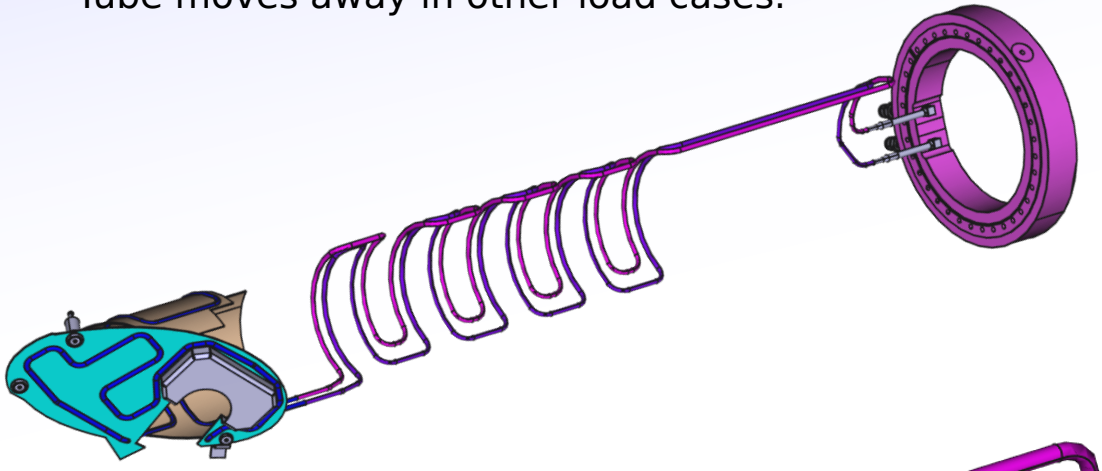
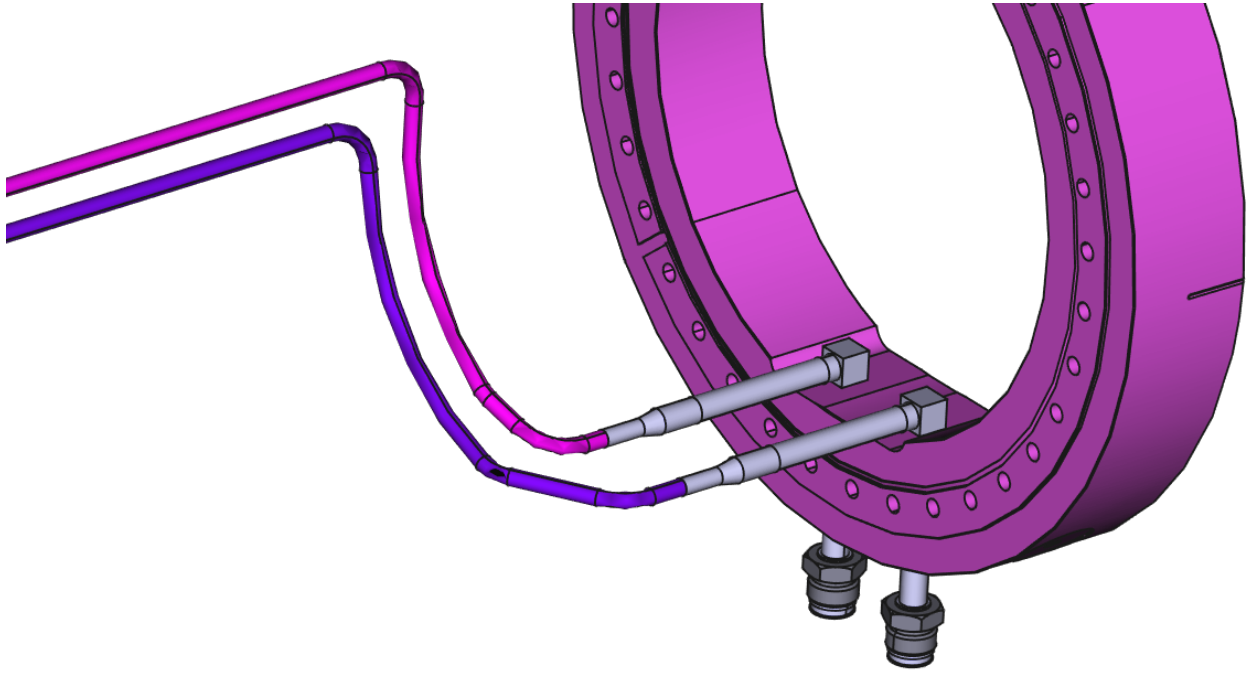


Welding tools (to passring) only available for 12mm pipes,
so need taper from 12mm to 8mm:

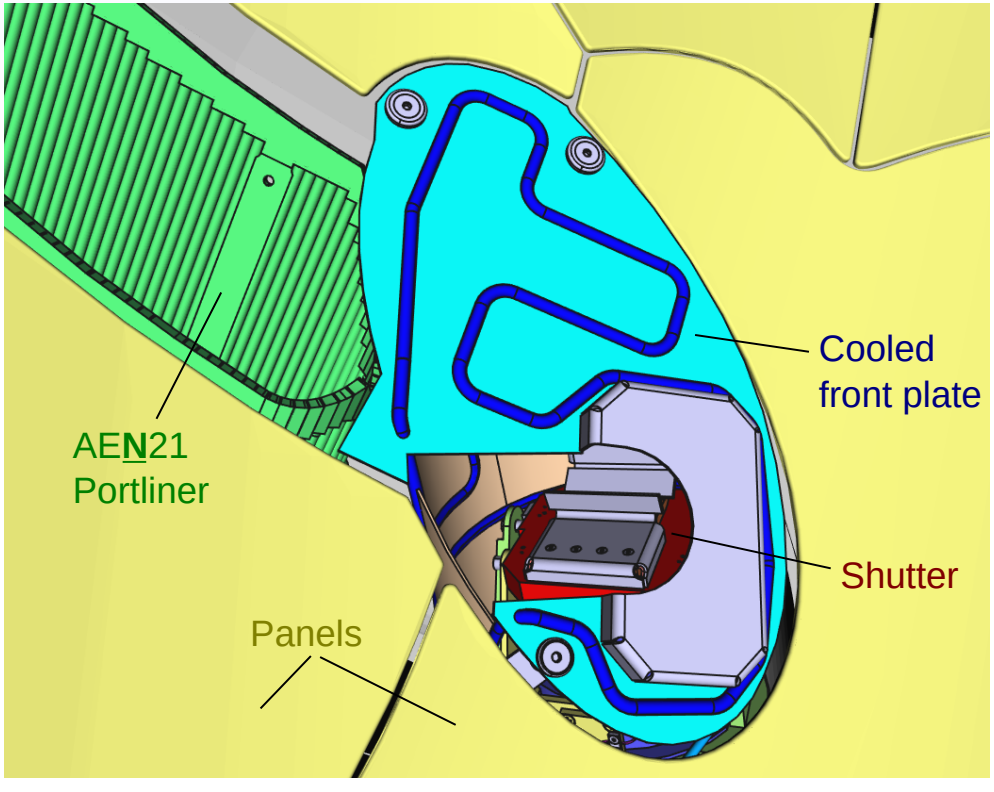


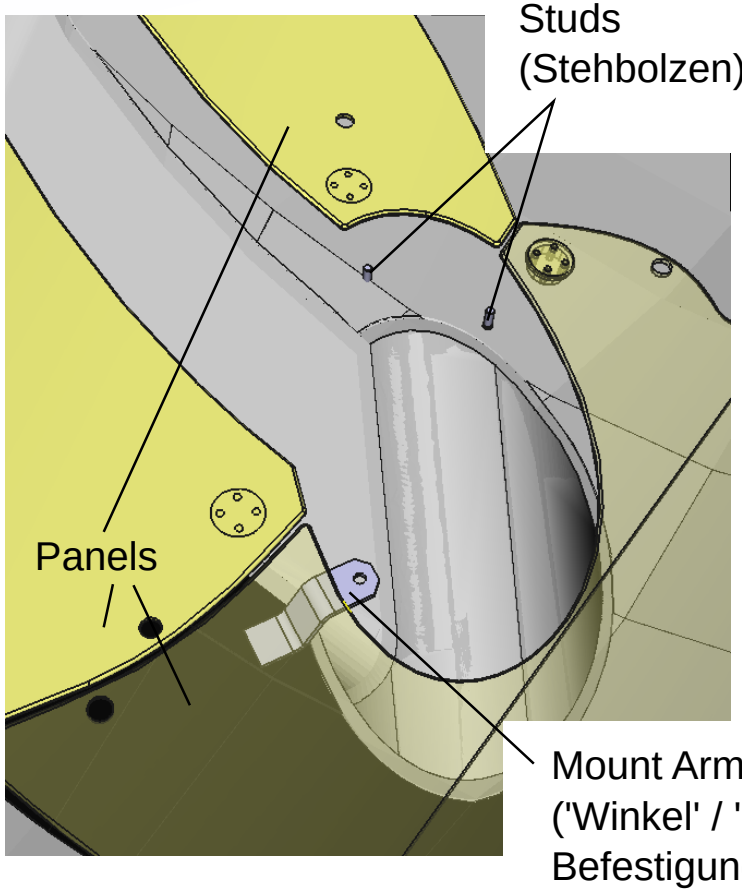
AEM21 port protection - Mounts

- Front plate mounted on two bolts and one metal bracket:
- Bolts and bracket to be installed before re-installation of surrounding panels (~Feb 21)
- Discussed with AS-Tech:
  - Need to provide bolts and brackets.
  - Panel mount pieces available from AS.
  - Precise positions/vectors to be provided to AS.

- Manufacture an aluminium 'dummy' front plate to assist/test mounts.

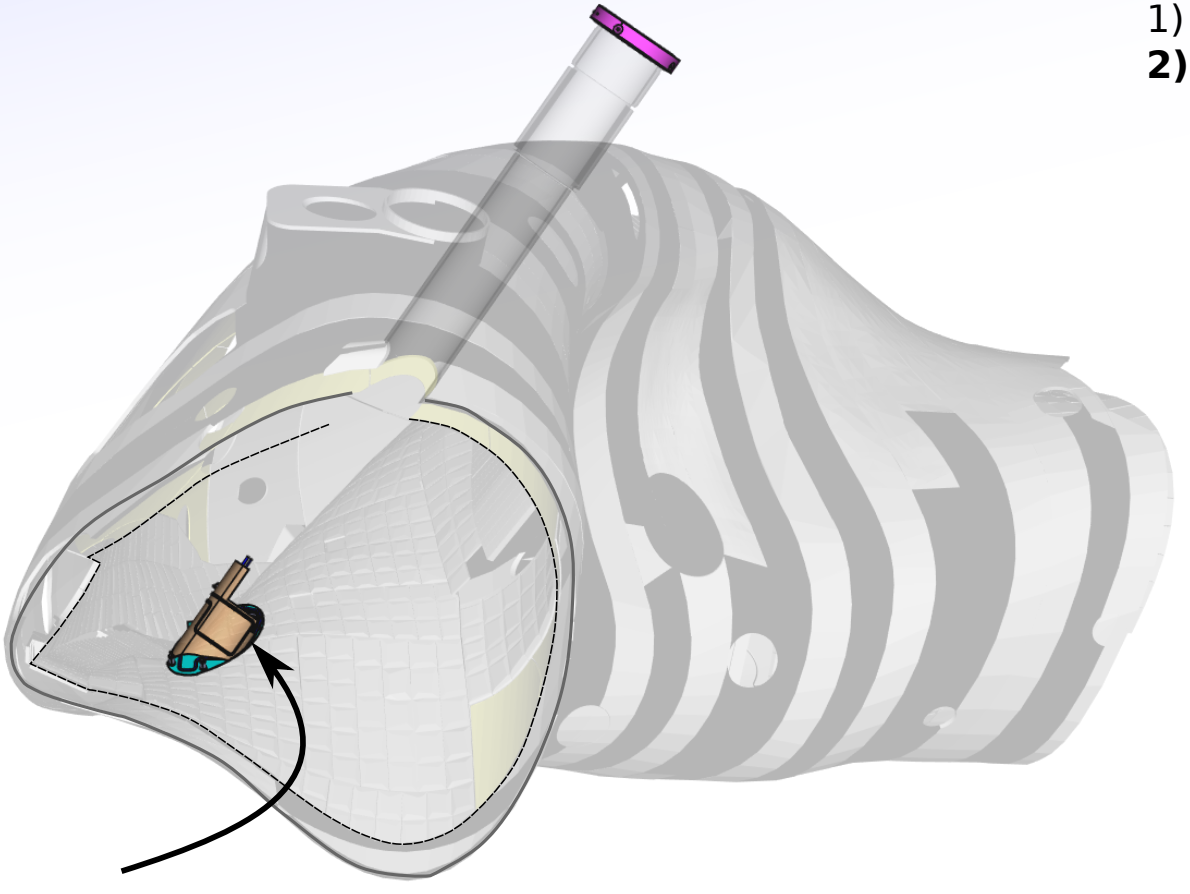
Head-on view (looking up at port from inside vessel):





AEM21 port protection - Installation

- Installation in stages, due to length of pipes:



1) Install passring.
2) Bring port protection into vessel

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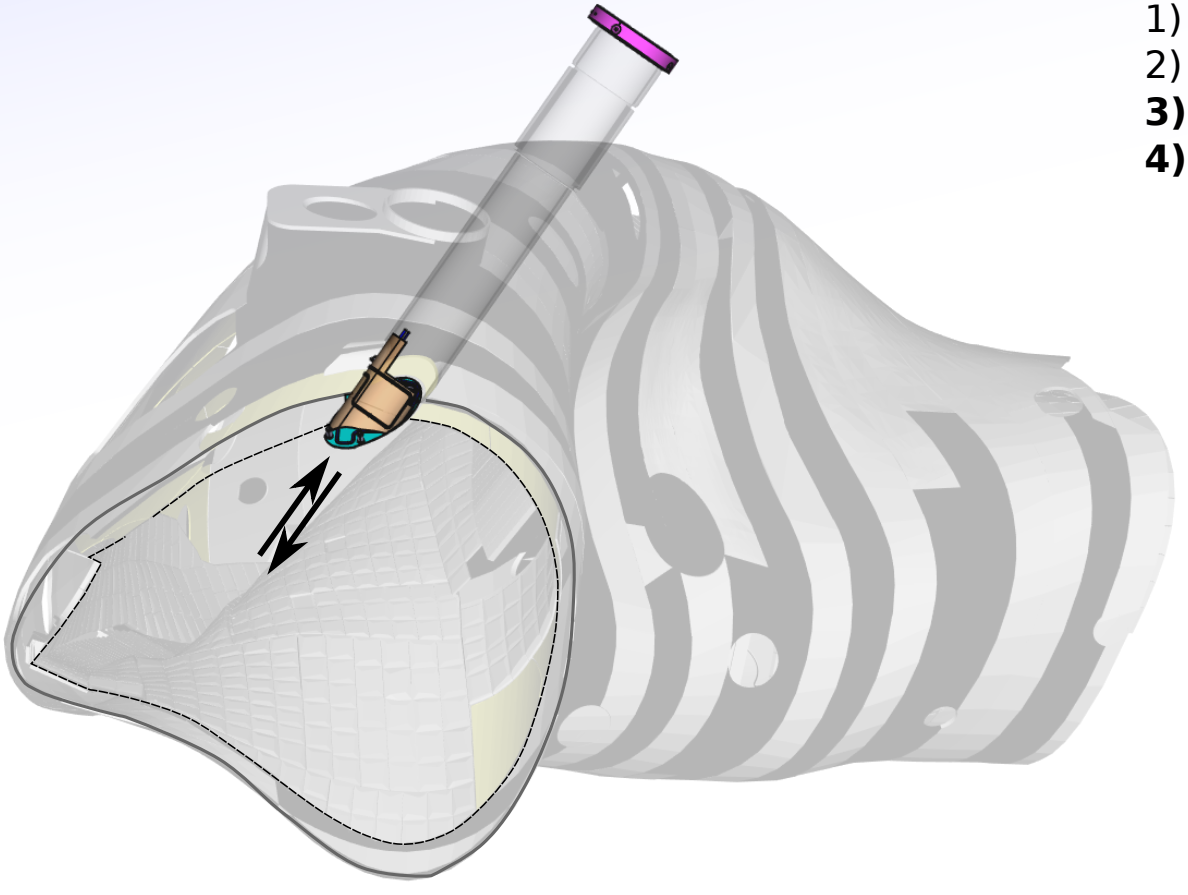

1) Install passring.
2) Bring port protection into vessel
3) Test install port protection.
4) Remove port protection

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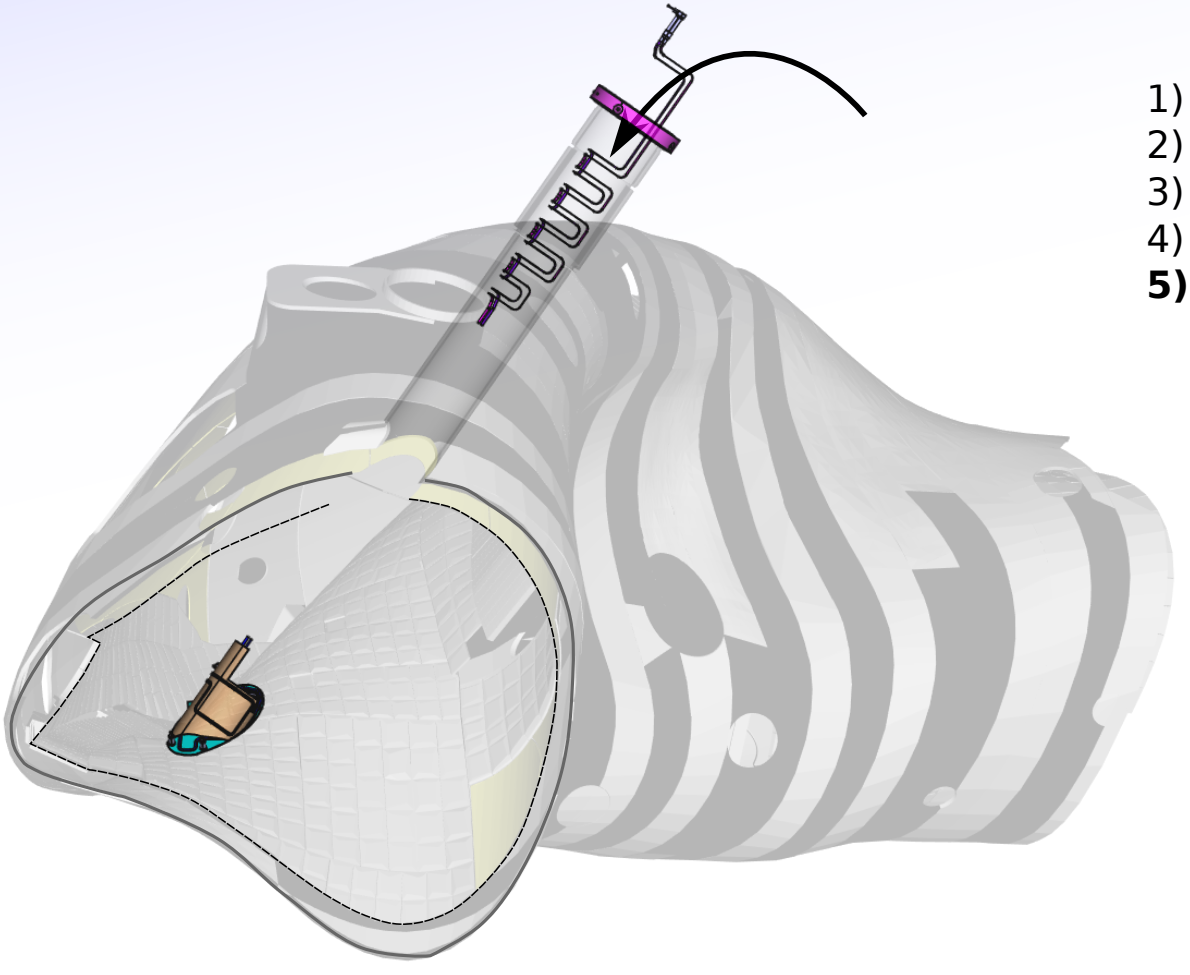

1) Install passring.
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5) Bring pipes into vessel via port.

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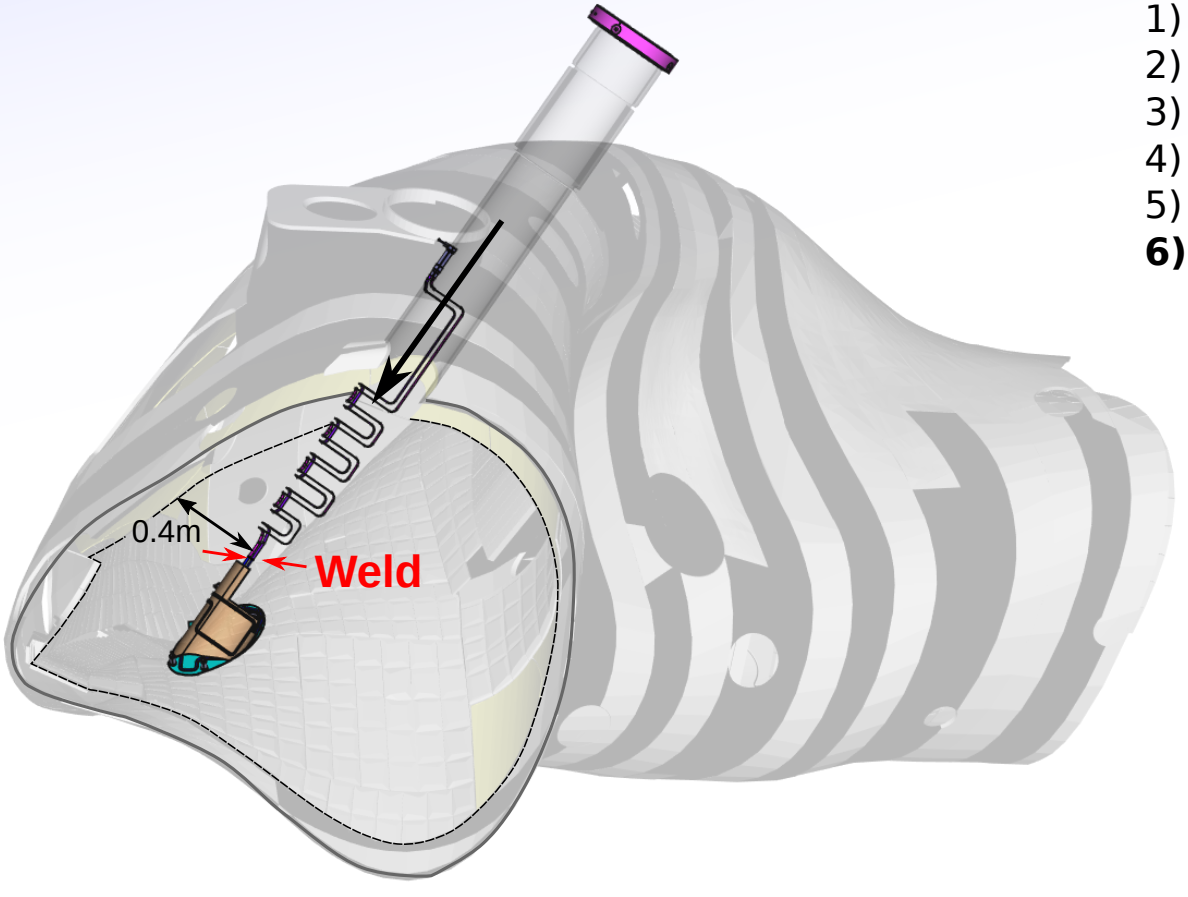
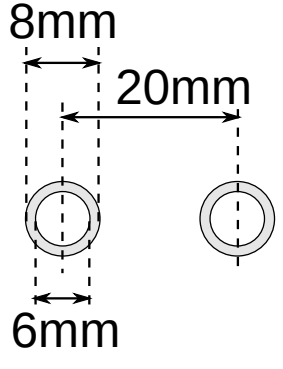


1) Install passring.
2) Bring port protection into vessel
3) Test install port protection.
4) Remove port protection
5) Bring pipes into vessel via port.
6) Weld pipes to port protection in vessel.



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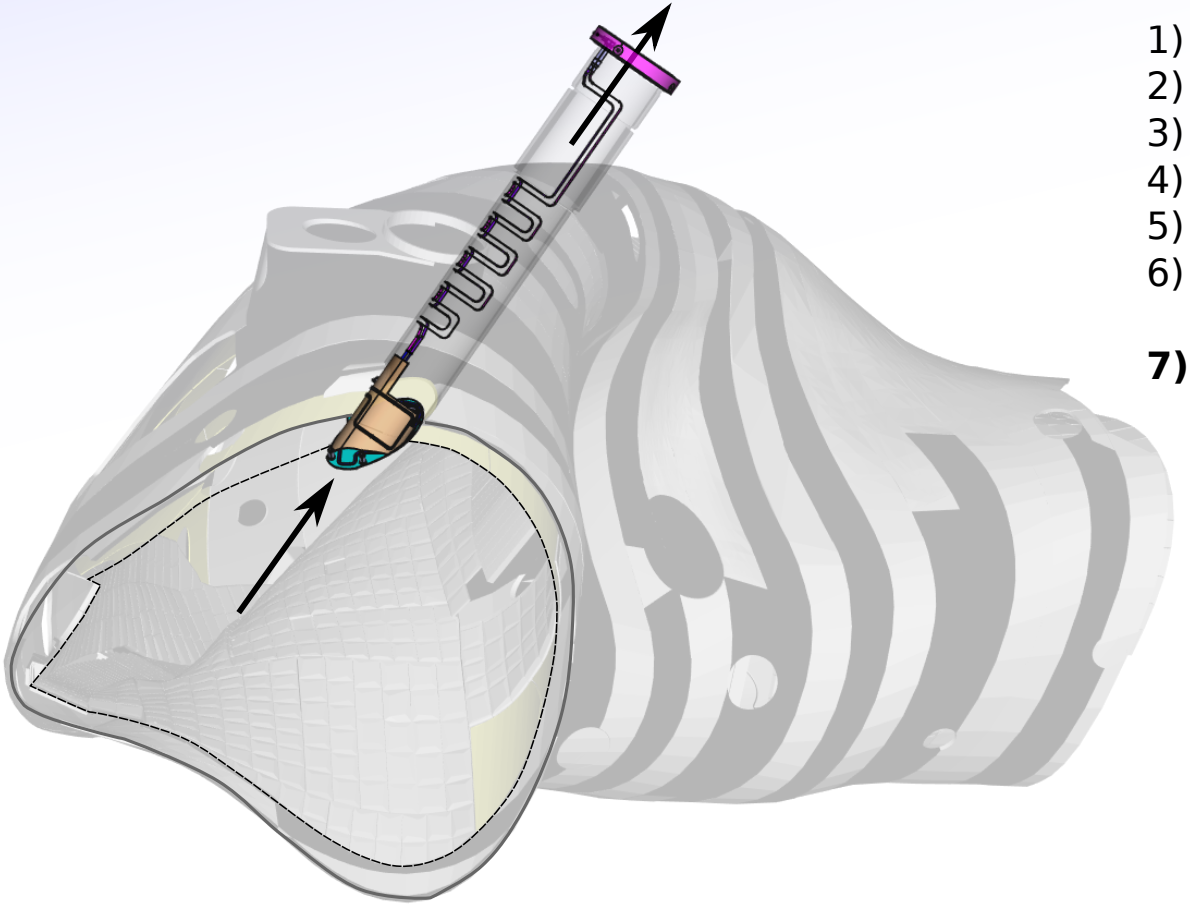

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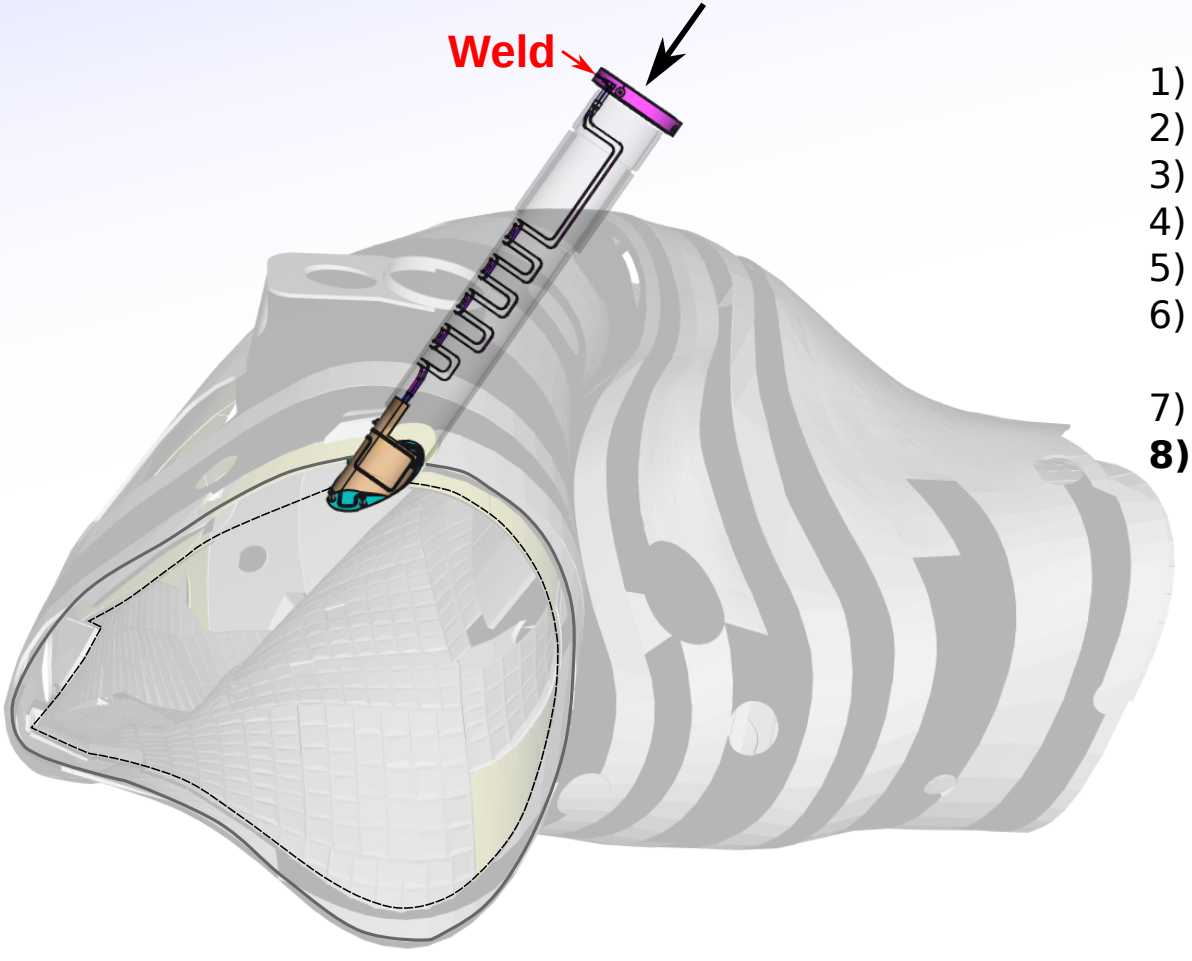

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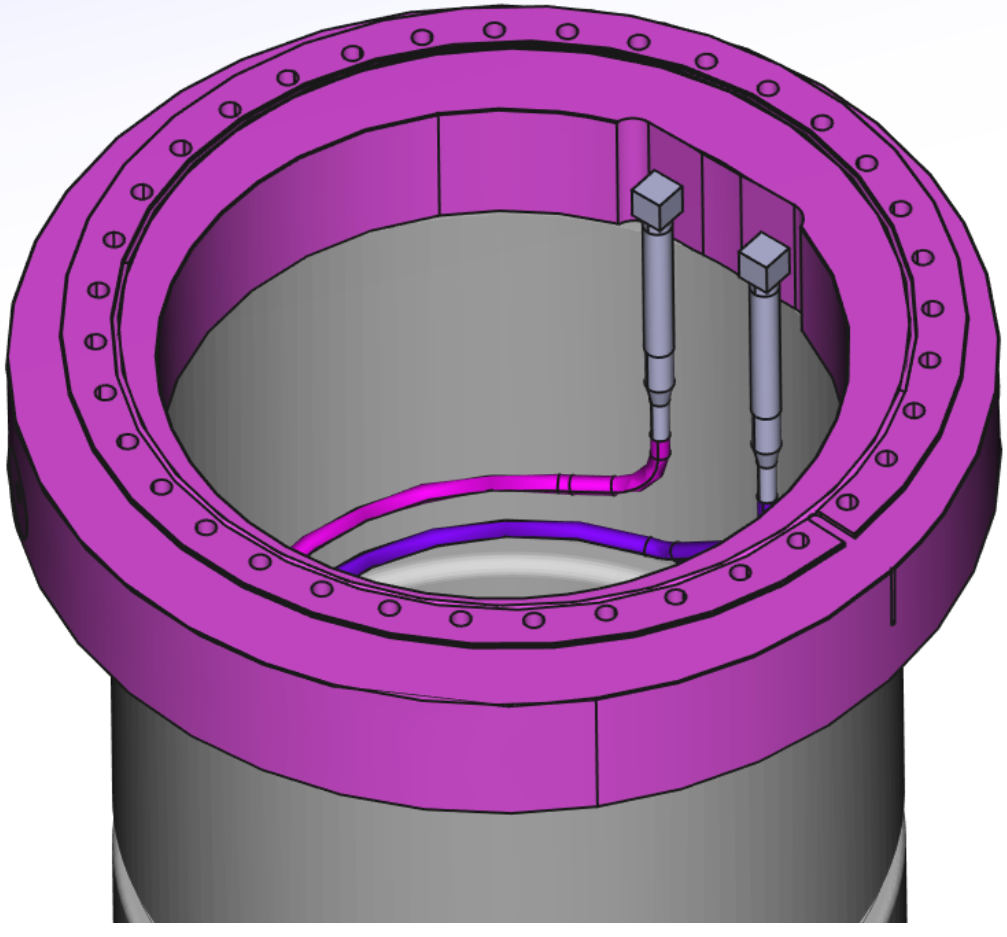
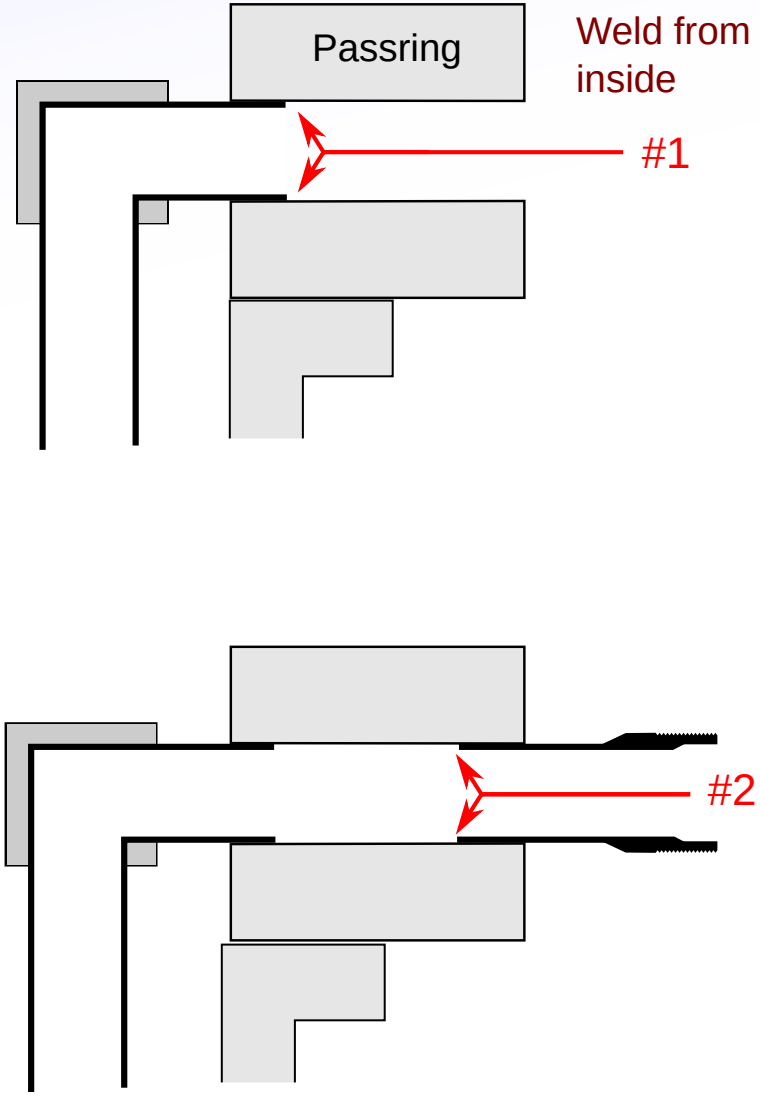
4) Remove port protection
5) Bring pipes into vessel via port.
6) Weld pipes to port protection in vessel.
7) Install port protection.
8) Weld pipes to passring.

AEM21 port protection - pipes to passring

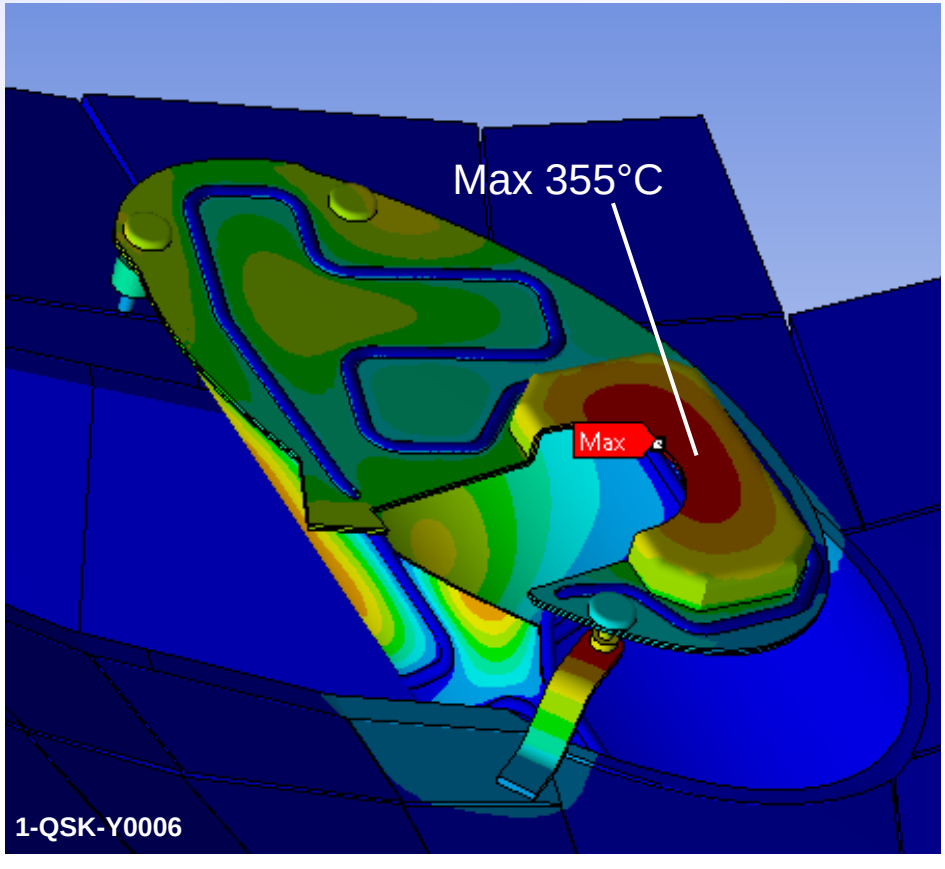
Welding of pipes to passring:
- Weld inside pipe from outside of port due to limited space inside passring. (similar to AEM41 portliner)

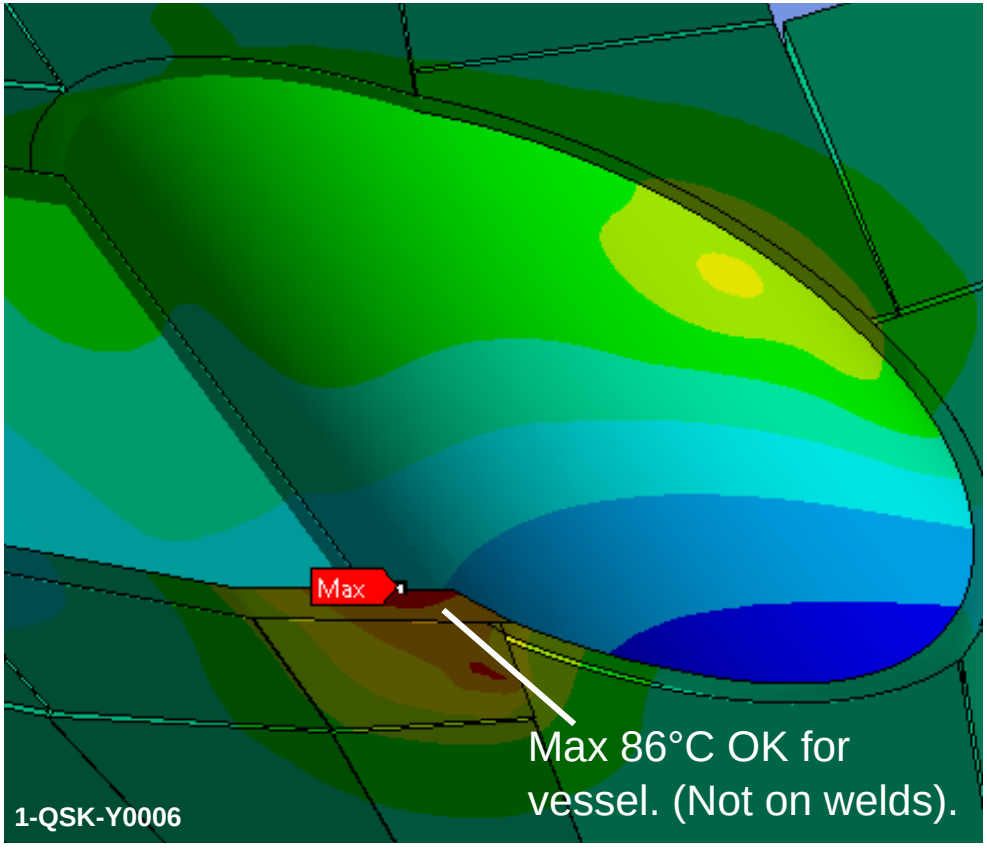




AEM21 port protection - thermal analysis

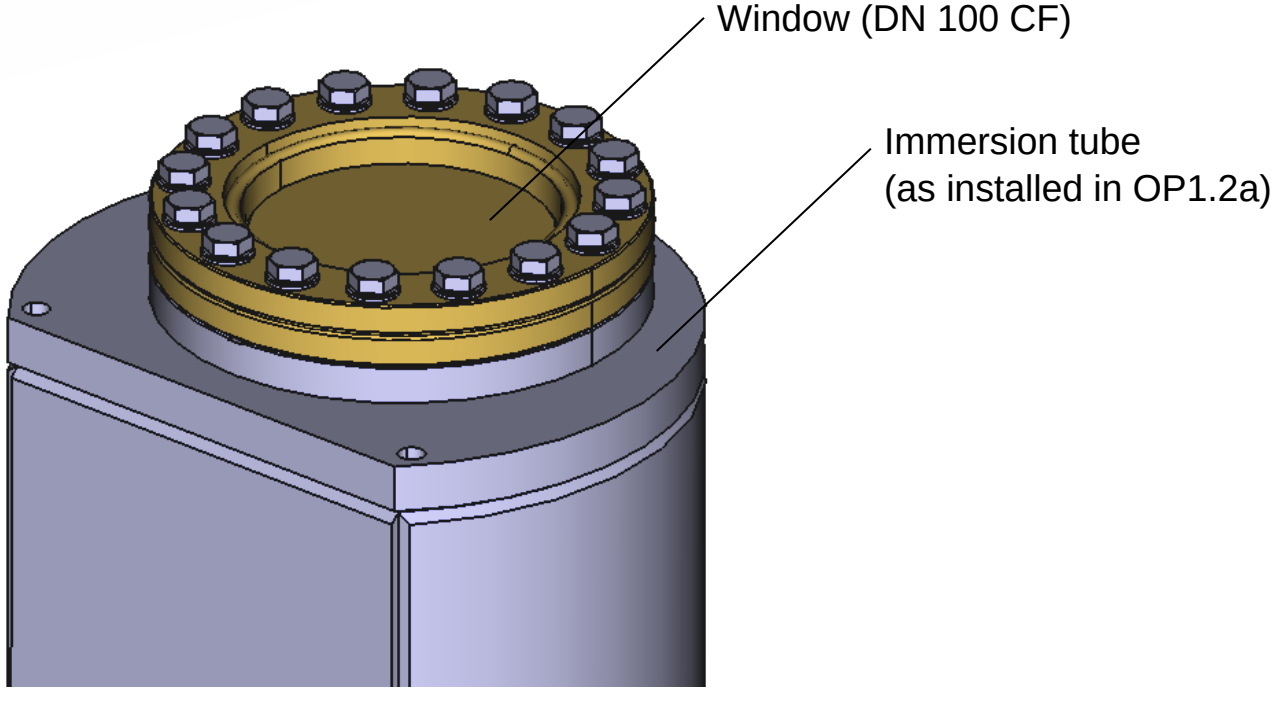
Thermal analysis of the port protection shows acceptable temperatures:
- Max 355°C on front plate, max 86°C on vessel [1-QSK-Y0006 by EN (M. Khokhlov)]
- Water flow rate and pressure drop OK and sufficient for cooling.





AEM21 Immersion Tube

AEM21 immersion tube:



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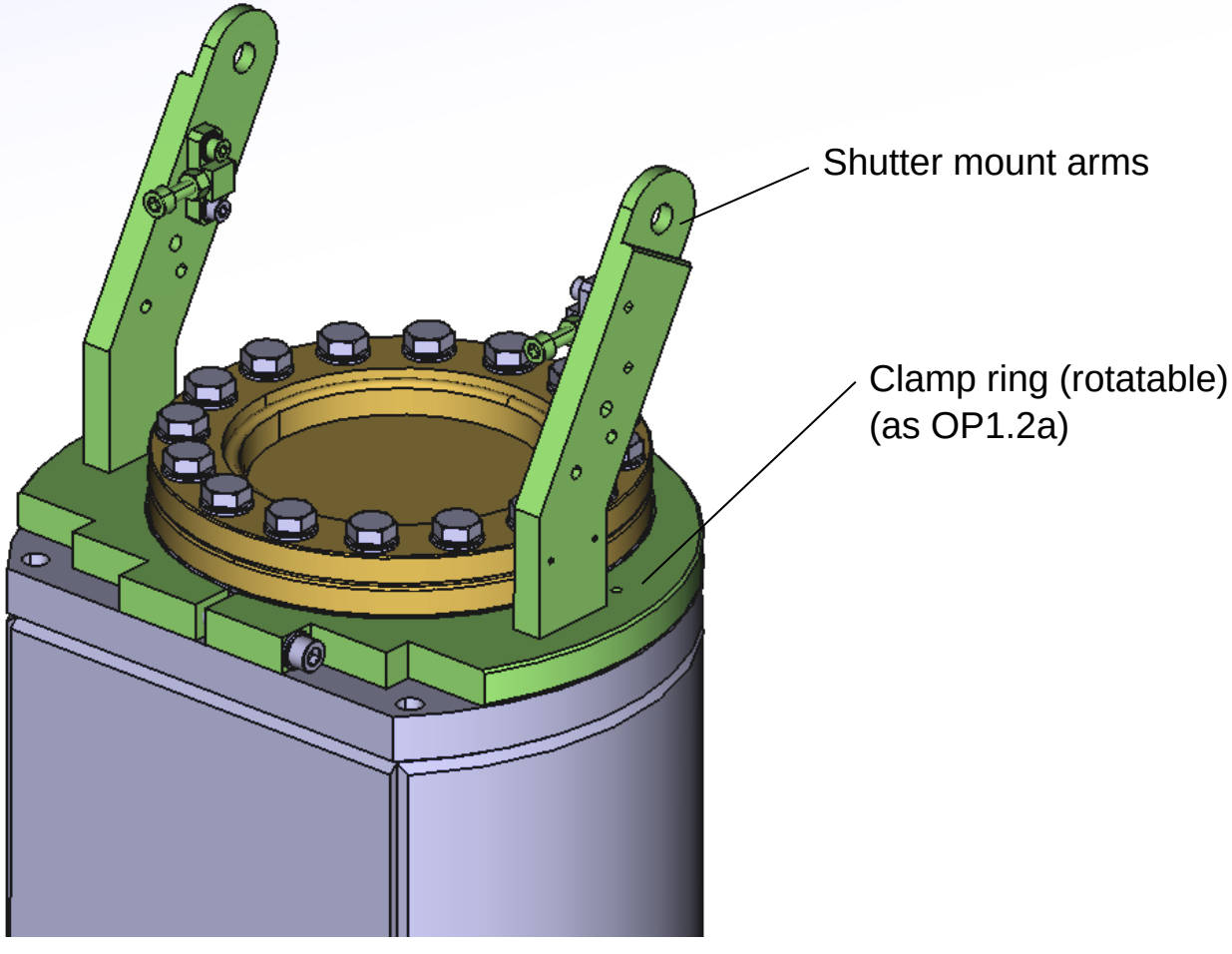
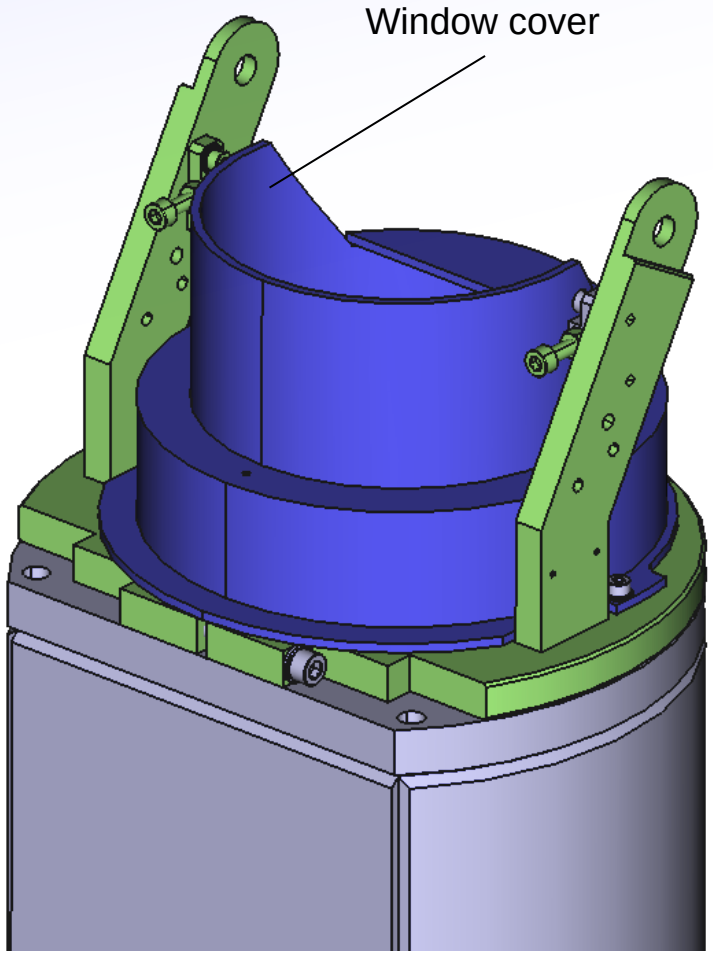
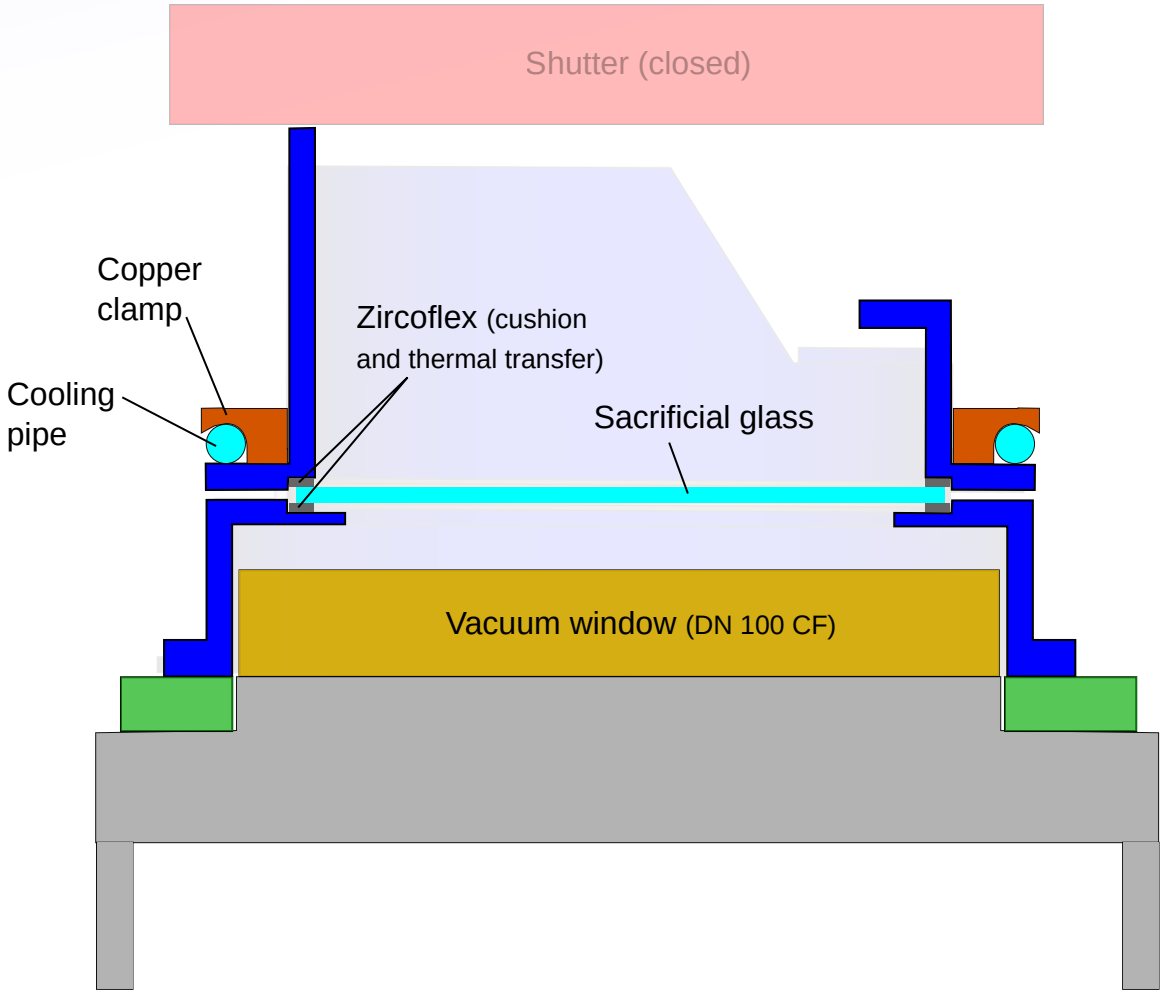


AEM21 Immersion Tube

AEM21 immersion tube:

- OP1.2 window cover (welded thin sheet) fit poorly and made ring rotation difficult.
- Rebuild from machined steel parts.
- Include sacrificial window for extra protection of main window from plasma radiation (shutter open) and ECRH stray radiation (shutter closed)





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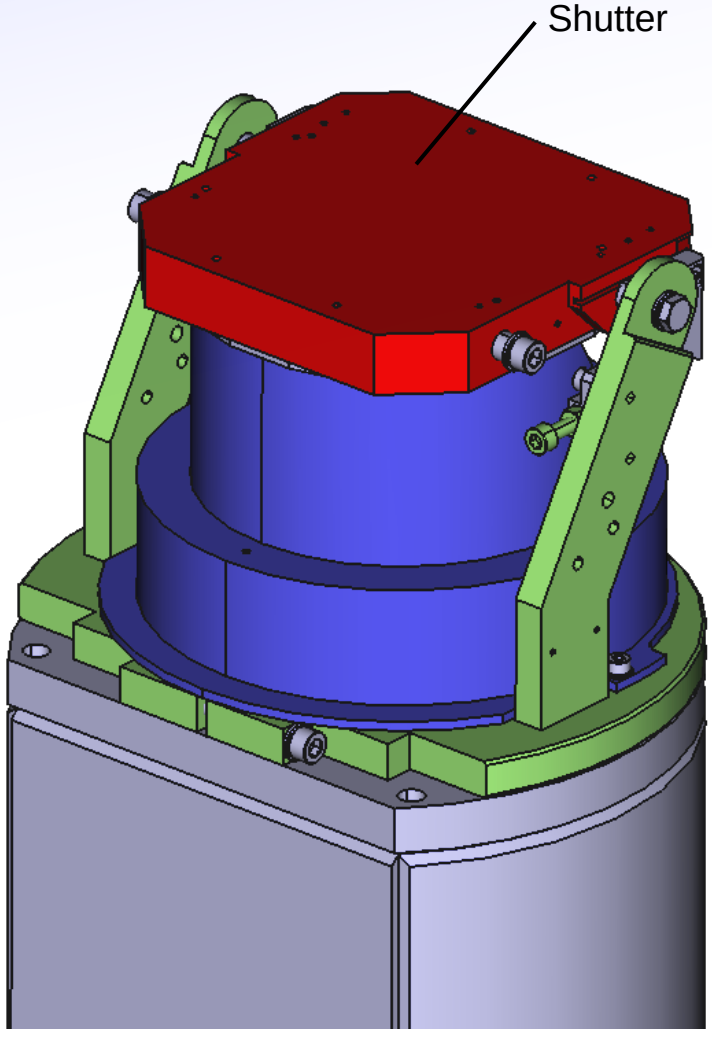

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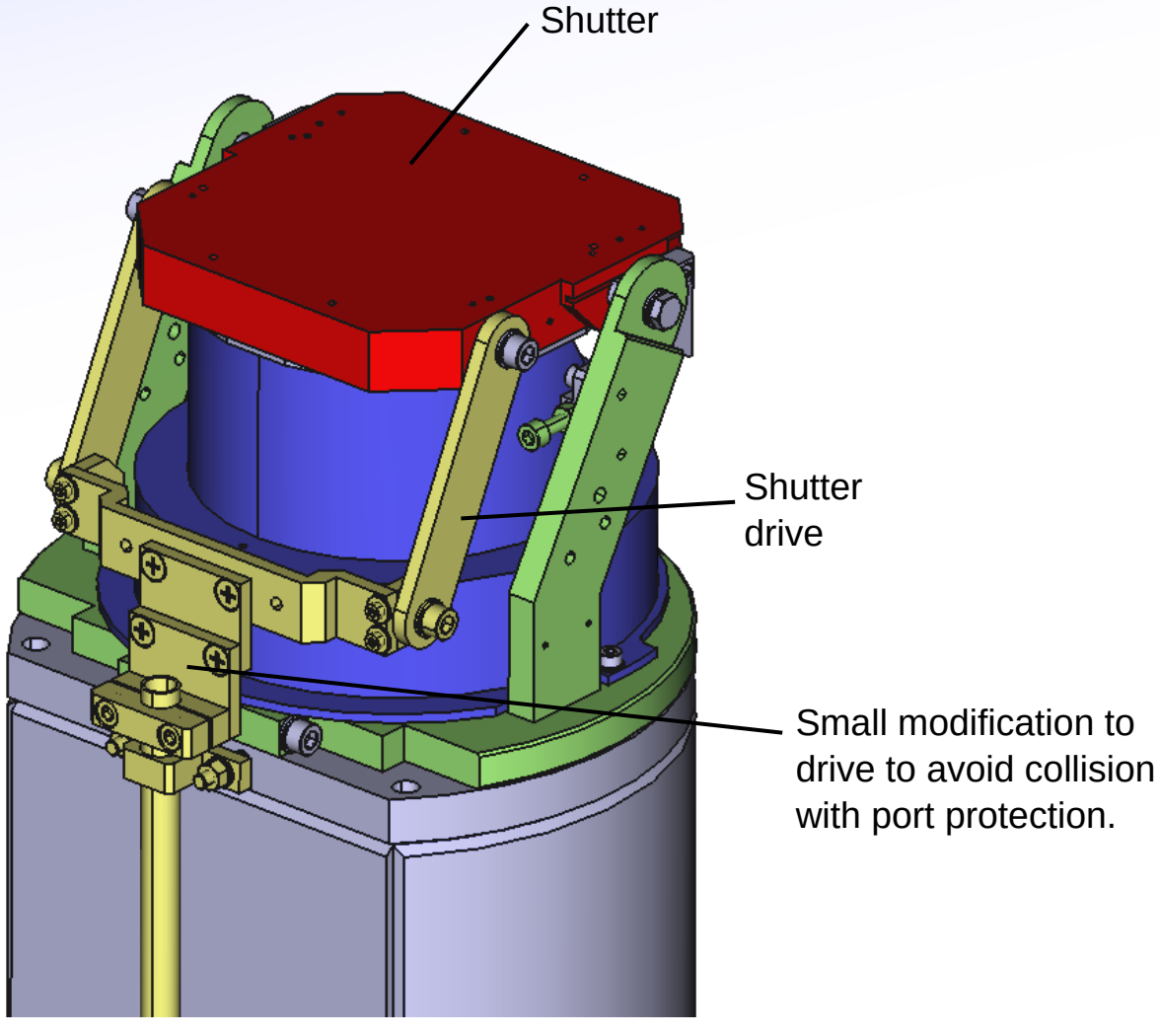

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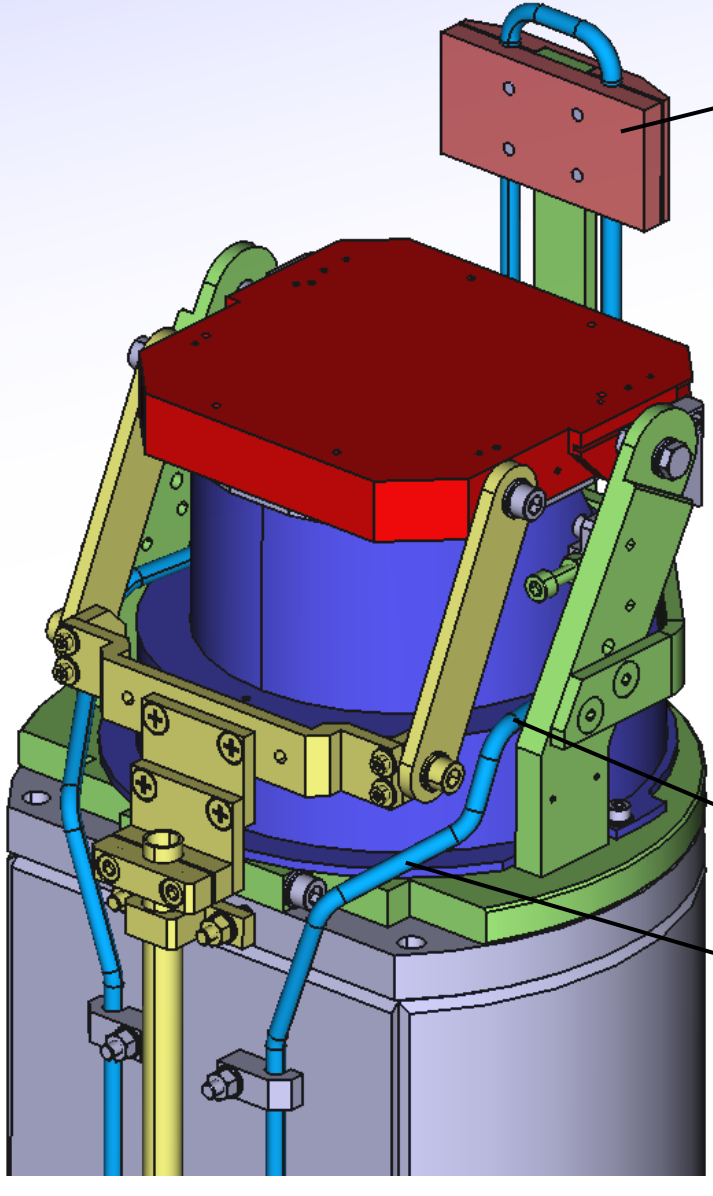

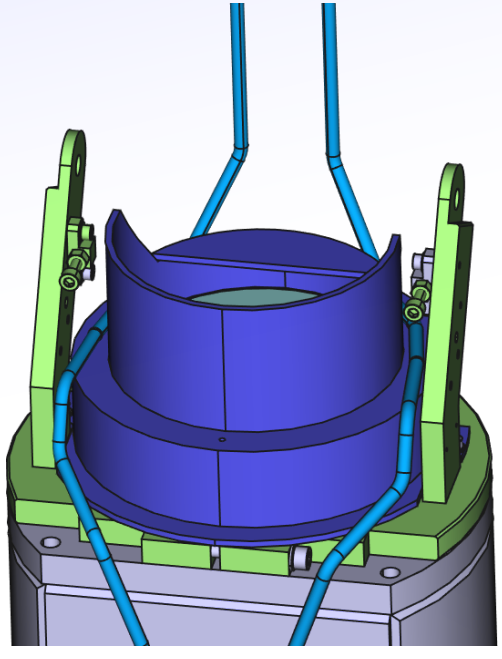

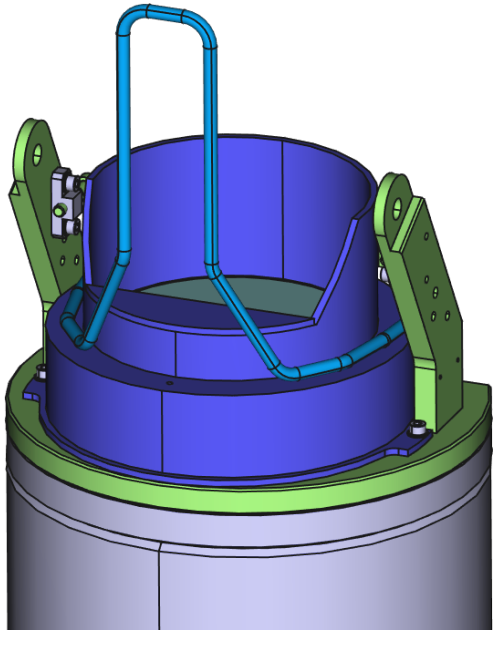

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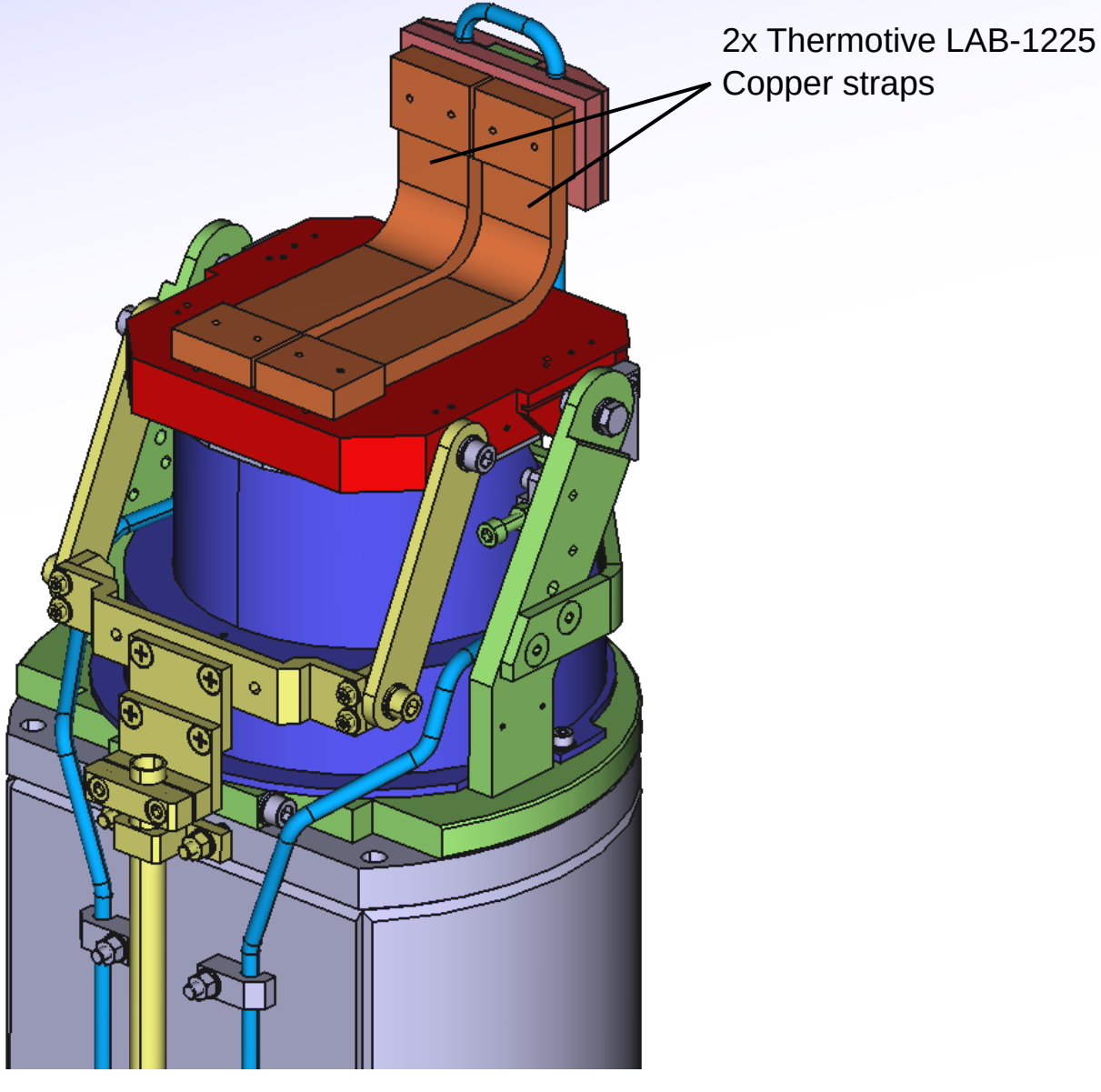

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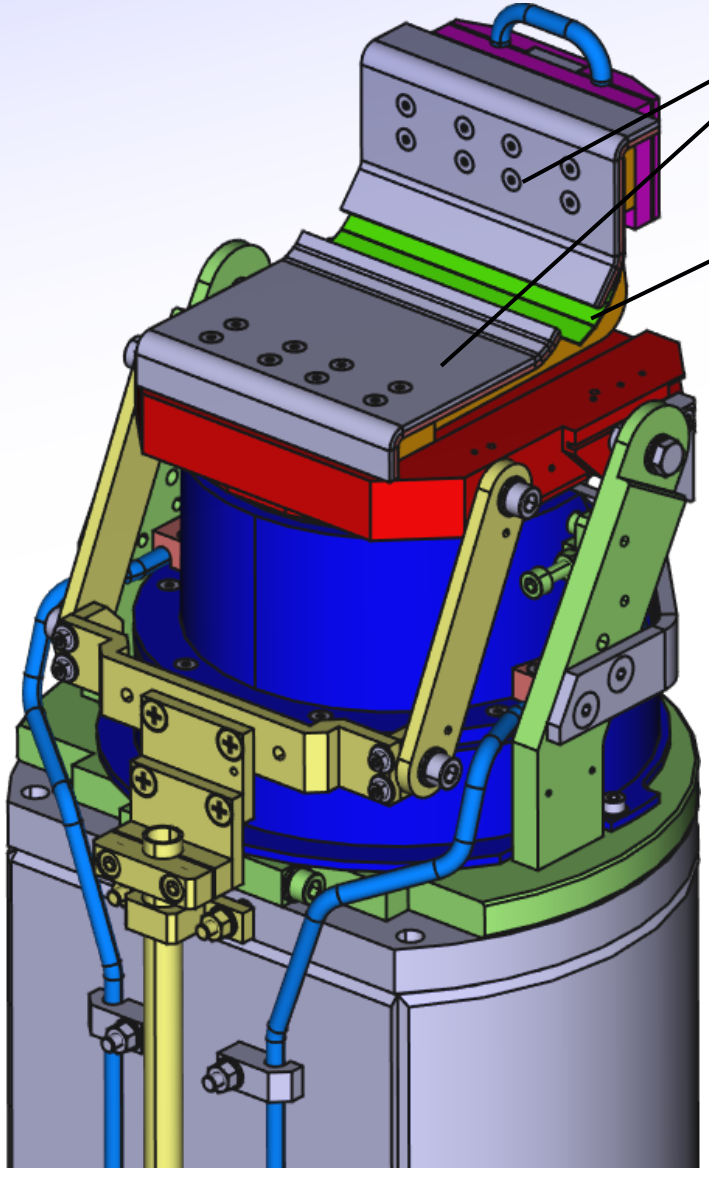
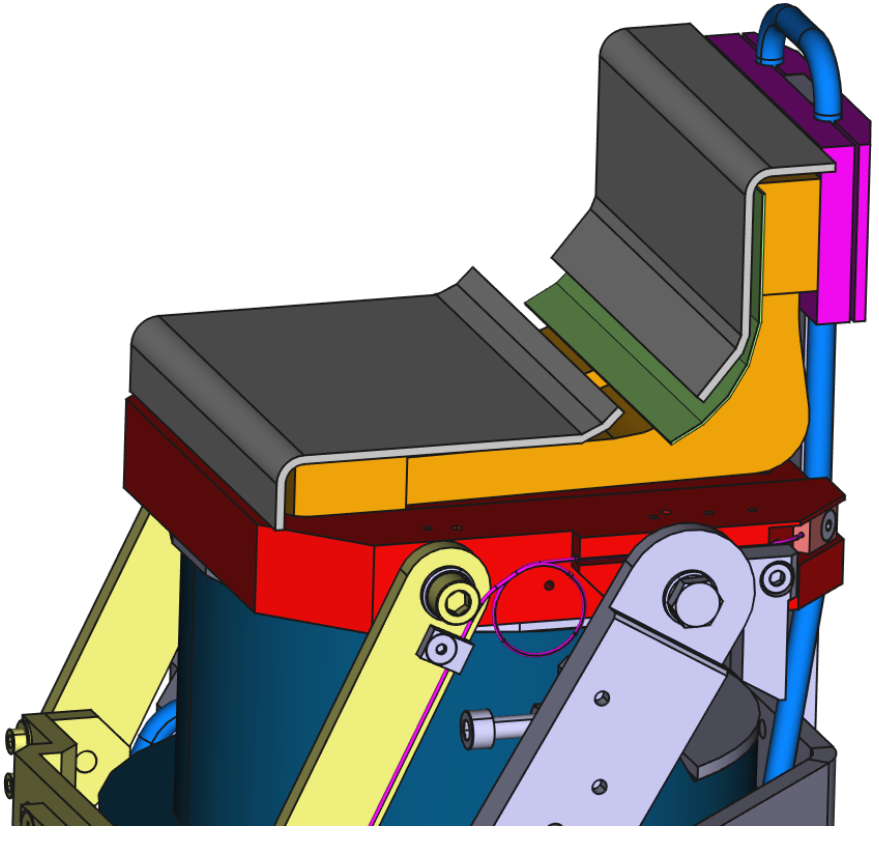


Steel covers to avoid direct exposure of straps to plasma.
- Copper plated on rear side to avoid hot spots on covers.

Flexible steel-only foil to cover remaining gap.



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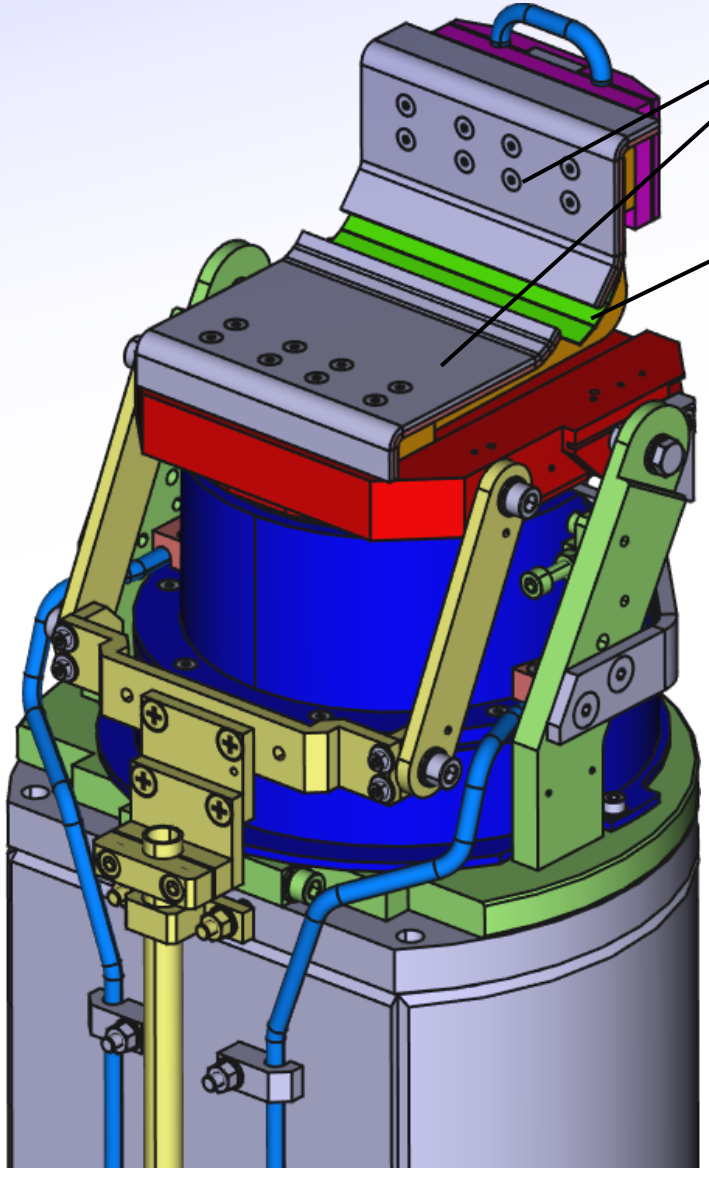

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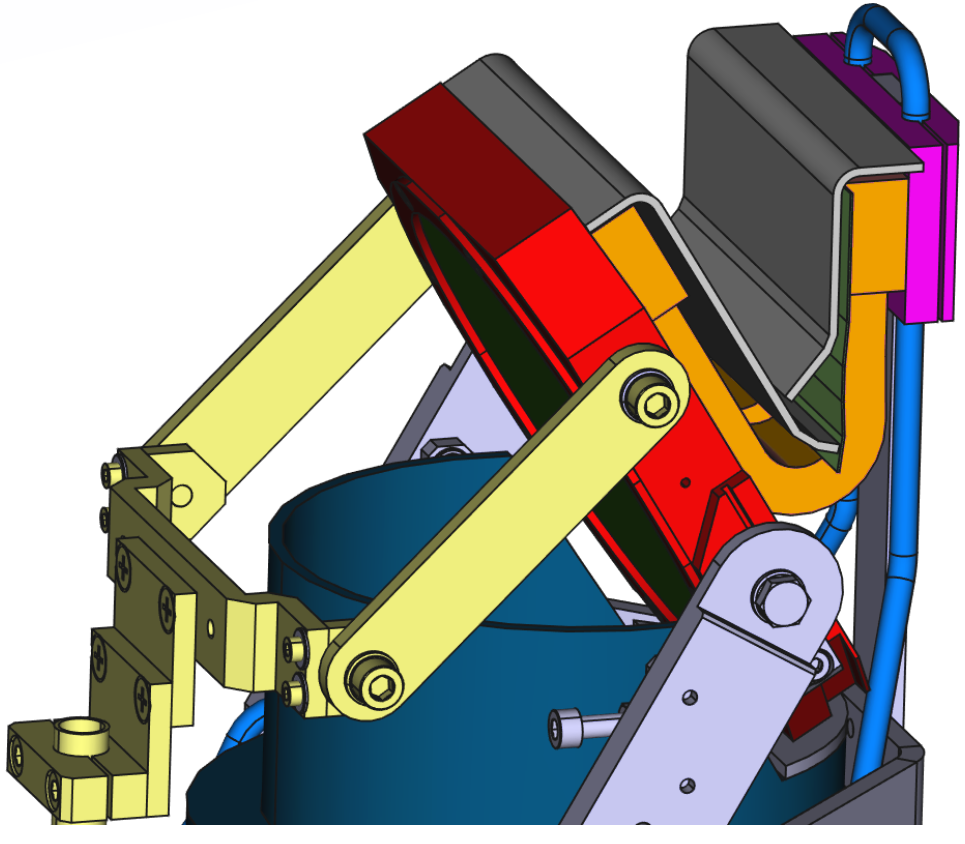
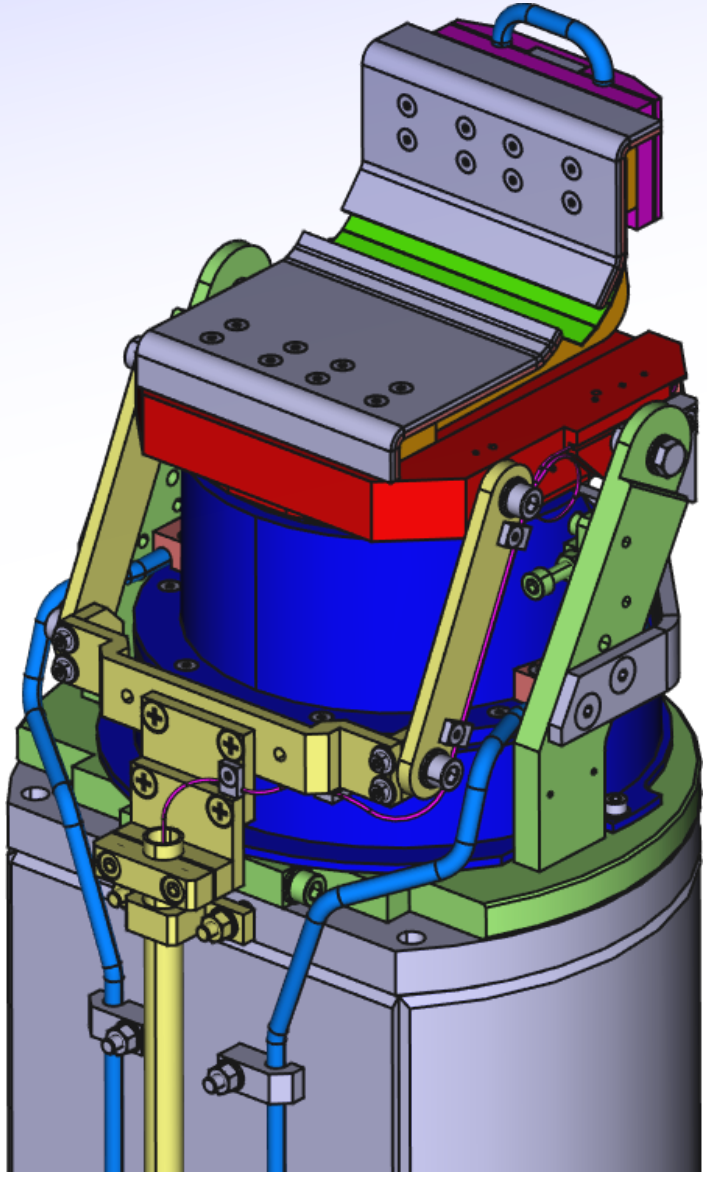
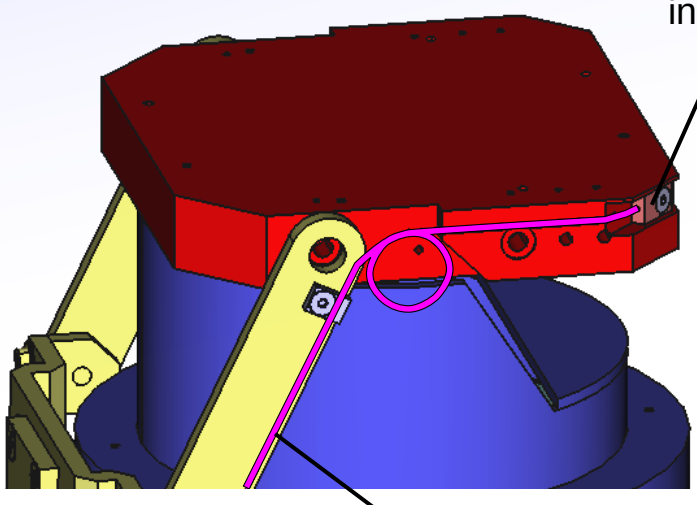


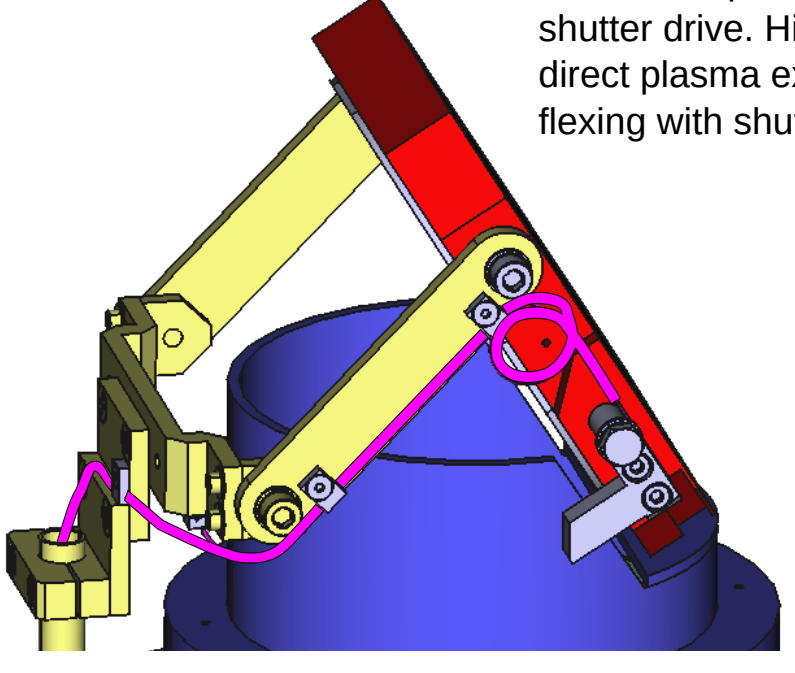
AEM21 Immersion Tube

Thermocouple mounted to shutter block to measure equilibrium temperature of shutter --> max temperature of aluminium mirror.



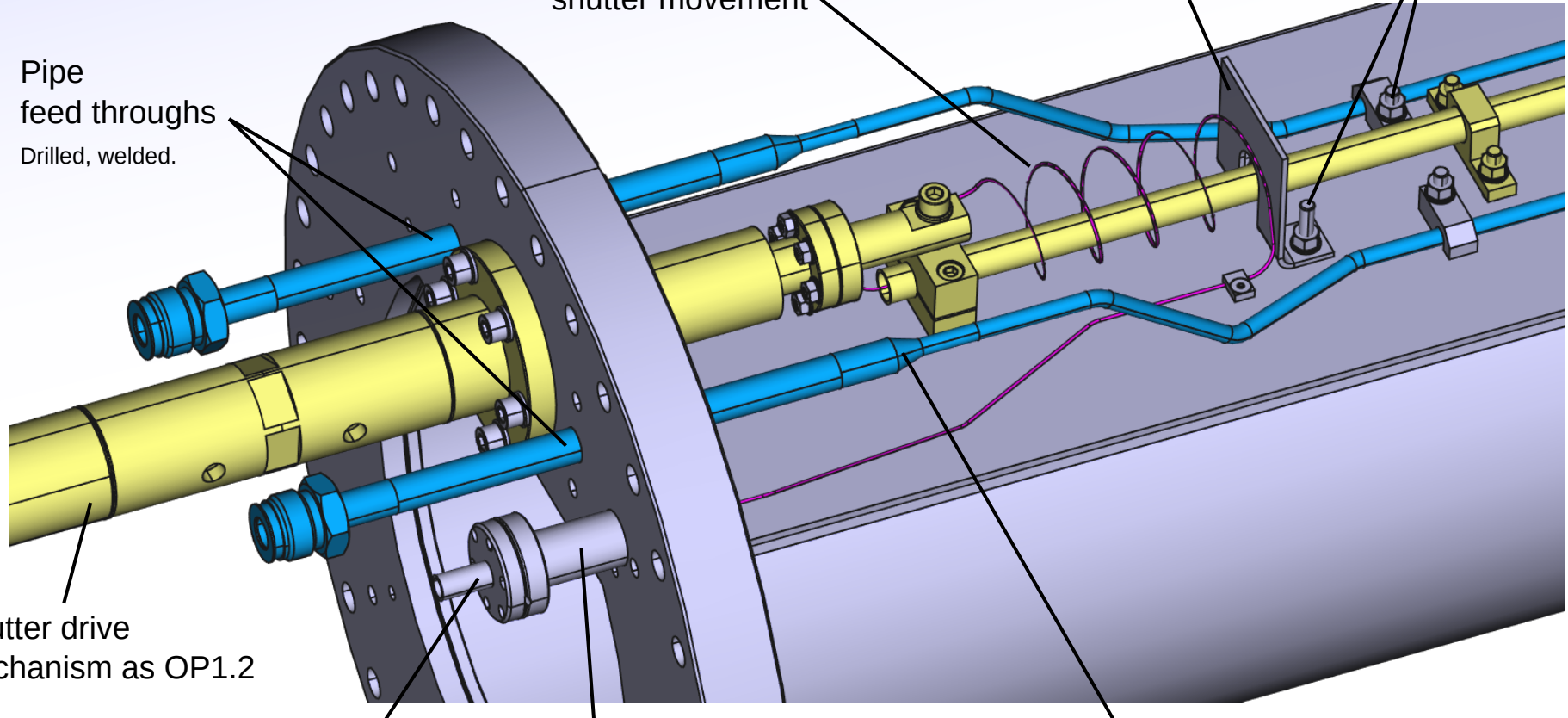


Thermocouple wire runs along shutter drive. Hidden from direct plasma exposure and flexing with shutter open/close.



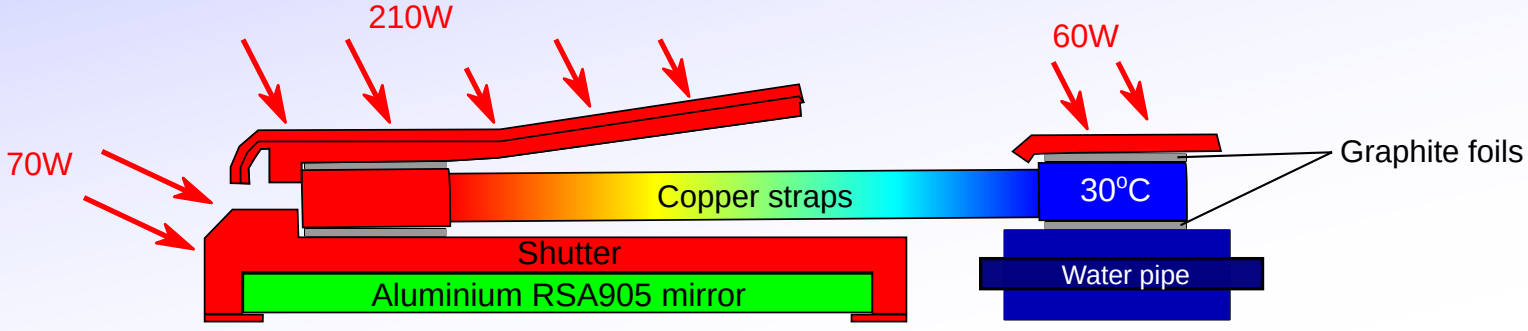
AEM21 Immersion Tube

Modifications required to flange:



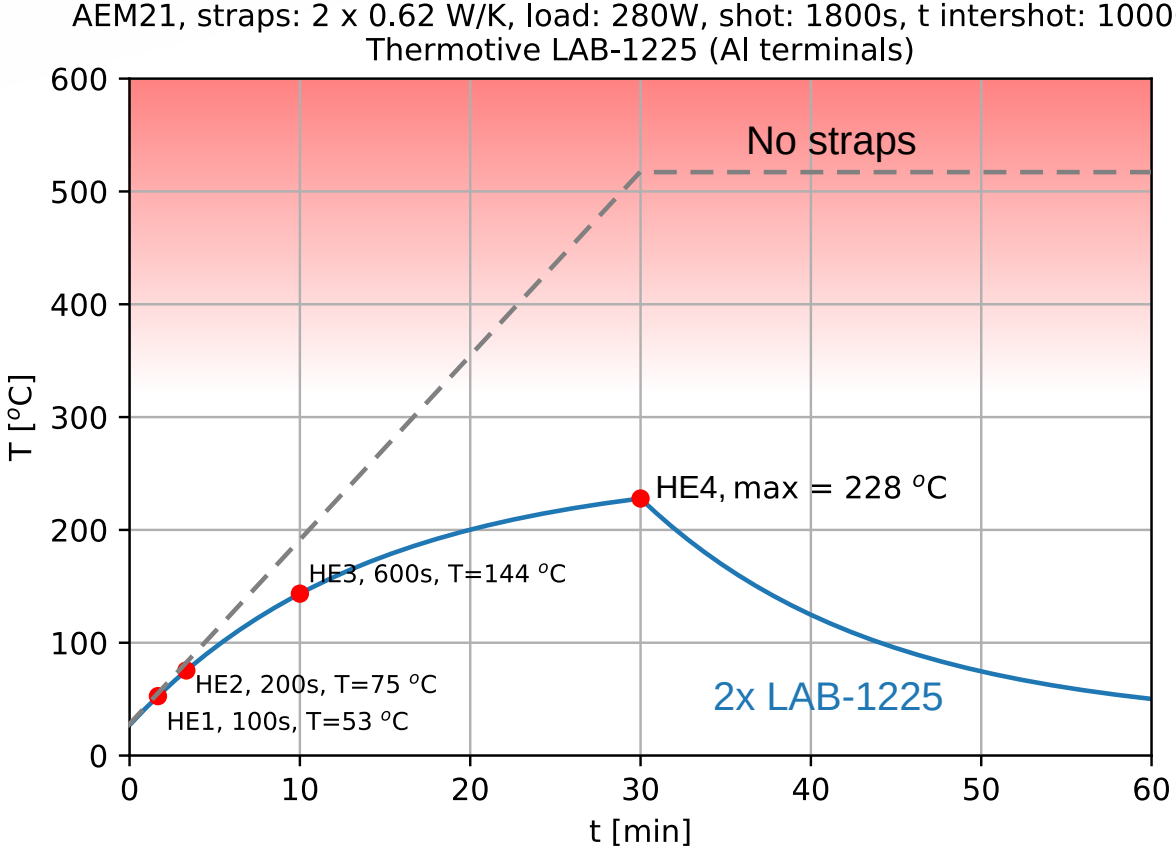
AEM21 Immersion Tube - Thermal

With shutter closed, body connected by thermal straps recieved 280W:



Initial tests of thermal straps + interfaces from gas-puff-imaging diagnostic:
- Achieved ~55% of advertised 'ideal' conductivity due to extra interfaces.

2x Thermotive LAB-1225 'standard' straps
- max 230°C at 18GJ
- **OK for HE4**

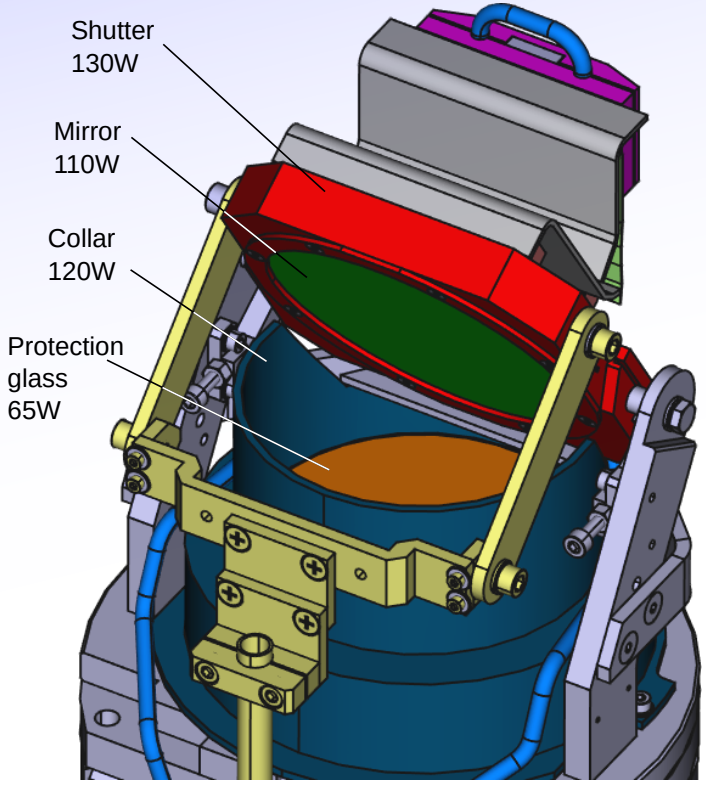


*Temperature solution is a balance of strap conductivity and the heat capacity of the steel shutter.

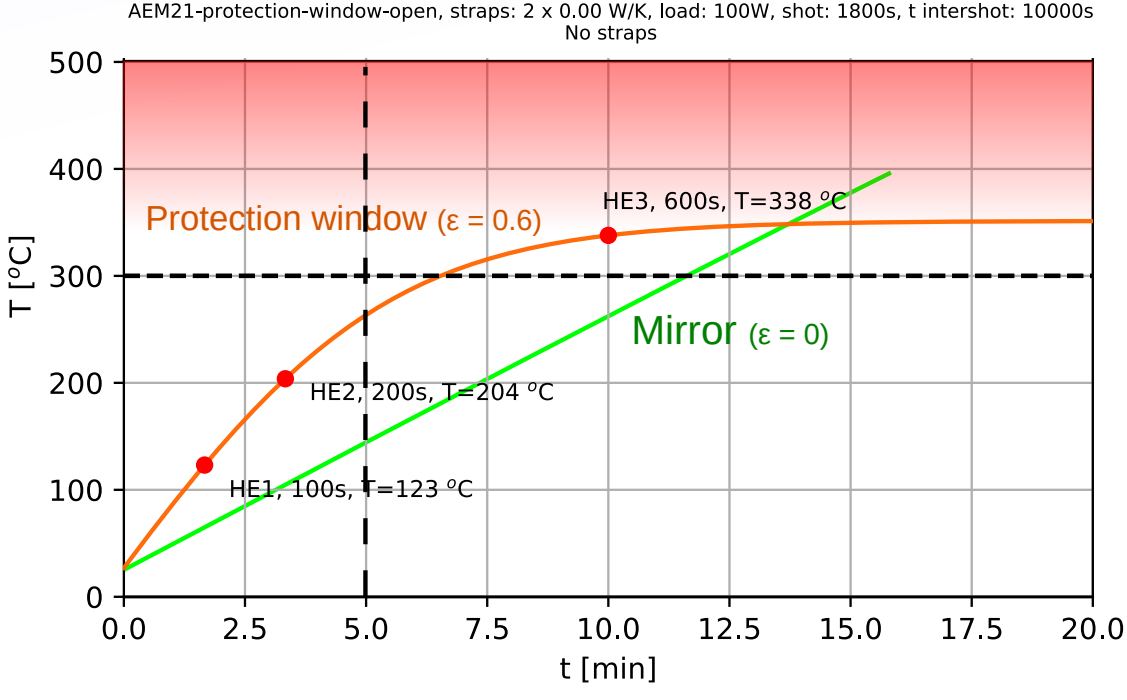
With no straps, 520°C would be reached.

AEM21 Immersion Tube - Thermal - Open

With open shutter:



Even without any heat transfer through contact with shutter, mirror can be safely exposed to full heat load for several minutes (once per day):



Protection glass can handle up to ~7 minutes
--> **Set maximum shutter open time = 300 seconds**

AEM21 Immersion Tube - ECRH stray radiation

Window used in OP1.2 was ITO coated but test in MISTRAL showed incorrect layer and strong absorption:
- At 12kWm^-2 --> ~25 °C/min >> 2 °C/min MAX

- Window did not break in MISTRAL tests or in OP1.2, so probably OK, but not certain.

Options for OP2:

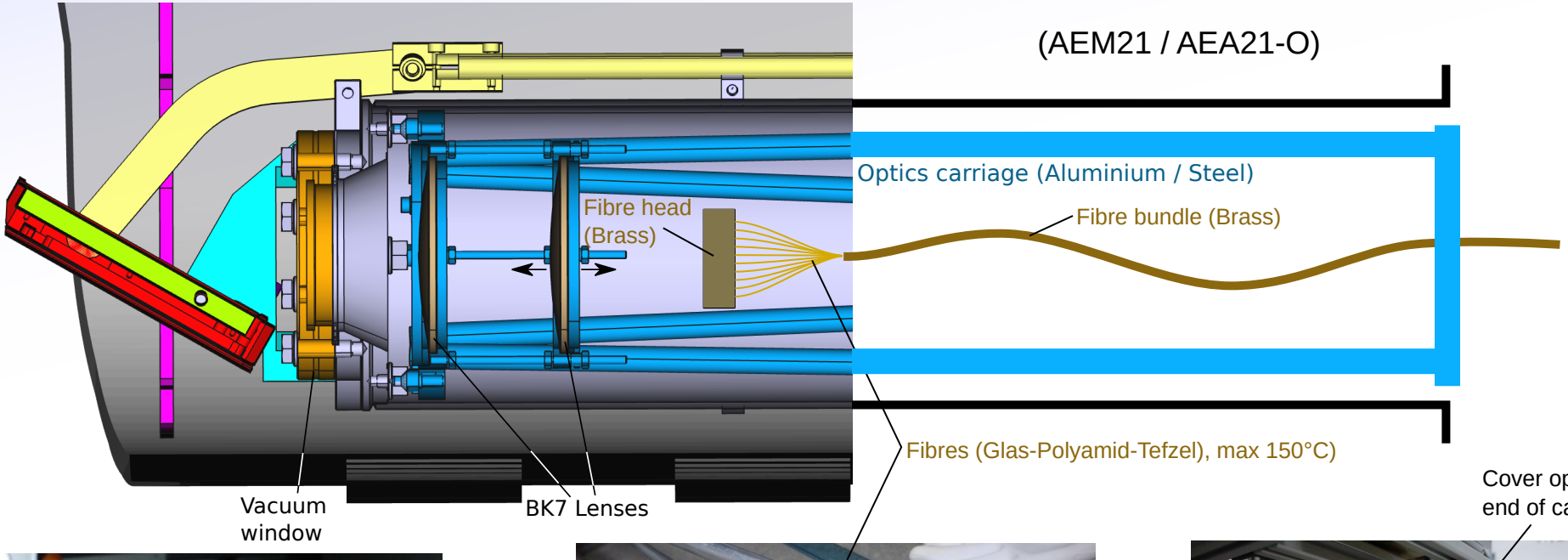
1) Keep windows, possibly take alternate option for OP2.2.
--> Risk of vacuum loss if significant stray radiation arises.

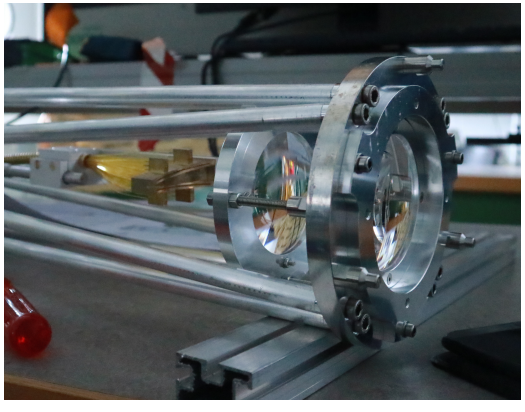
2) Replace with window with correct ITO coating.
- Manufacturer and specification not yet determined.
--> Probable significant delay to L-port test of immersion tube and vacuum closing.

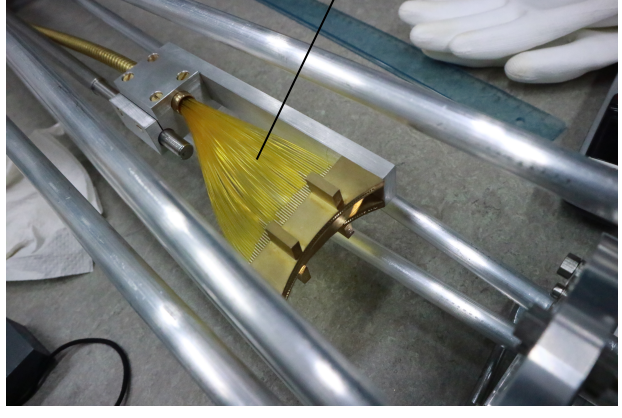
3) Replace with window without ITO coating:
- DN 100 CF window purchased and used in MISTRAL for long durations with no significant heating.
- Standard components that should arrive relatively quickly, so low risk of delay.
--> Need to ensure no ECR absorbing components in immersion tubes.

AEM21 Immersion Tube - ECRH stray radiation

Contents of tube (AEM21 and AEA21-O):
- Stainless steel and aluminium mouting components.
- Brass optic fibre bundle protection tubes.
- BK7 lenses are possibly mild ECR absorbers. **--> Test in MISTRAL**
- Tefzel coated single fibres. **--> wrap in thick metal foil.**

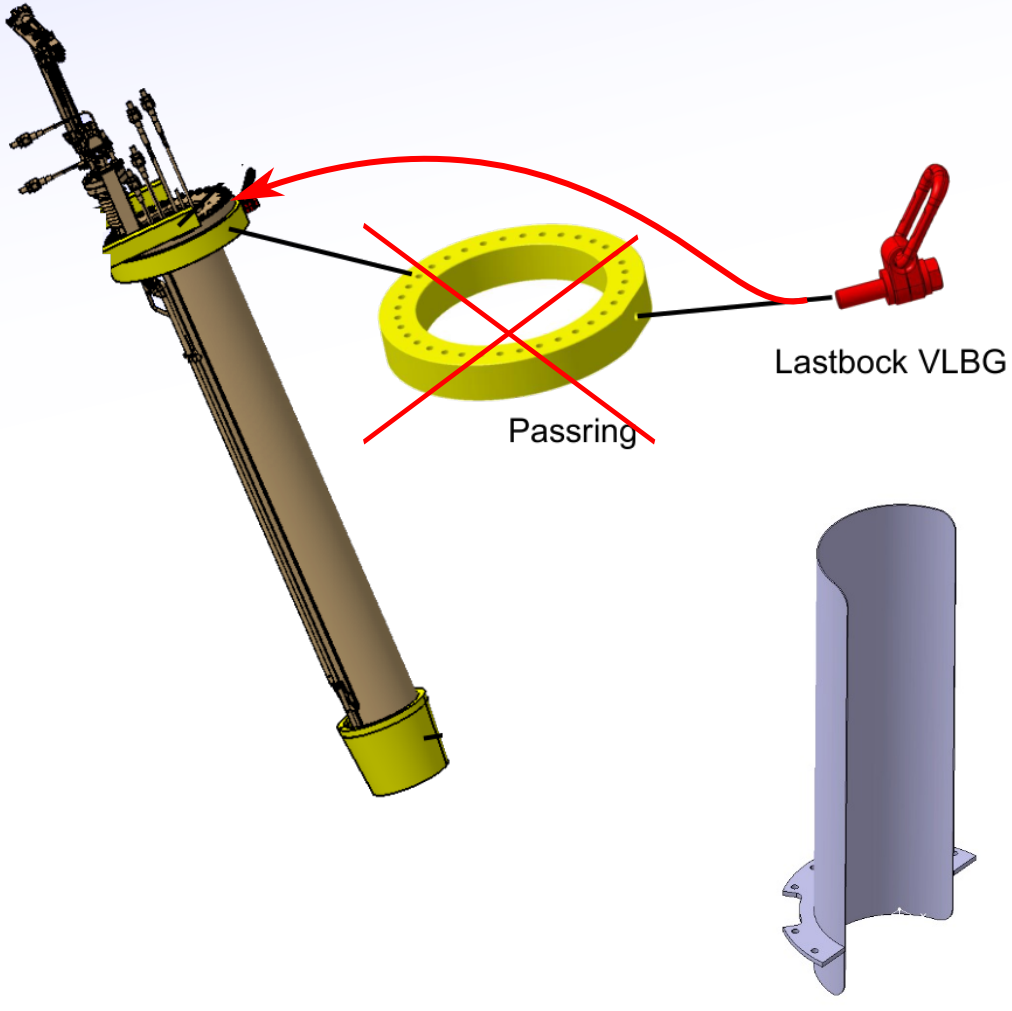


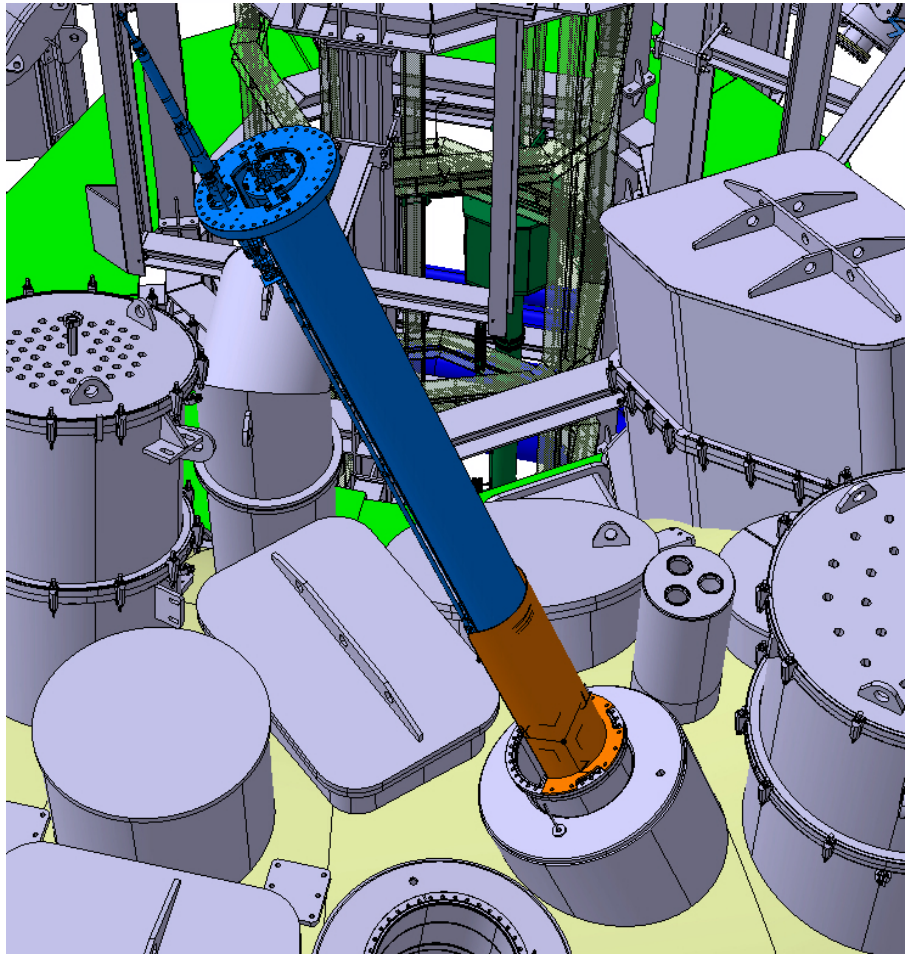




AEM21 Immersion Tube - Installation

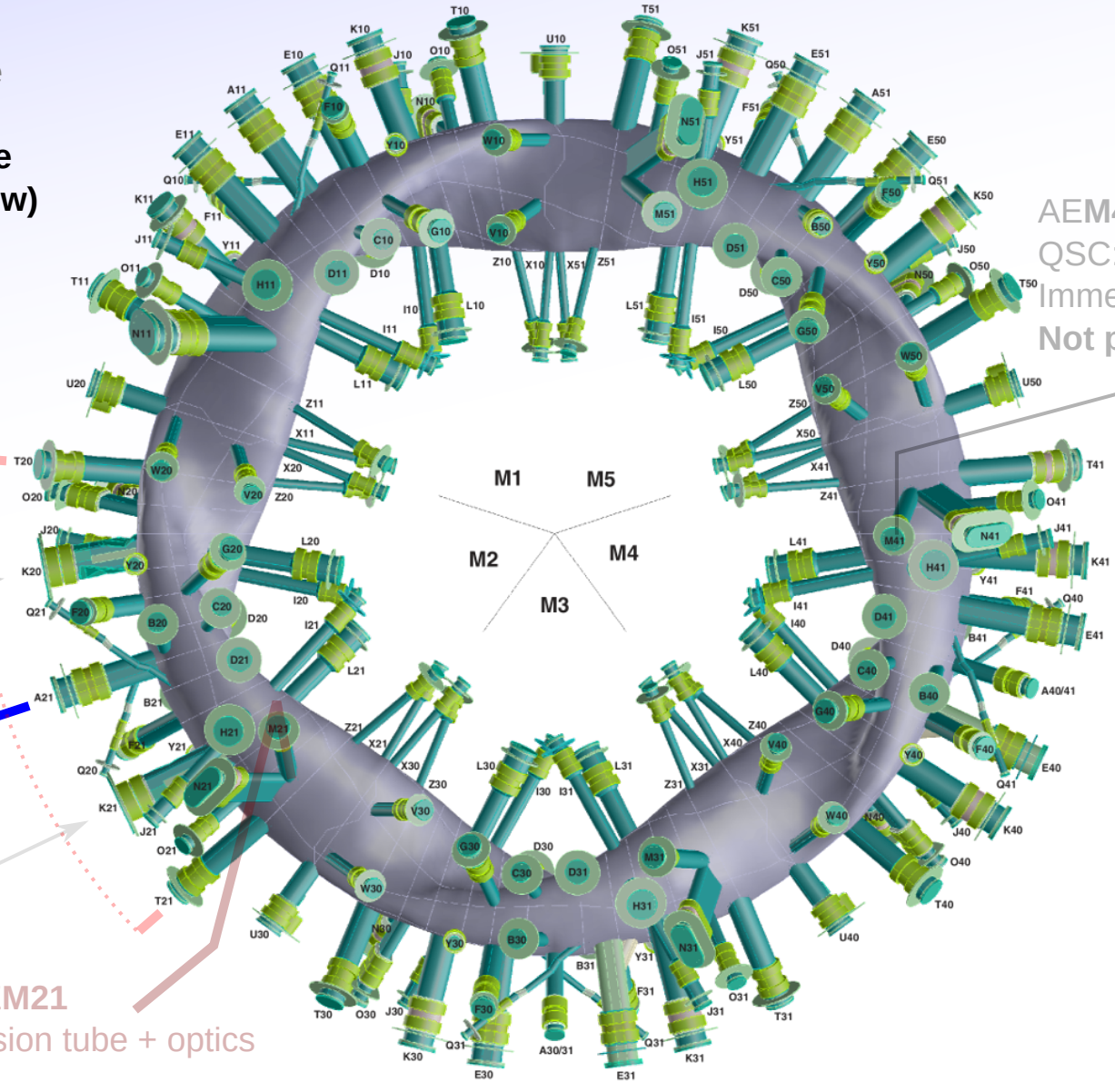
Installation as OP1.2, with modifications:
- Crane mount needs to be moved to immersion tube as passring is now installed with port protection.
- Guidance tube for lowering tube into place:





Component Overview

Outline:
1) AEM21: - Port protection
- Immersion Tube
2) AEA21: - Front plate
- Immersion tube
- Lower tube (new)
3) AET21: - Fibres
4) Documentation etc.



AE**M41**
QSC: CXRS am RuDIX
Immersion tube
Not part of QSK!

RuDIX

K3: AE**T20/21**
Immersion tubes + optics
(In QYB/P0008)

NI20

AE**K41**
K6: Passive CXRS

K1: AE**A21**
Immersion tube
+ optics

NI21

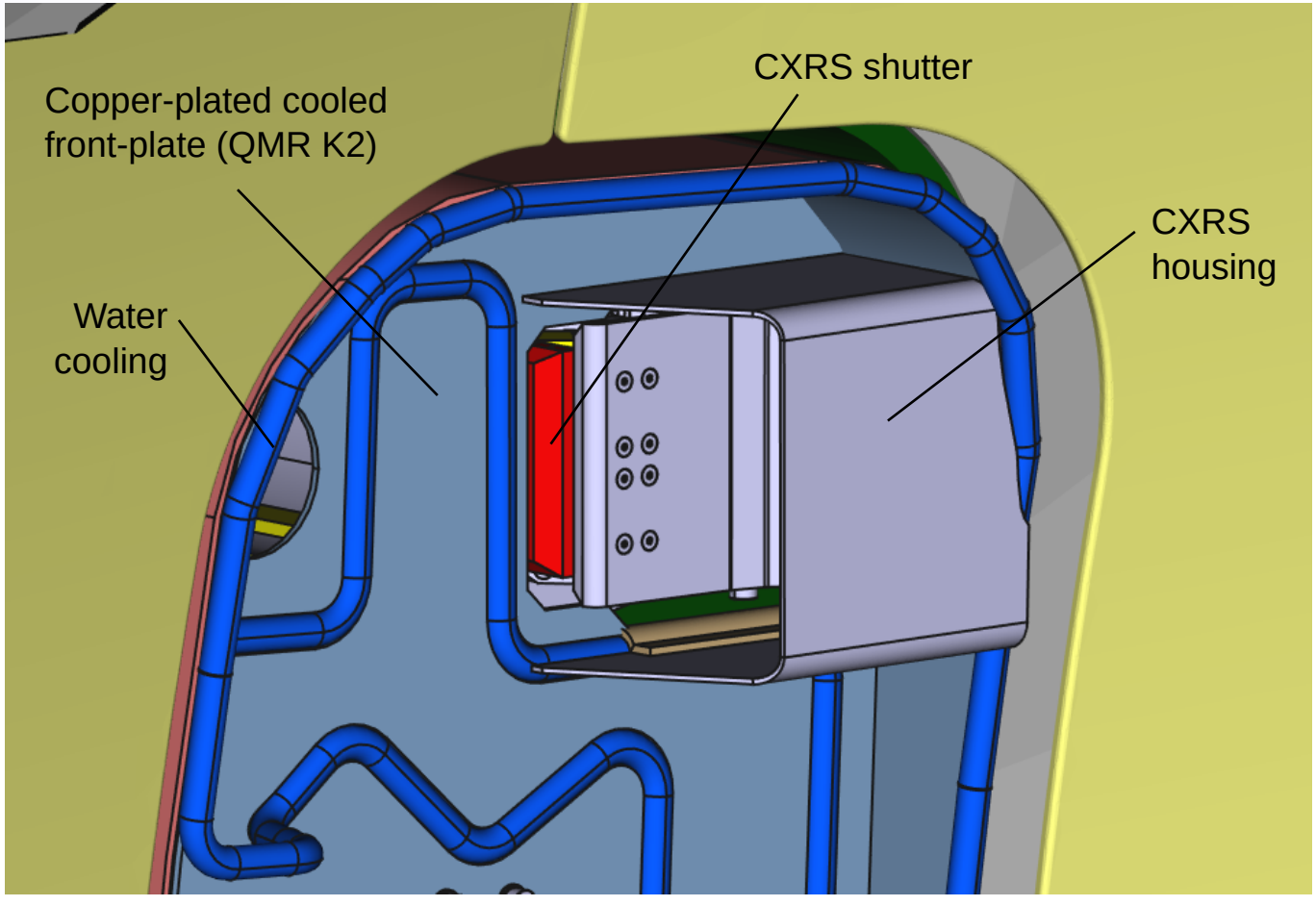
K2: AE**M21**
Immersion tube + optics

K4: Fibre optic transfer to lab.
K5: Spectrometers and components in lab

Complete in OP1.2b, no changes for OP2 - not covered in this CDR!

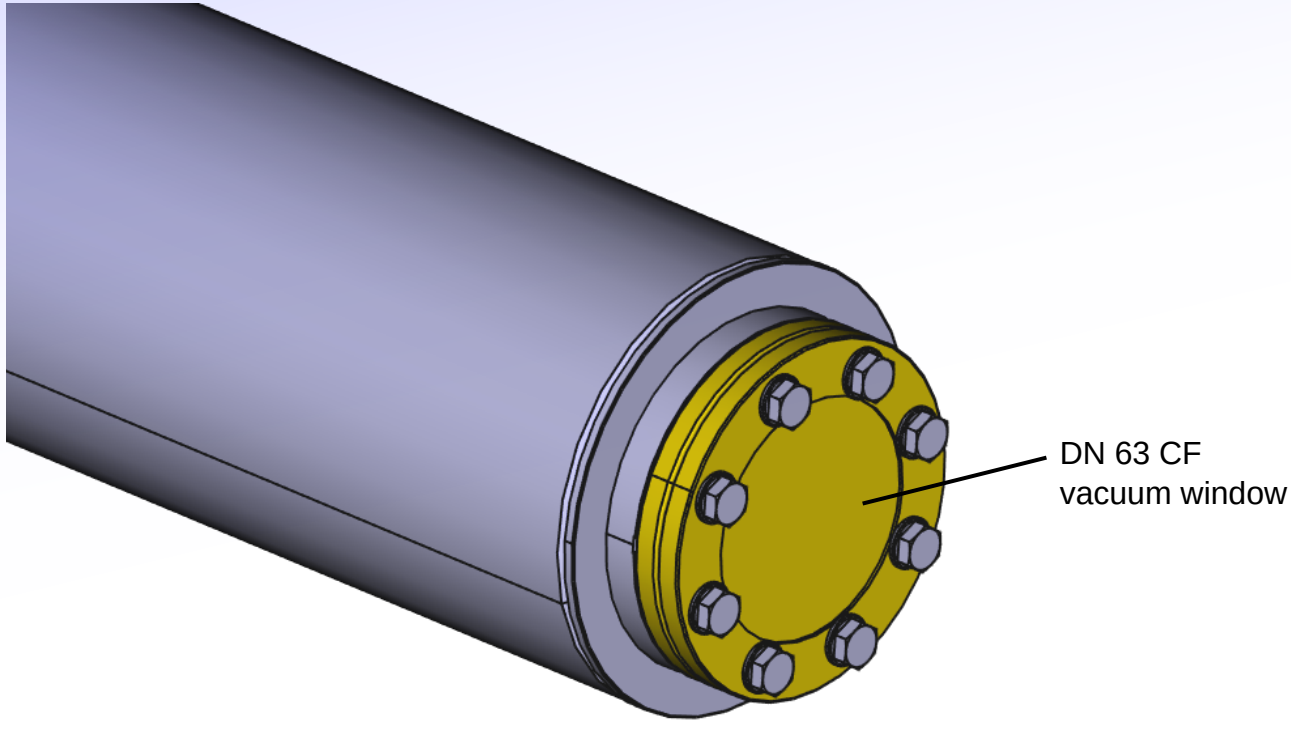
AEA21 Immersion Tube - Overview

- Common cooled front plate for all AEA21 diagnositcs (QMR K3)
  - Addition of 'CXRS Housing' to reduce load to closed shutter.



AEA21 Immersion Tube

Details of tube, shutter etc largely the same as AEM21:



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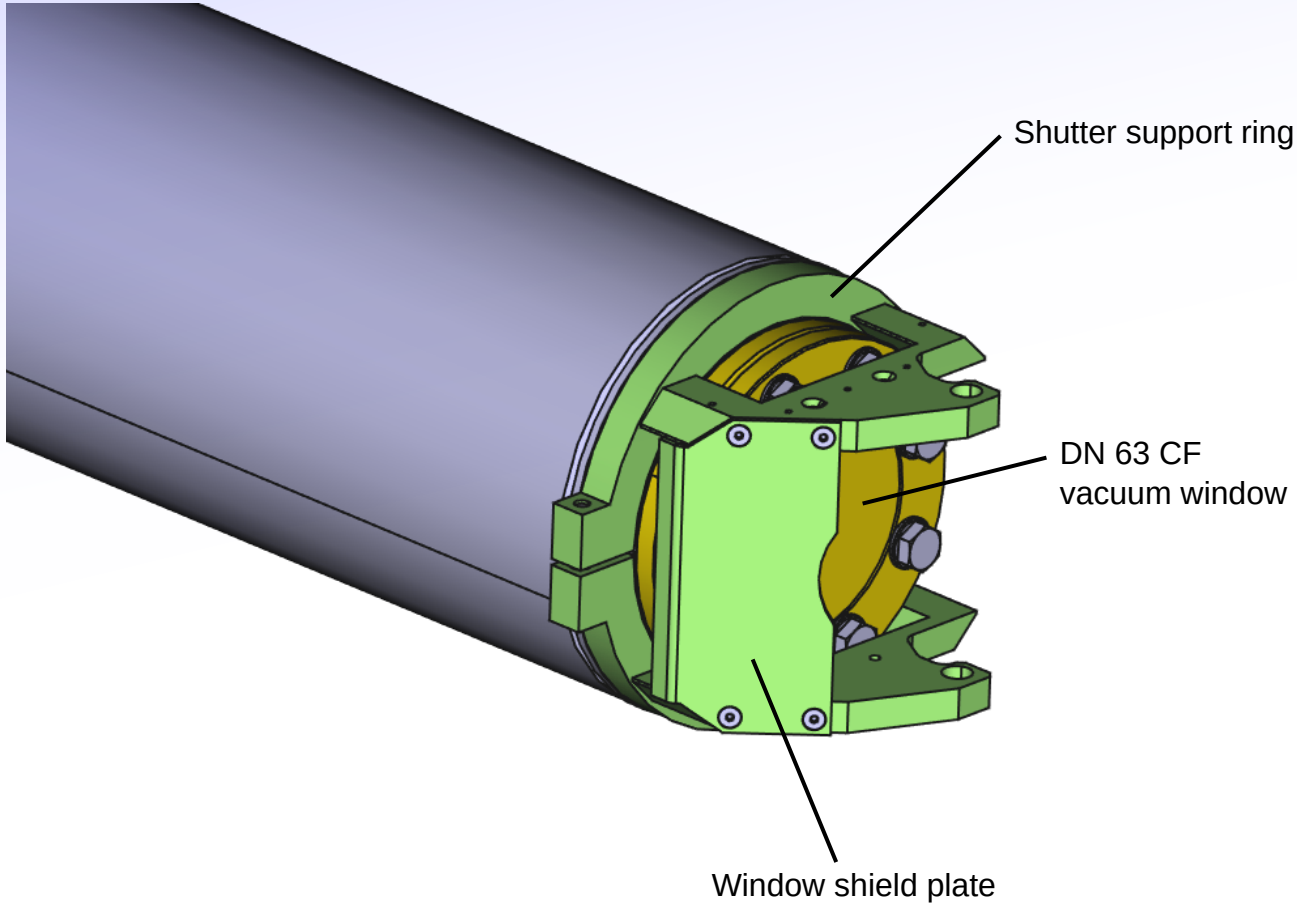

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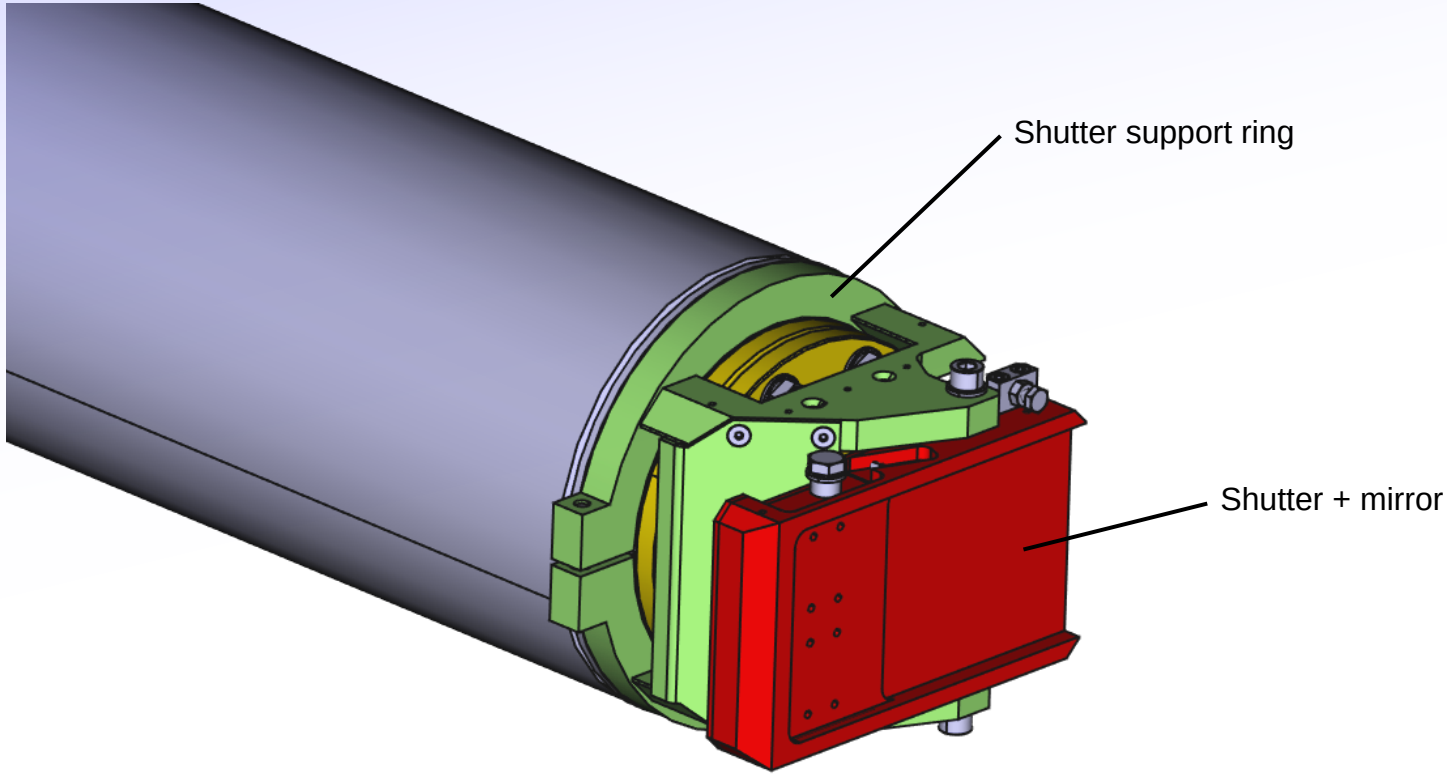

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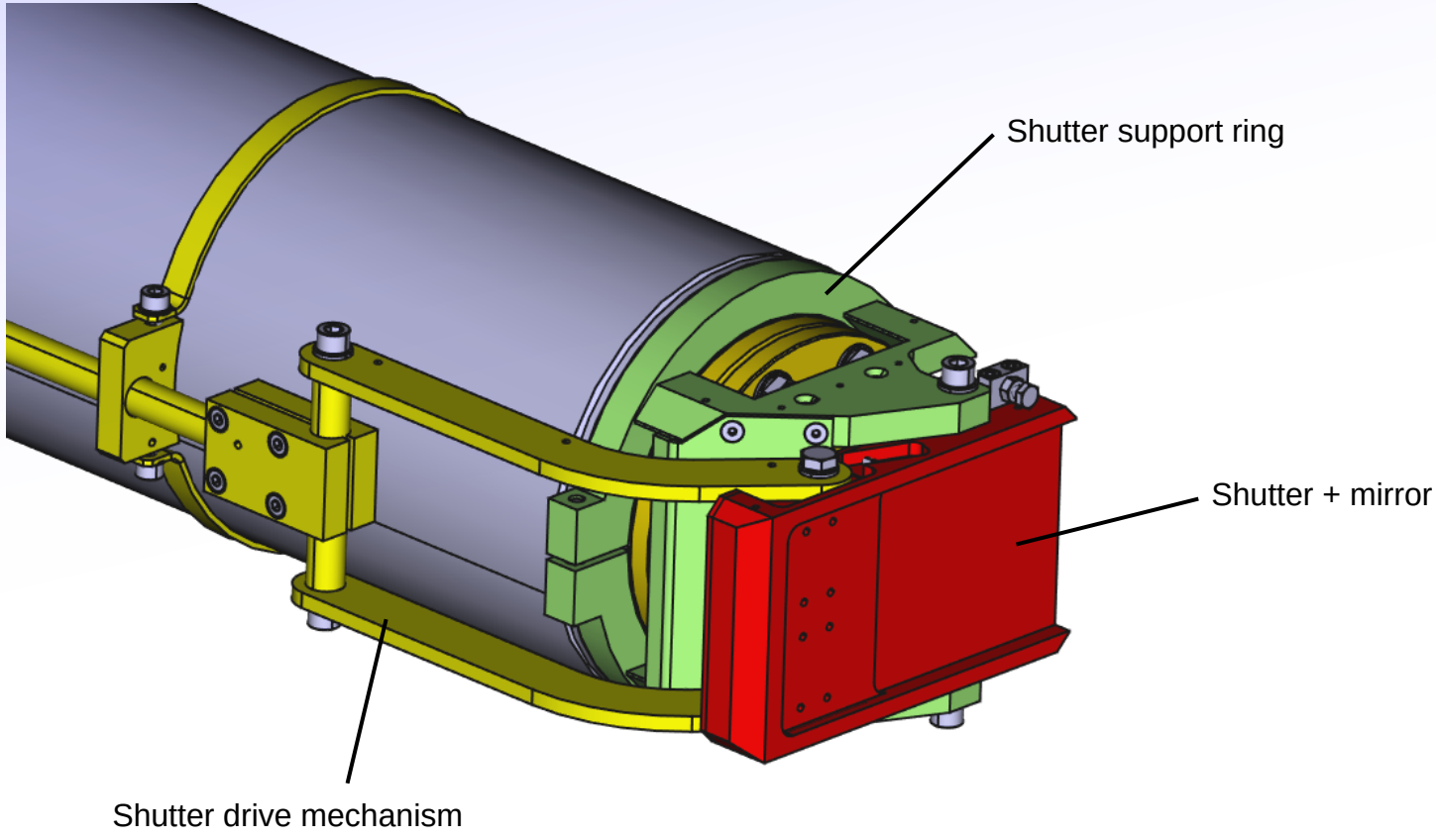

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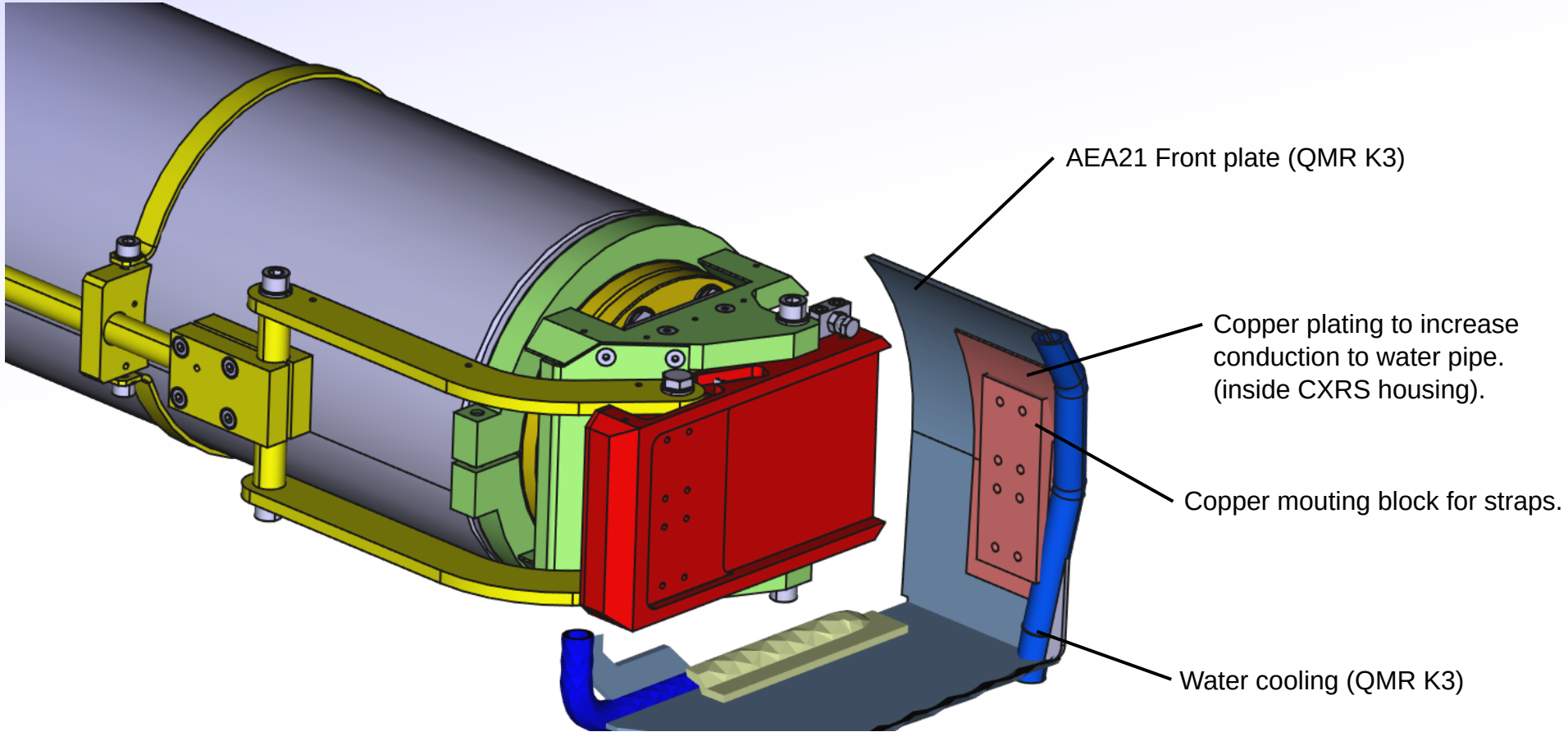

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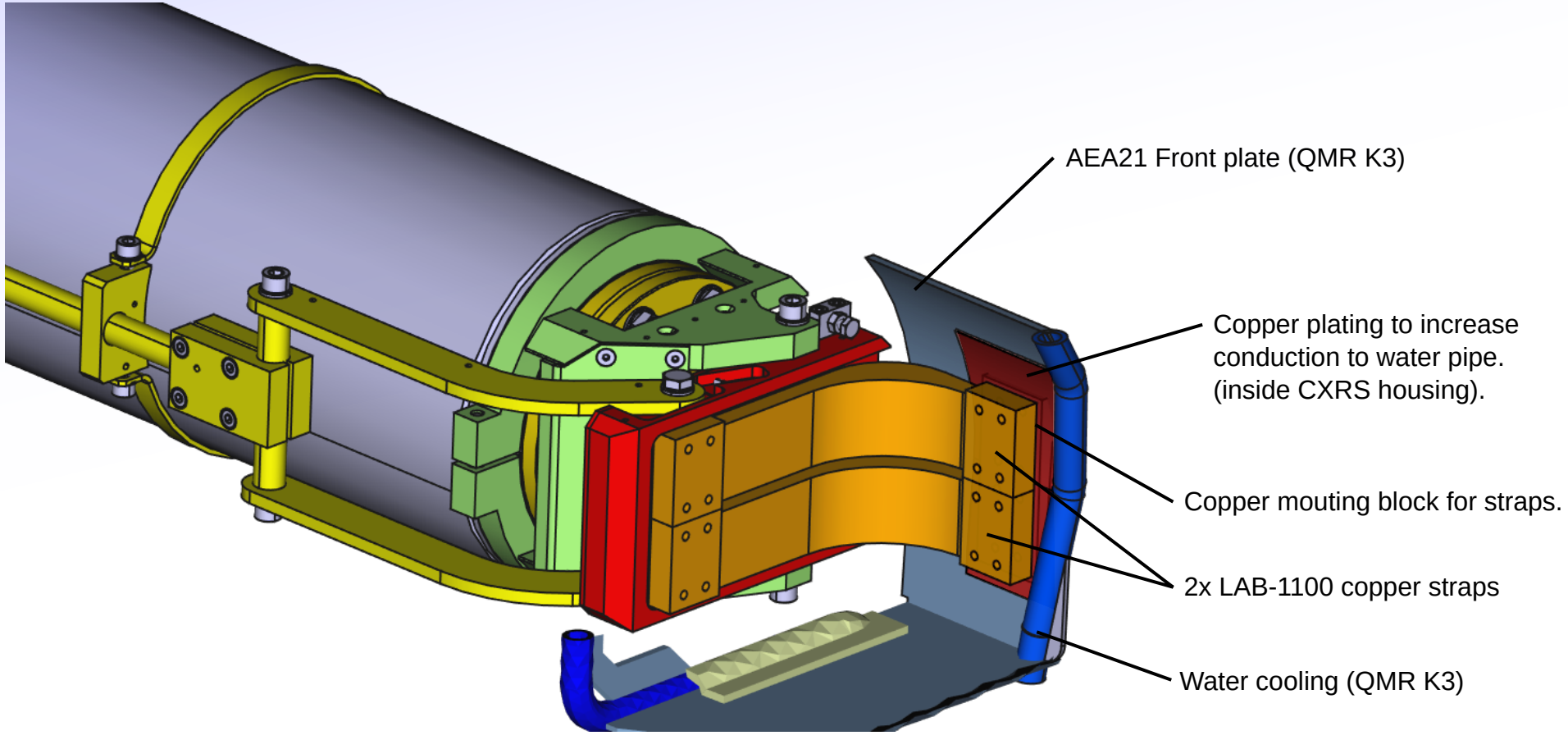

AEA21 Immersion Tube

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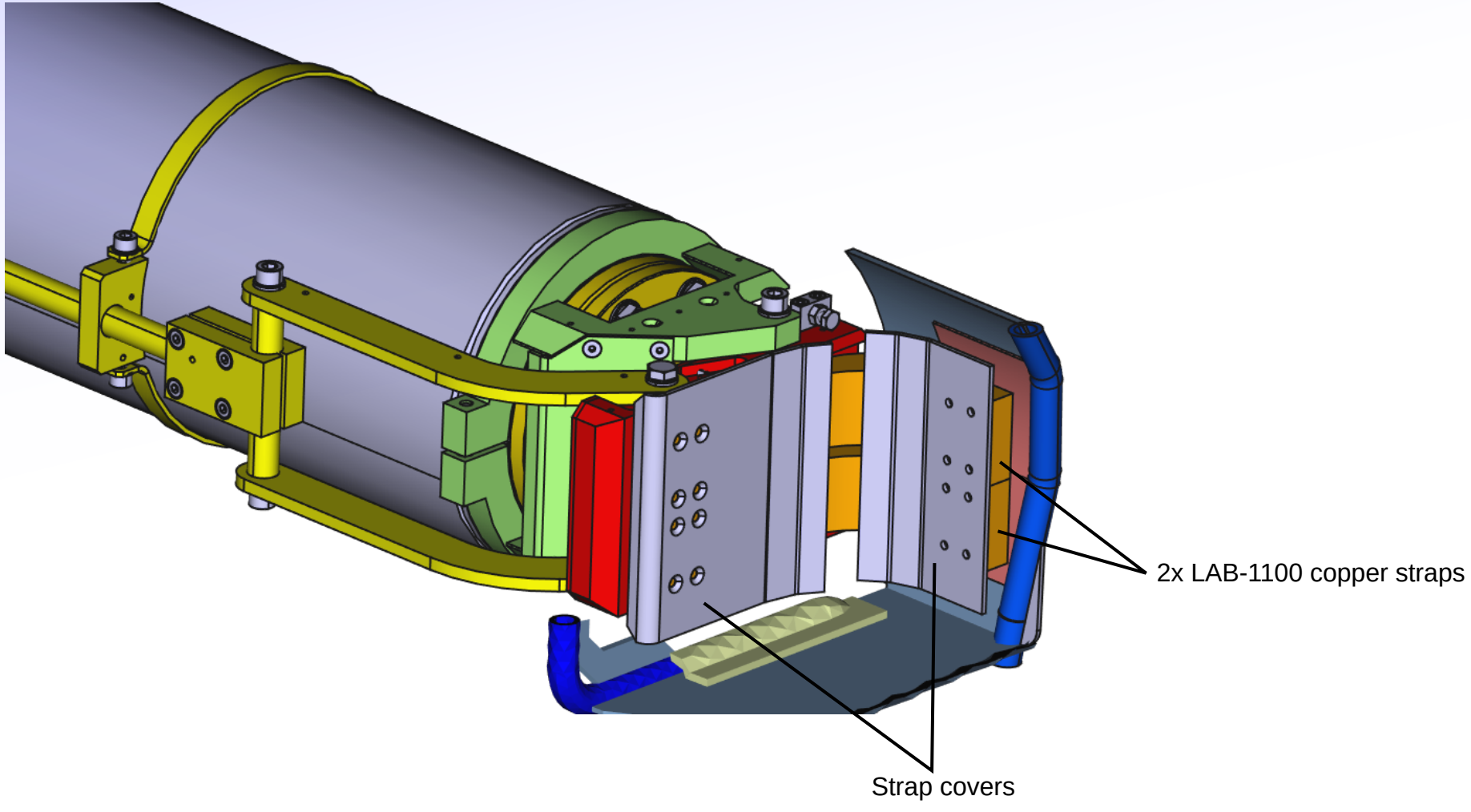

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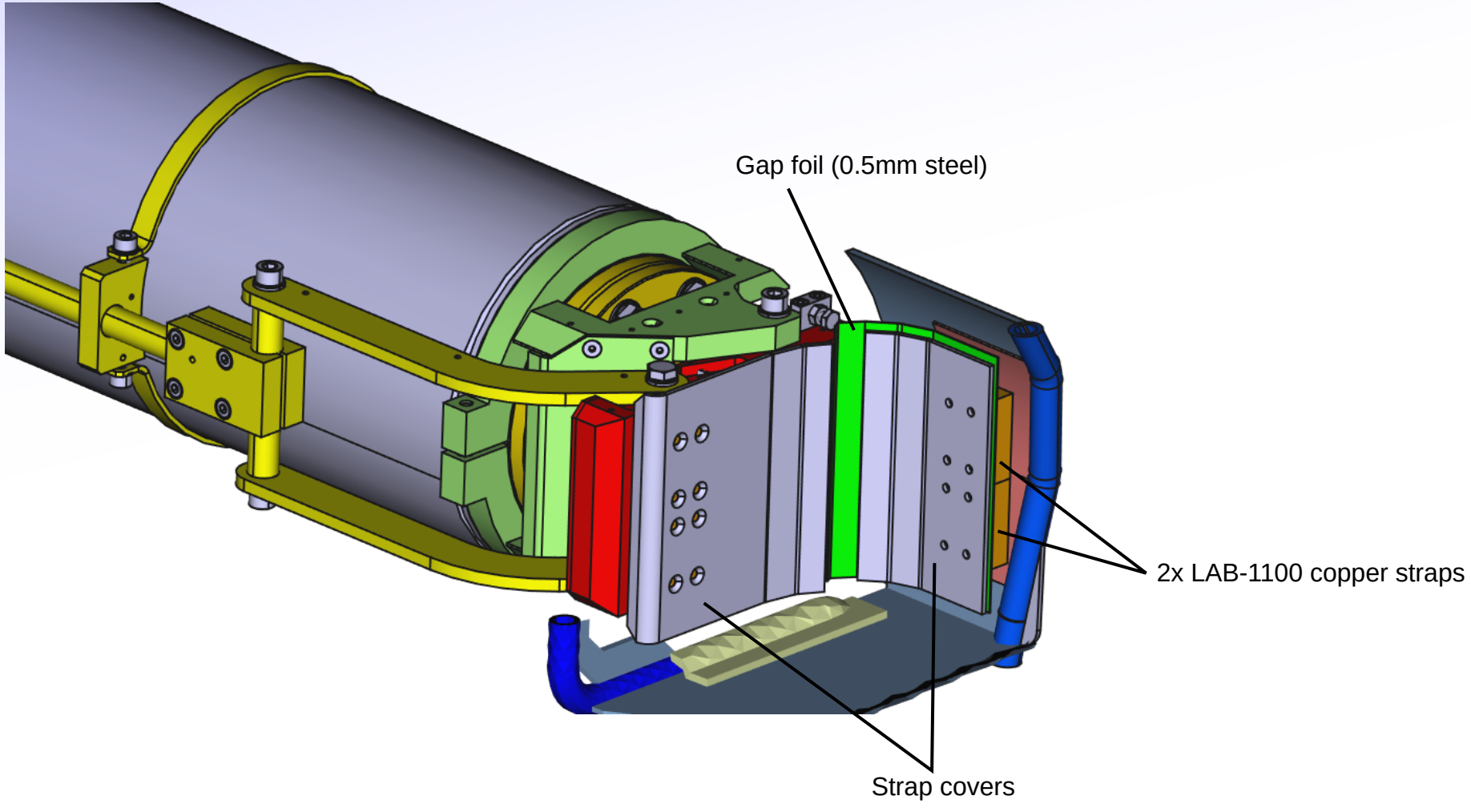

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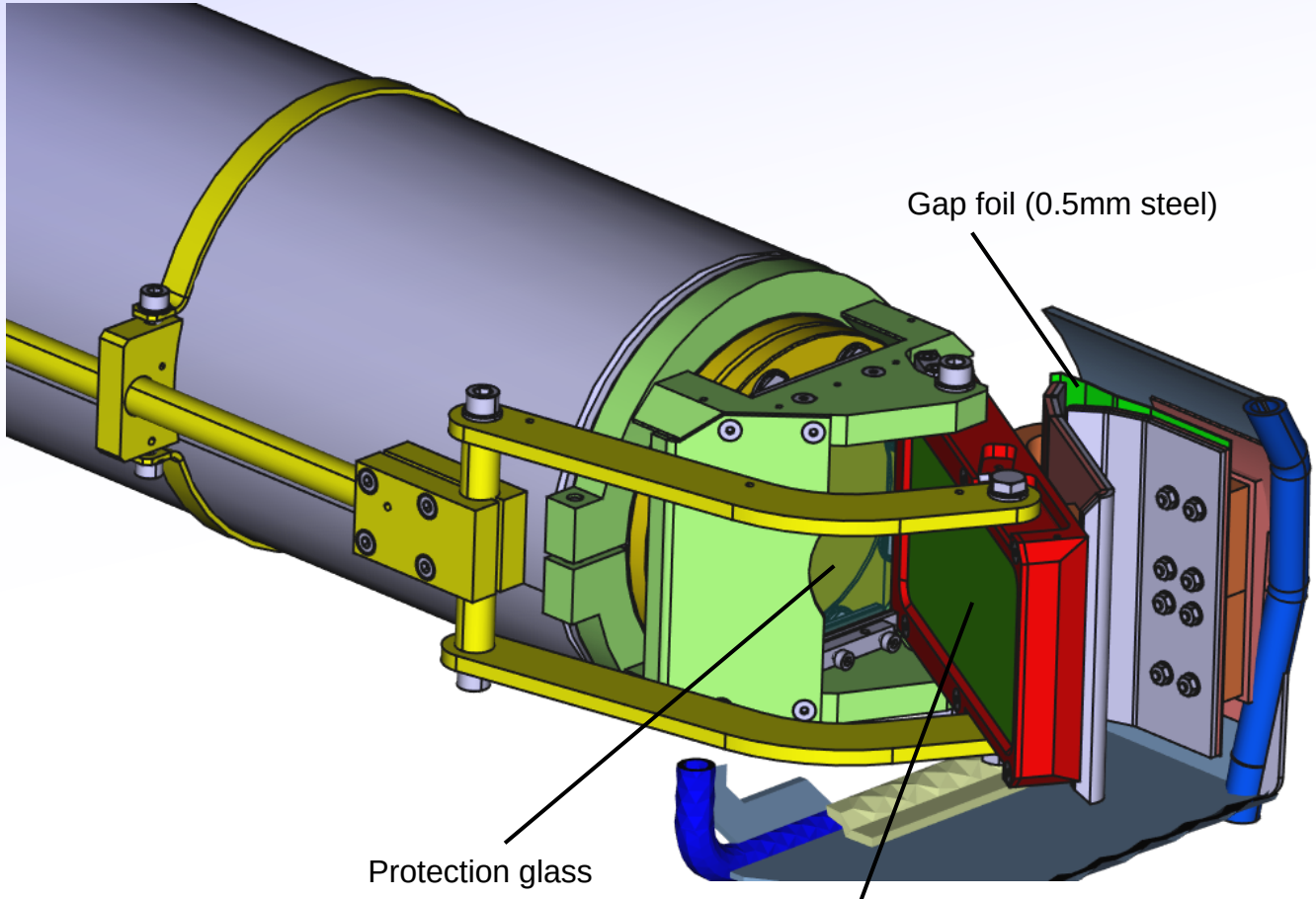

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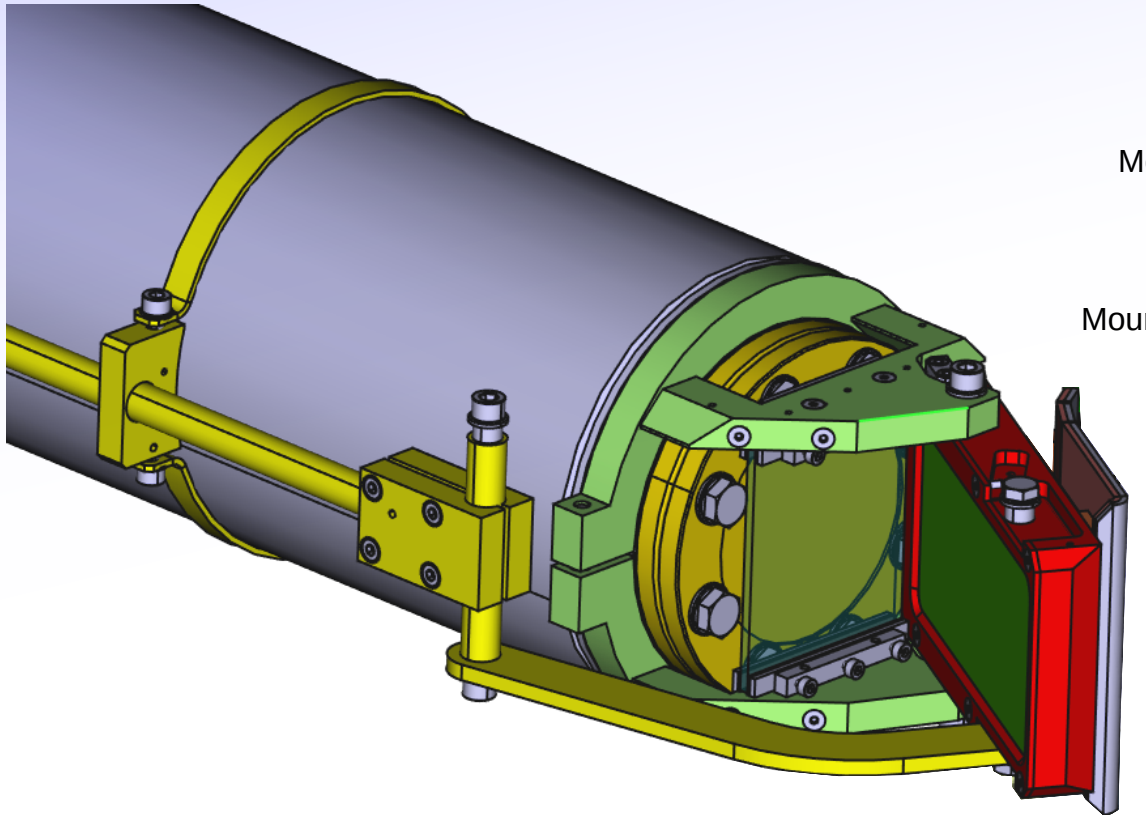
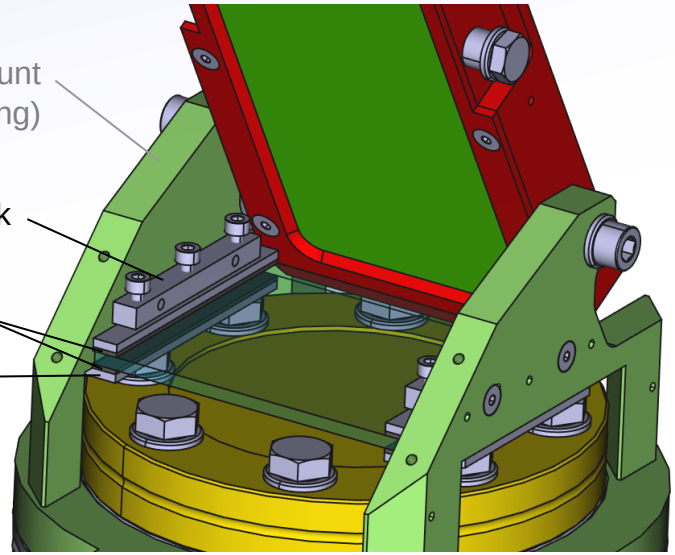
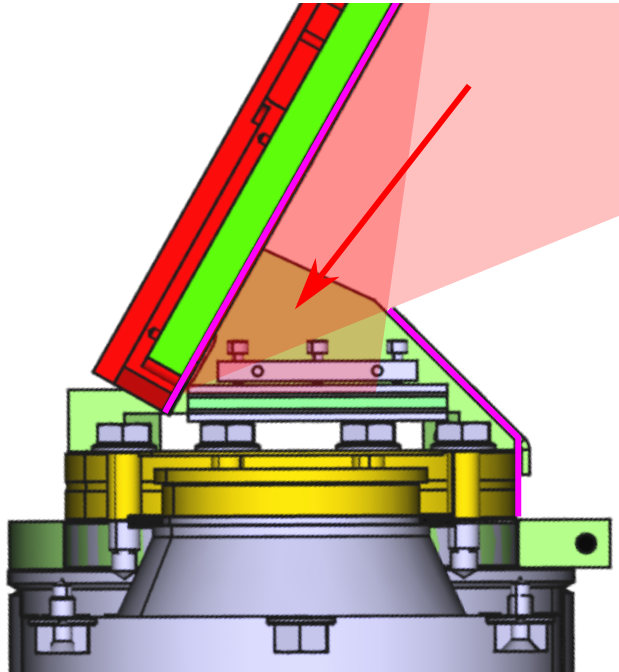




Shutter open: Limited exposure to plasma. Window completely protected by glass:



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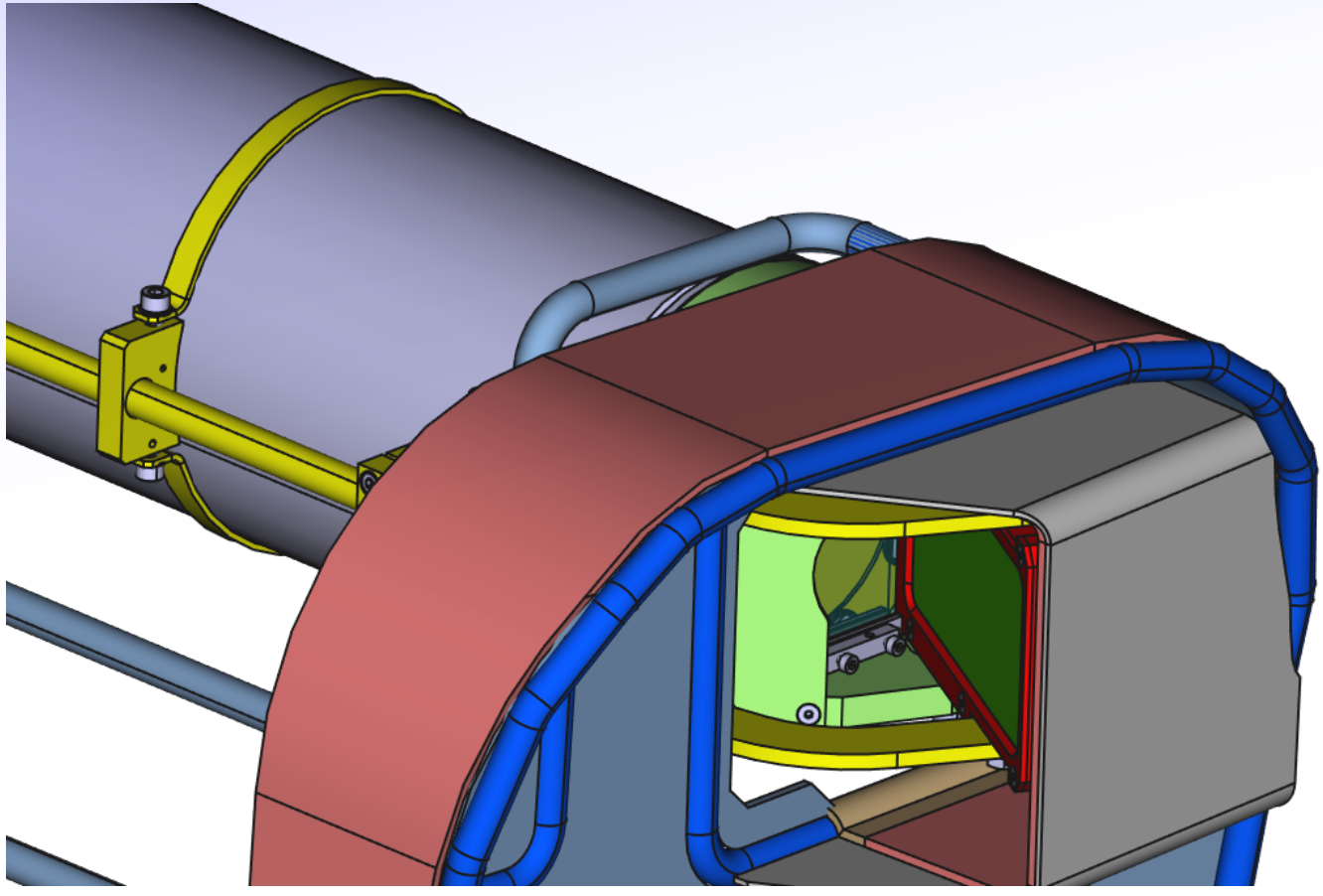
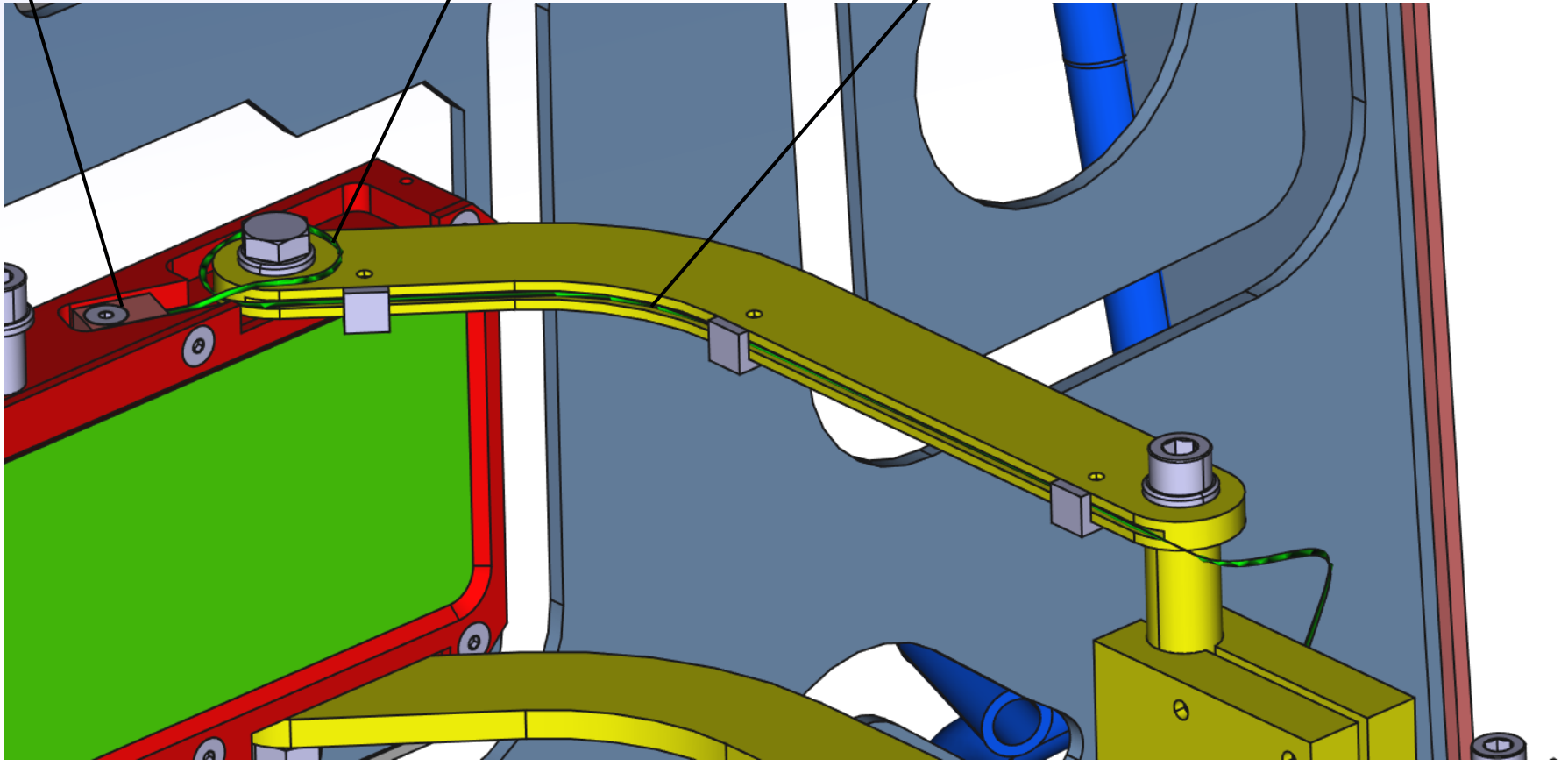


AEA21 Immersion Tube - Thermocouple

Thermocouple mounted on top of shutter.

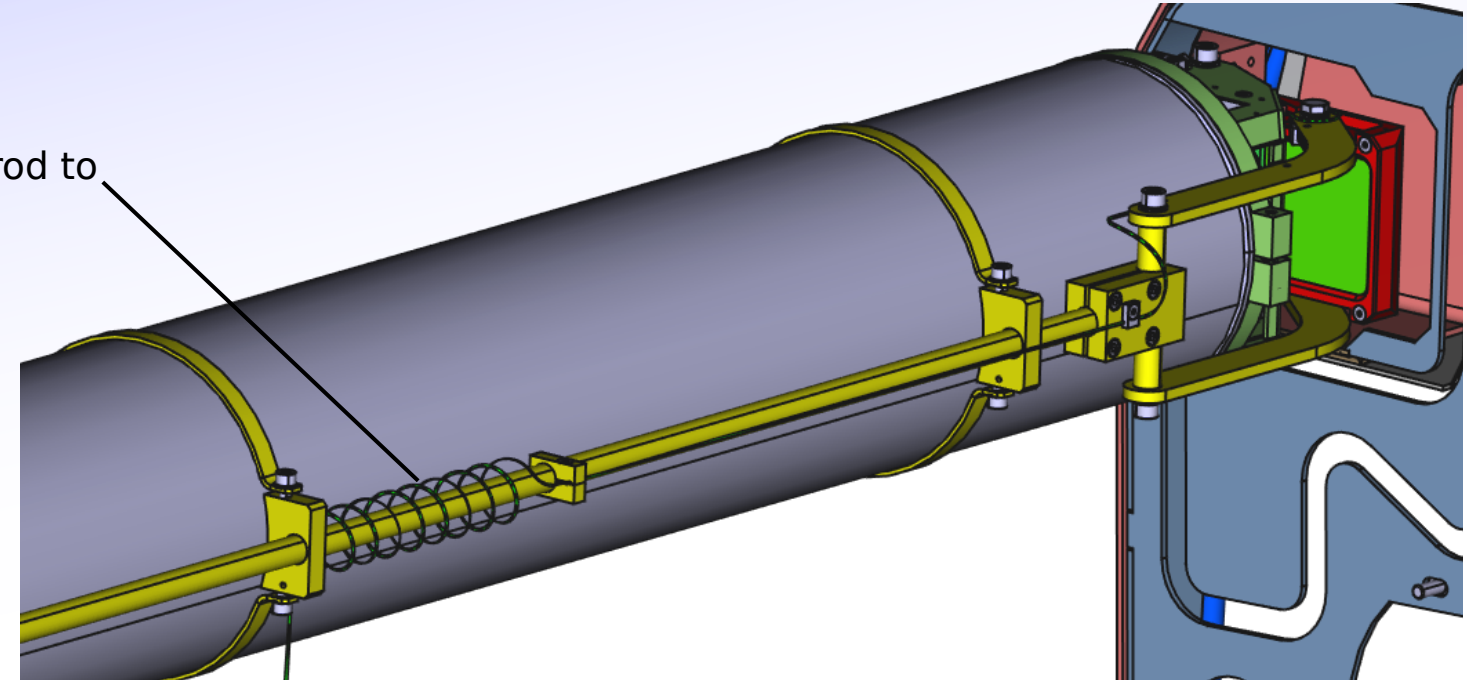
Loop to allow movement at drive bar hinge

Slot in drive bar to hold and protect wire when shutter open.

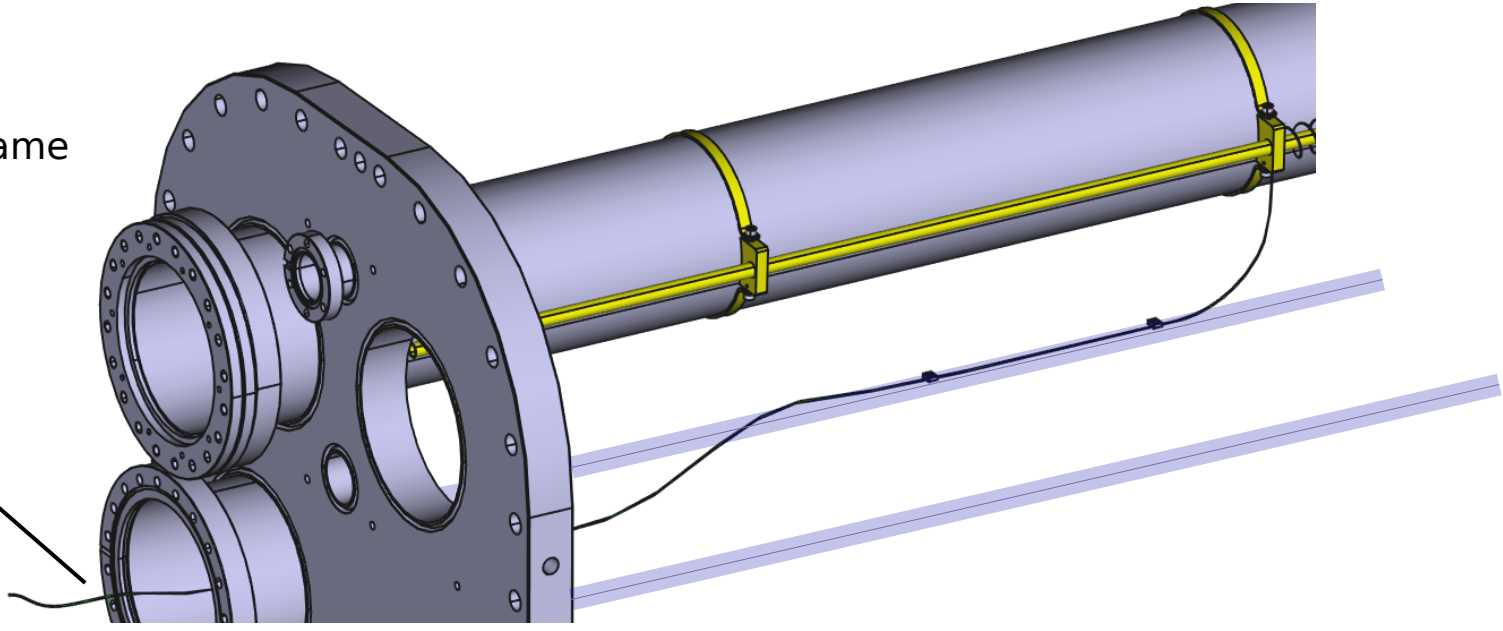


AEA21 Immersion Tube - Thermocouple

Wire coil on drive rod to allow movement.

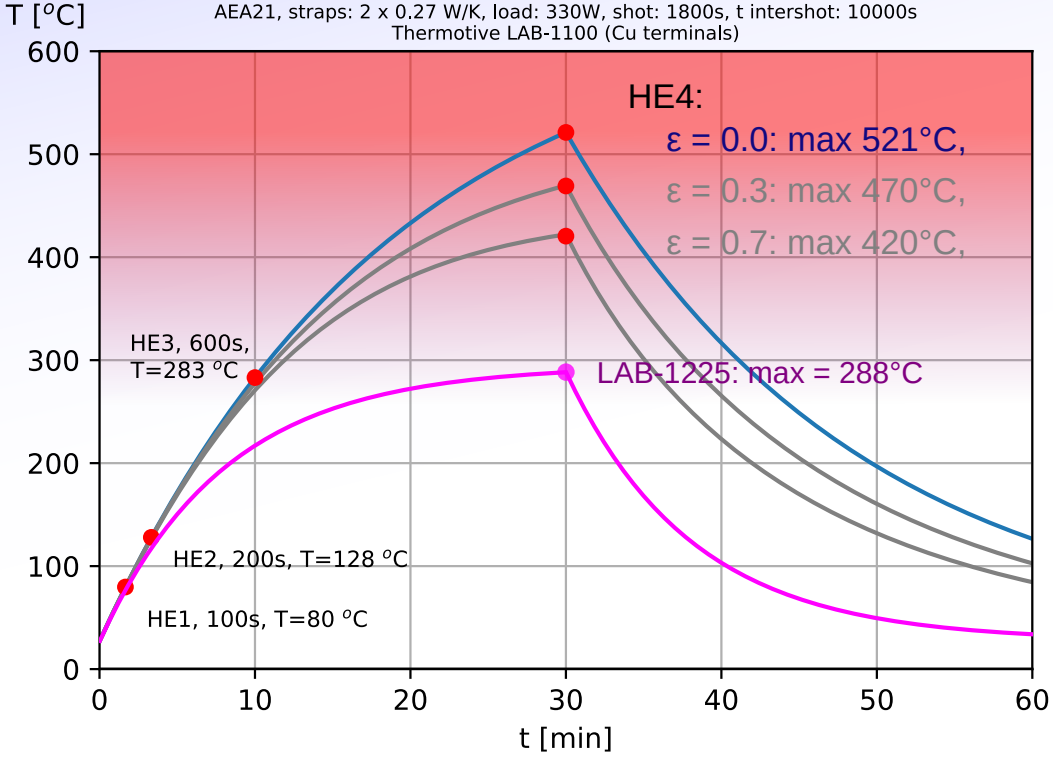


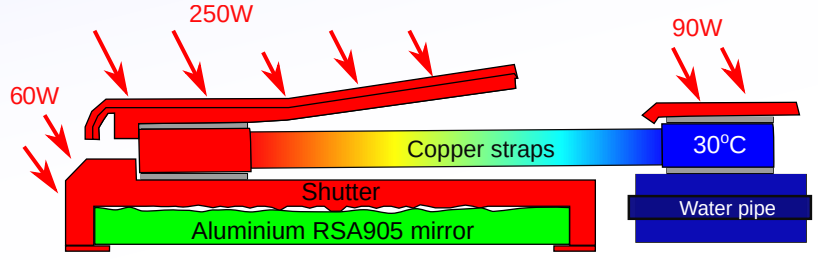
Wire transfers to QMR frame and exits via combined feed-through on other sub-flange.



AEA21 Immersion Tube - Radiation loads

Heat load of 330W on shutter assembly.
Temperature evolution faster than AEM21 due to larger heat flux and smaller LAB-1100 straps.



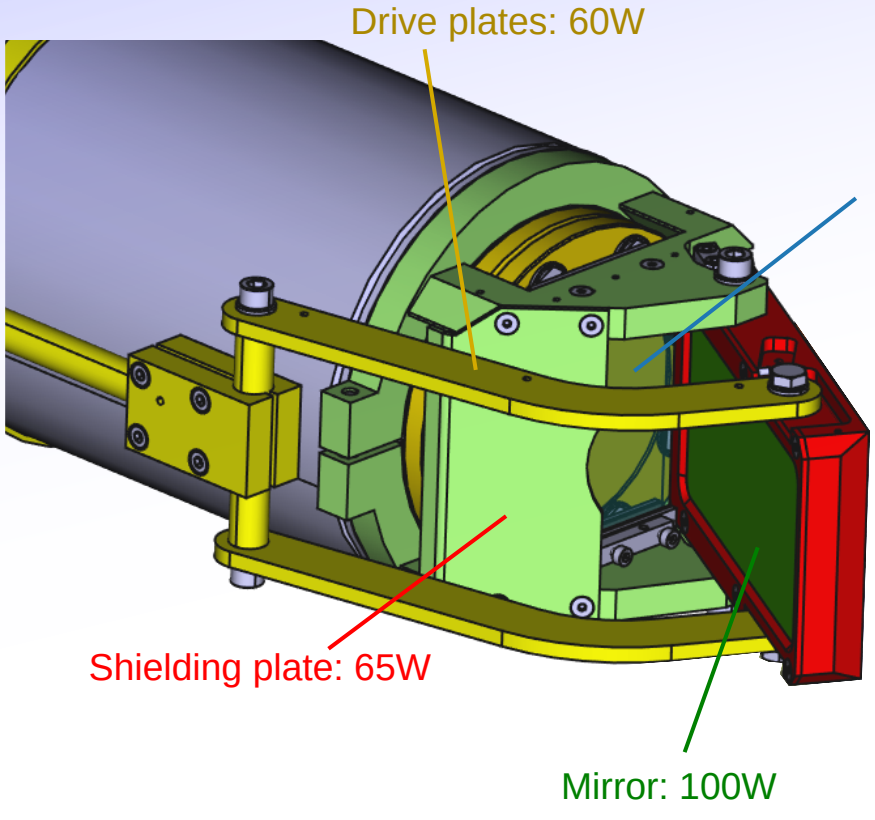


- Acceptable up to **HE3**.
- At HE4, max temperature critical, but assumptions are already extreme:
  1) No assumed emissivity.
  2) 450°C acceptable for shutter/cover (steel + copper) and thermal conduction to aluminium is likely to be poor.

3) 100kWm^{-2} assumption is already ~2x the actually expected radiation [Eich, Werner 2008].
4) Stable deteachment expects ~80% radiation.
5) Assumes 100% absoption of plasma radiation (no reflection).
- Relaxing any single assumption brings max temperture into safe region.

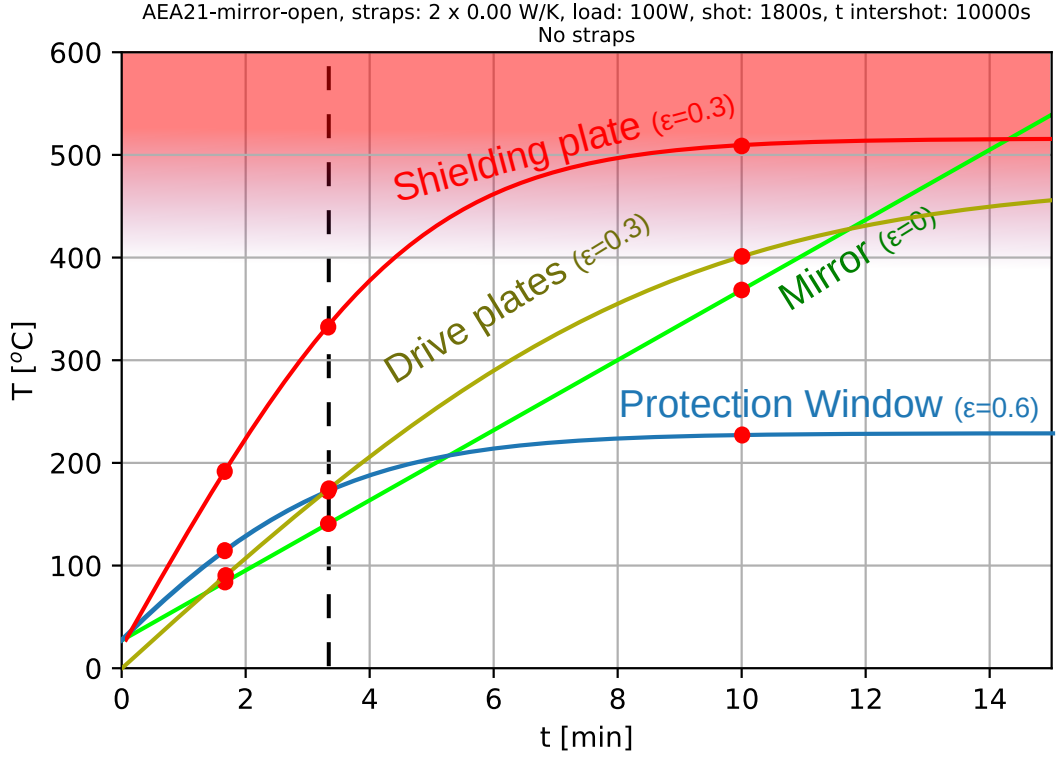
--> Accept this design for HE3 and monitor real temperature evolution of shutter with thermocouple during OP2.1 - 2.3 detachment experiments.
- Redesign using LAB-1225 possible after OP2.1.

AEA21 Immersion Tube - Radiation - open



Protection window reaches max 220°C even if shutter remains open.

Thin steel shielding plate sets limit of ~200s (HE2) max **open** shutter time.



Thermal analysis - Summary

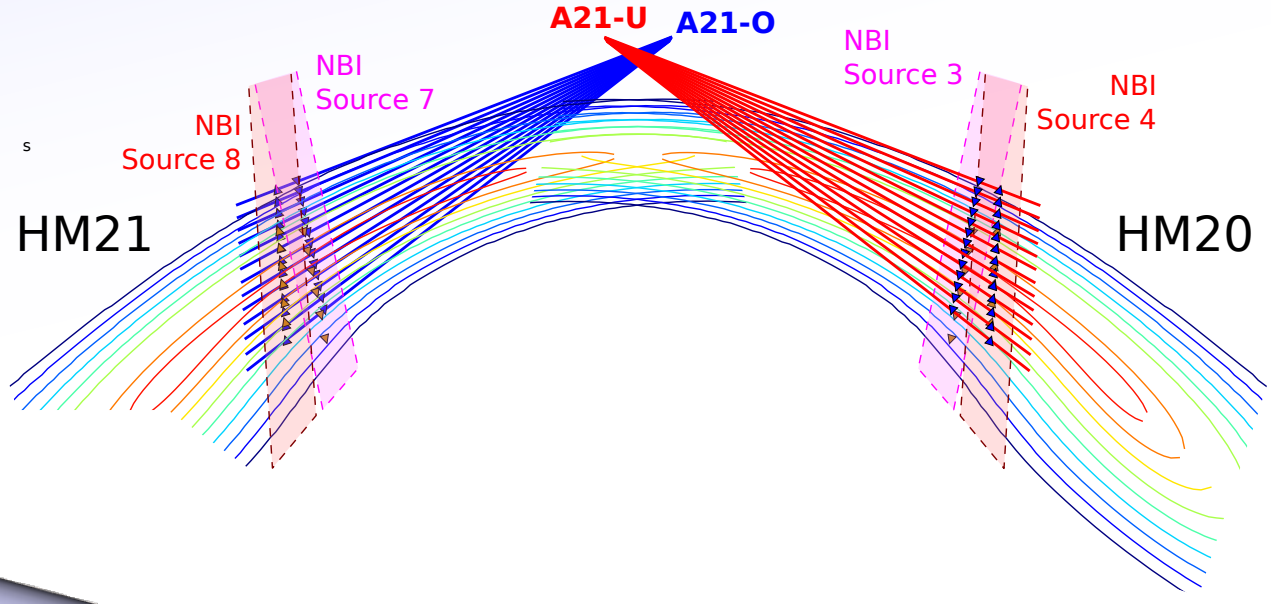
Implications of thermal analysis are summarised in the Safety Analysis [1-QSK-T0003]:

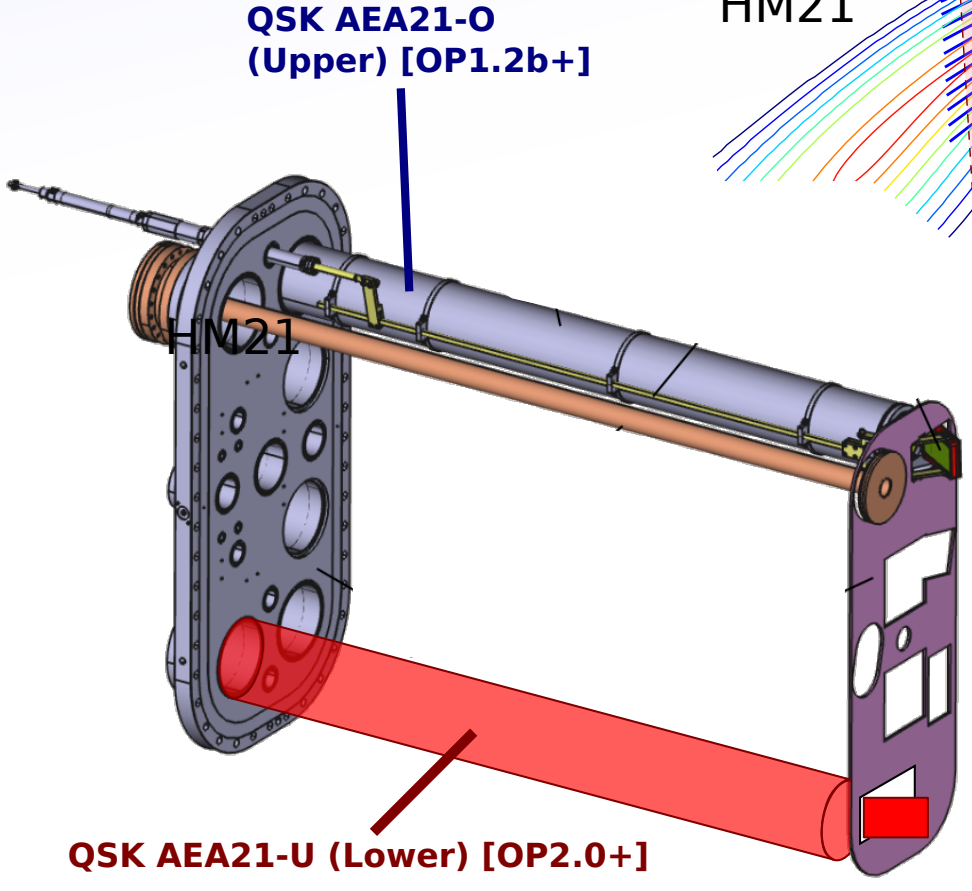
Component	Shutter	1GJ (HE1)	2GJ (HE2)	6GJ (HE3)	18GJ (HE4)
K1: AEA21	Open	OK		Up to 200 seconds	
	Closed	OK			To be assessed
K2: AEM21	Open	OK		Up to 300 seconds	
	Closed	OK			
K3: AET21	OK (See Project QYB / P008)				
K6: AEK41	-	OK			

Table 1: Summary of thermal analysis

AEA21-U - Video, CIS, CXRS-CIS

- Copy of AEA21-O immersion tube and cooling components. (Stellarator symmetric)
- Toroidal view of HM20 for video (QSV), coherence-imaging (QRI) and CXRS-CIS (QSK/QRI)

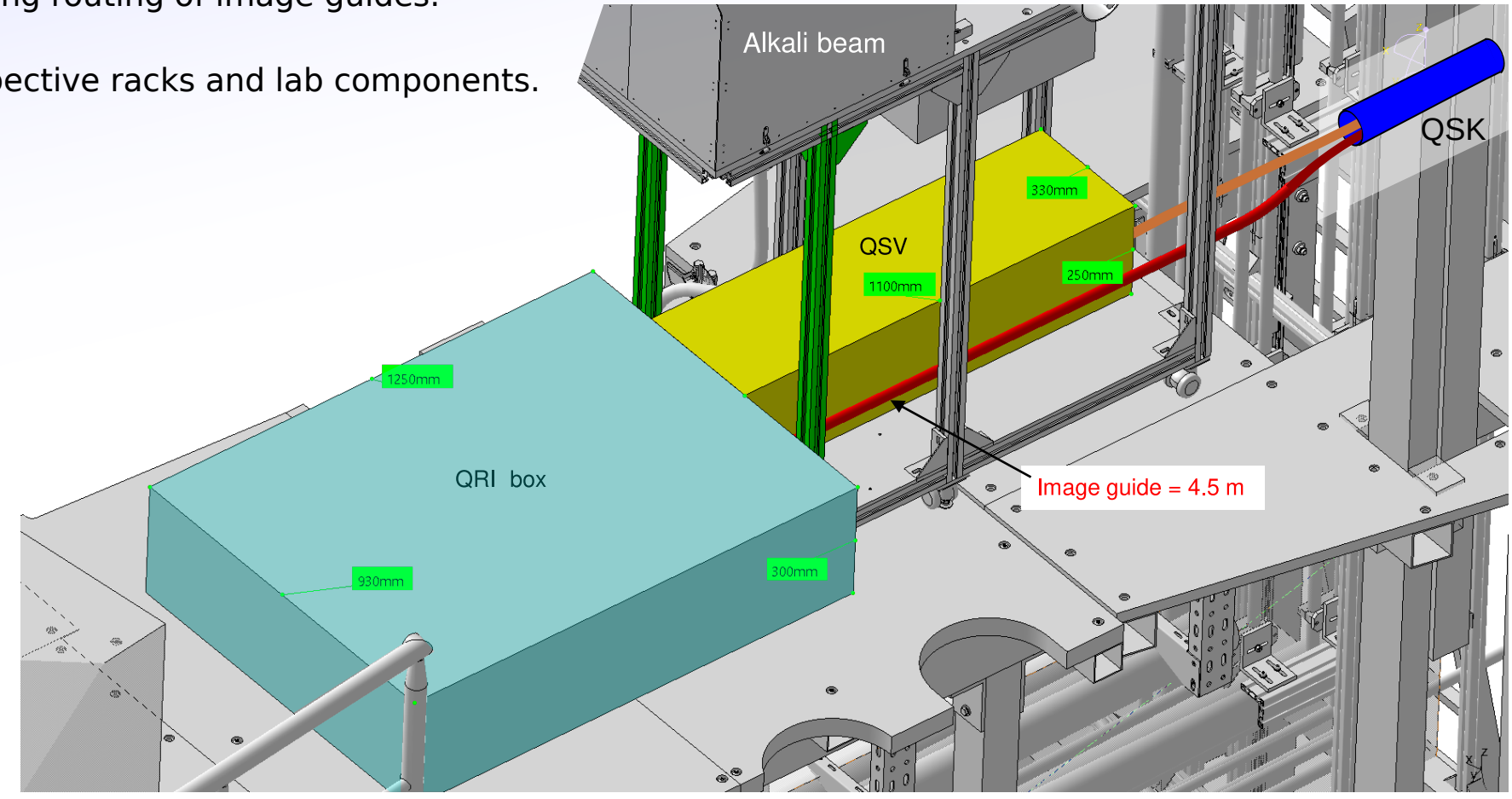




AEA21-U - Video, CIS, CXRS-CIS

- Extension of *existing* projects (QSV, QSK, QRI).
- Projects separated by physical components:
 1) QSK: Immersion tube, optics carriage and optics.
 2) QSV/QRI: Image guides, soft-iron boxes and contained components.
  - Including routing of image guides.

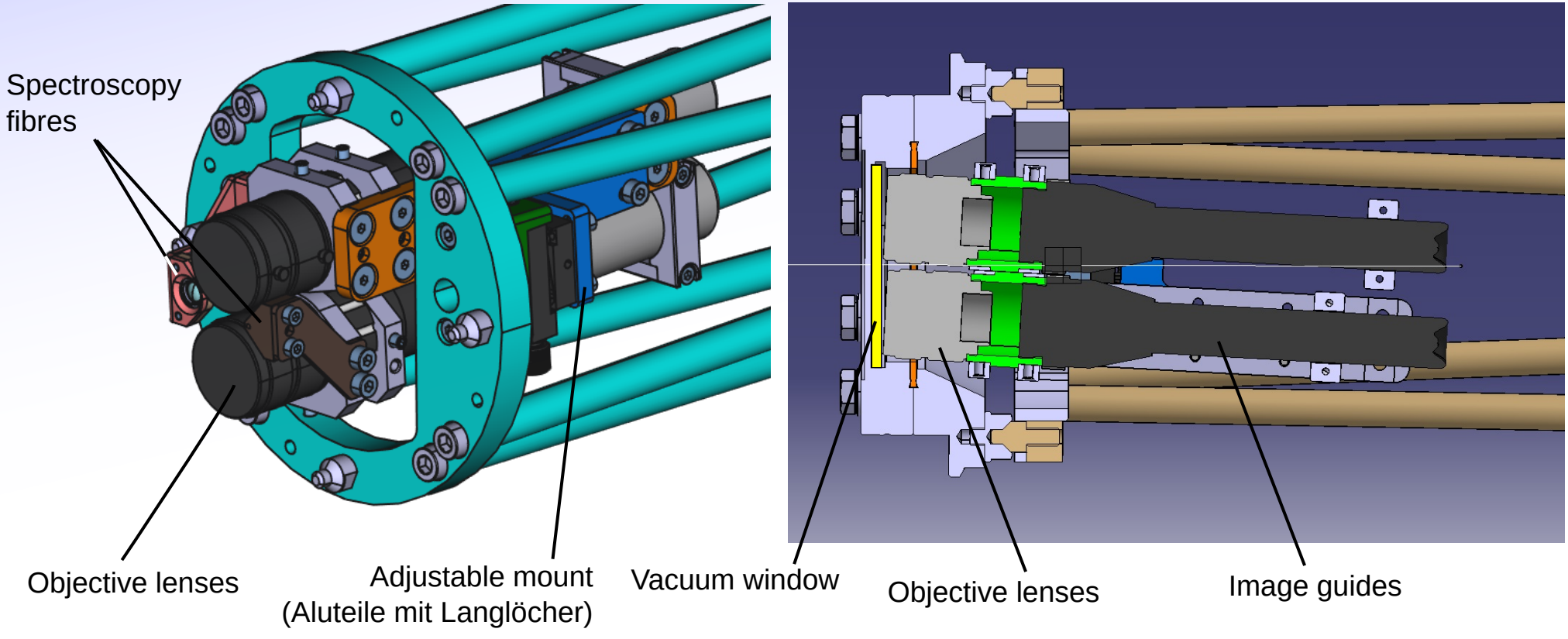
 3) All: Respective racks and lab components.



"*CXRS-CIS*": (No project)
- Design and purchase of optical components by University of Seville in 2021/22.
- Approximate copy of QRI components installed inside QRI soft-iron box.
- Data acquisition in QSK racks (LWL connection).

AEA21-U - Optics

- Optical design and manufacturing by QSV external (energia.mta.hu) --> Complete.



- Test installation of optics carriage in immersion tube required to set lenses close to, but not touching the vacuum window, align relative to A21 flange and do calibrations for QRI.
  --> before or after A21 vacuum test in MISTRAL.

Materials: All W7-X stainless steel, aluminium or brass, except:
- Objective lenses - Need to confirm magnetic properties --> Sonderfreigabe.
- Fibre bundles --> Used in OP1.2 in AEQ21. Glass, aluminium and non-magnetic steel mesh.

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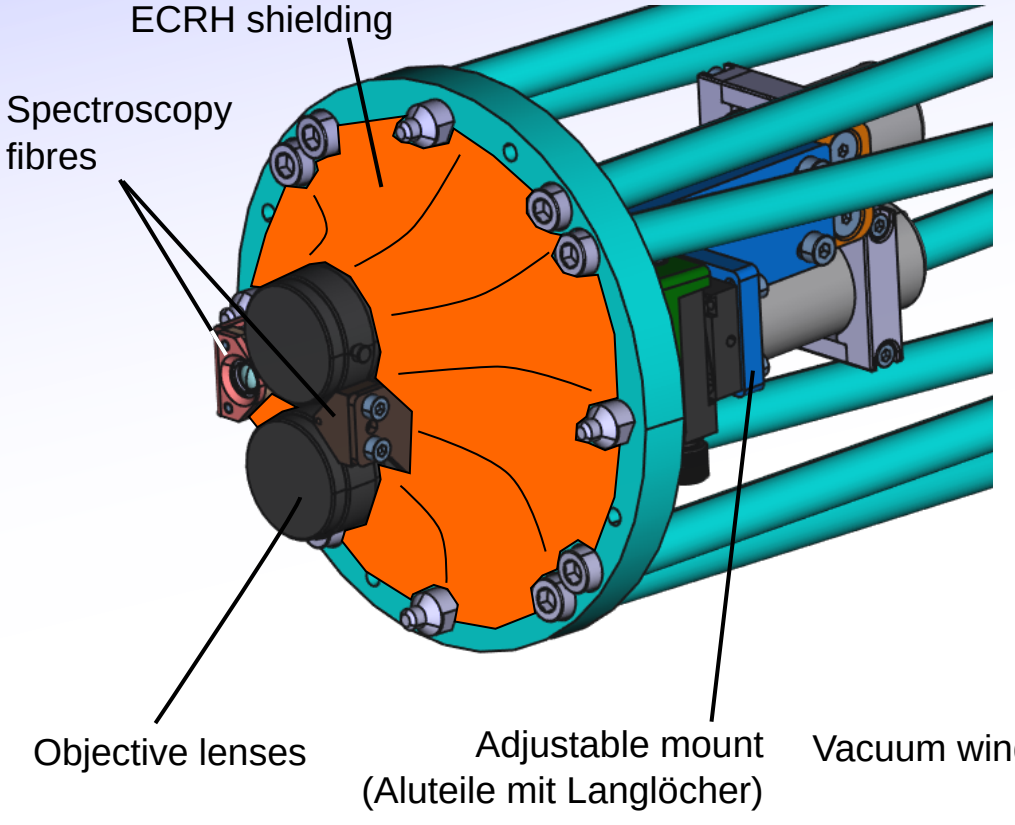

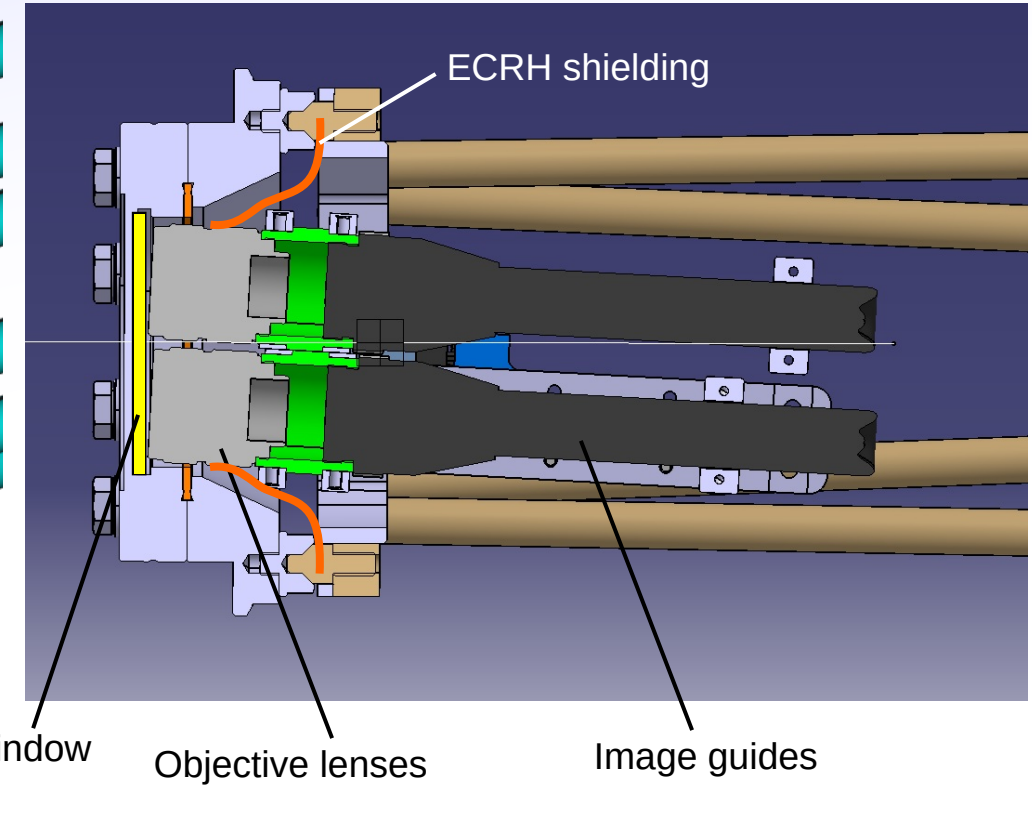

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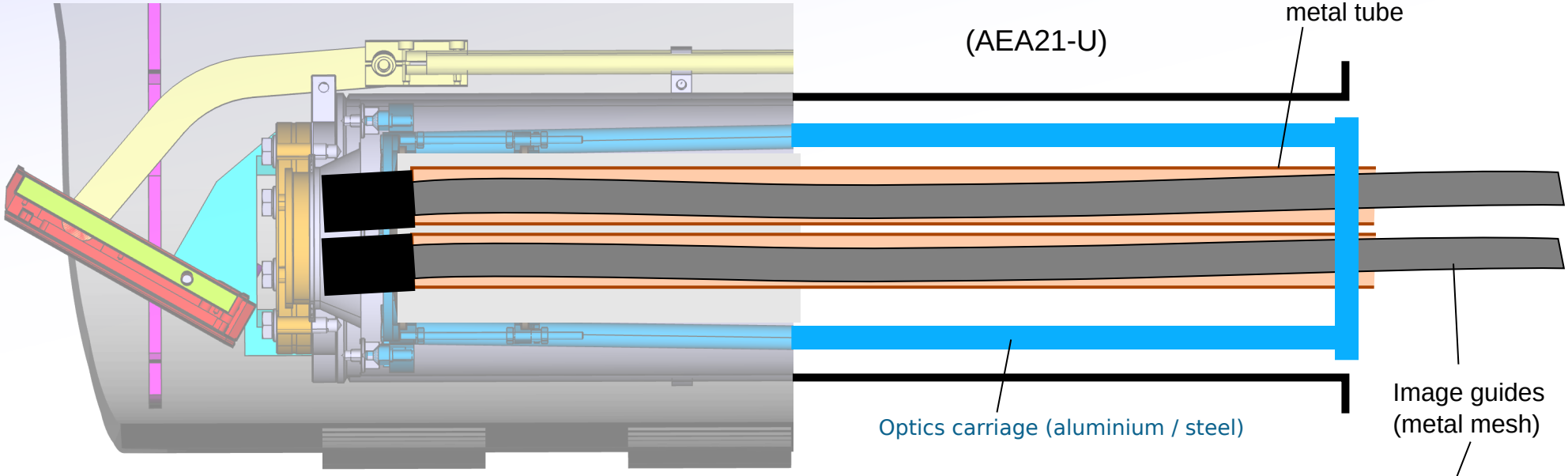
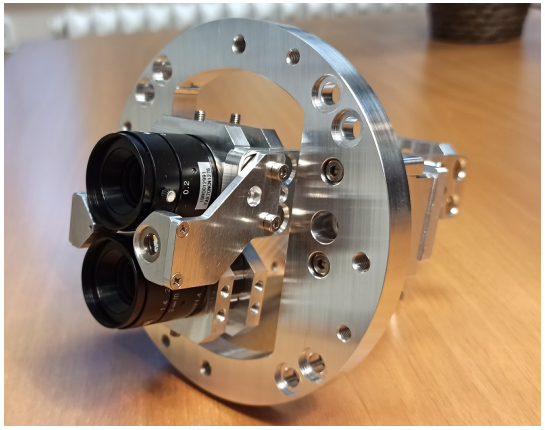
ECRH stray radiation - AEA21-U

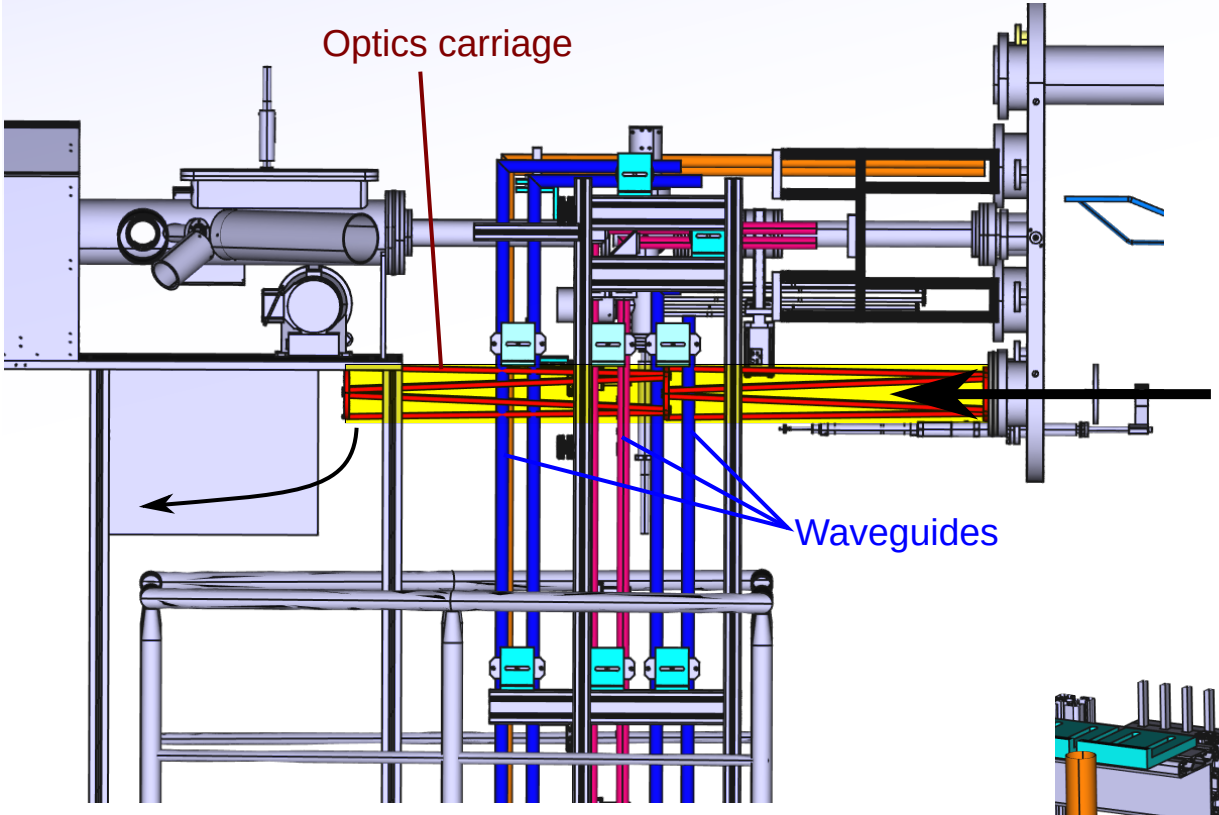
Contents of tube:
- Stainless steel and aluminium mouting components.
- Objective lenses - Anodised aluminium + unknown glass **--> MISTRAL test**
- Image guide - covered in thin wire mesh **--> Cover in foil or metal tube.**

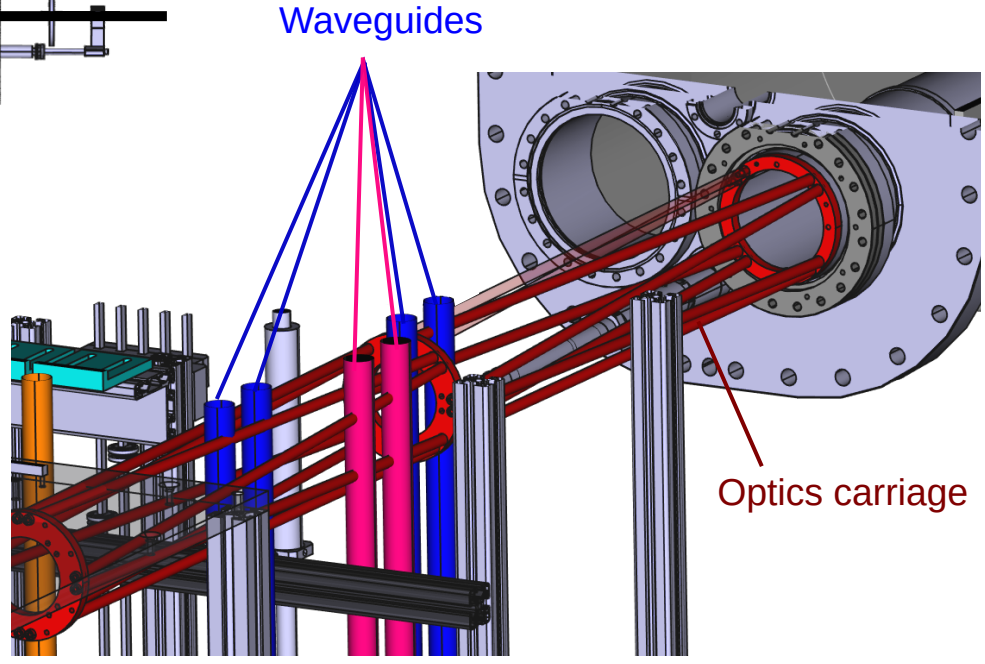




AEA21-U - Video, CIS, CXRS-CIS

- Reflectometry waveguides (QMR?) have been installed behind QSK immersion tube.
  - Installation of QSK optics carriage must take place **before** reinstallation of waveguides.
  - For maintenance of optics, waveguide section will be temporarily removed.
    (agreed with QMR RO)
  - Box installation, securing of fibre bundle etc covered by QRI/QSV (see CN 1-QRI-C0007)





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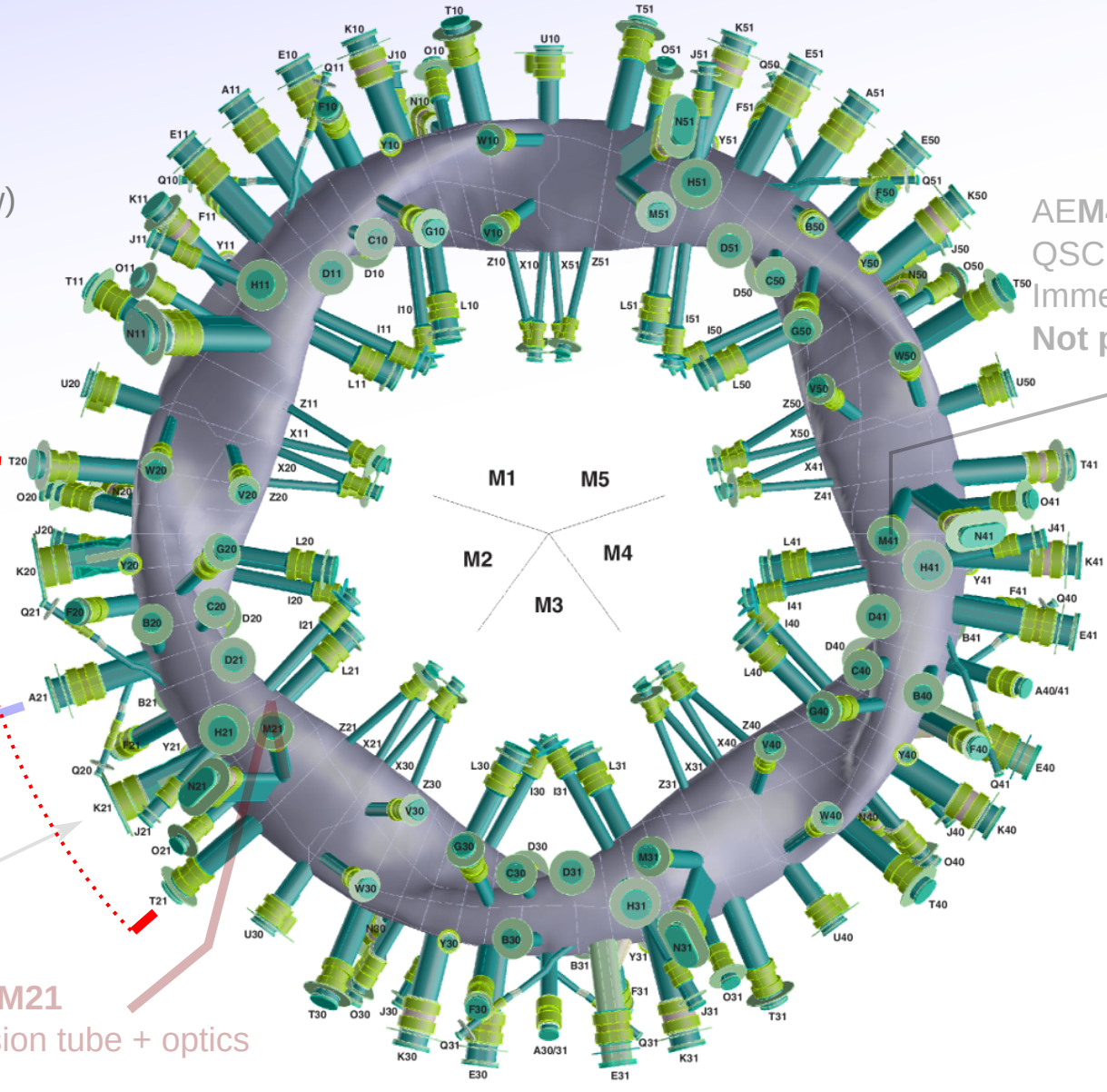


AE**M41**
QSC: CXRS am RuDIX
Immersion tube
Not part of QSK!

RuDIX

K3: AE**T20/21**
Immersion tubes + optics
(In QYB/P0008)

AE**K41**
K6: Passive CXRS

NI20

K1: AE**A21**
Immersion tube + optics

NI21

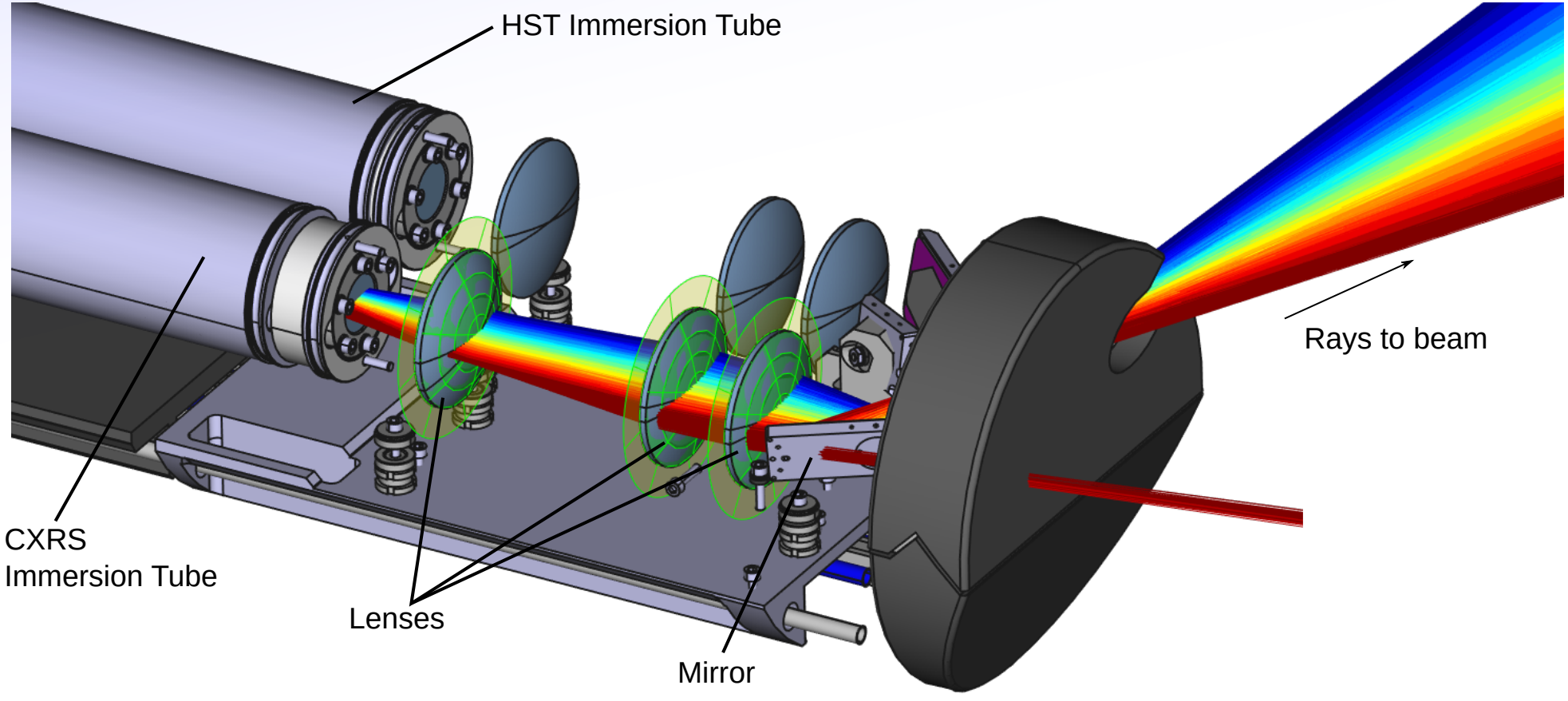
K2: AE**M21**
Immersion tube + optics

K4: Fibre optic transfer to lab.
K5: Spectrometers and components in lab

Complete in OP1.2b, no changes for OP2 - not covered in this CDR!

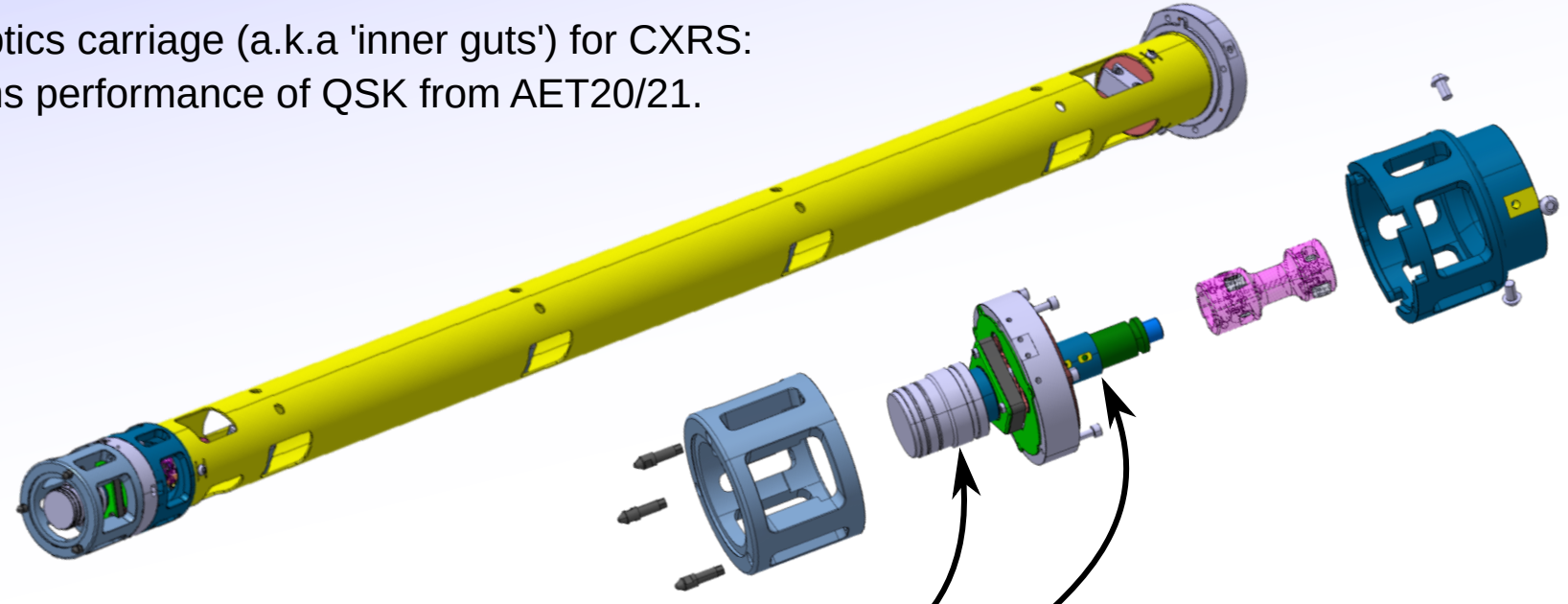
AET20/21 - Optics in HST

- QYB plug-in redesigned for OP2.
- Optics designed together with CXRS: Share view
- Front plate, vacuum components, safety etc, all part of QYB --> P008 CDR, DDR

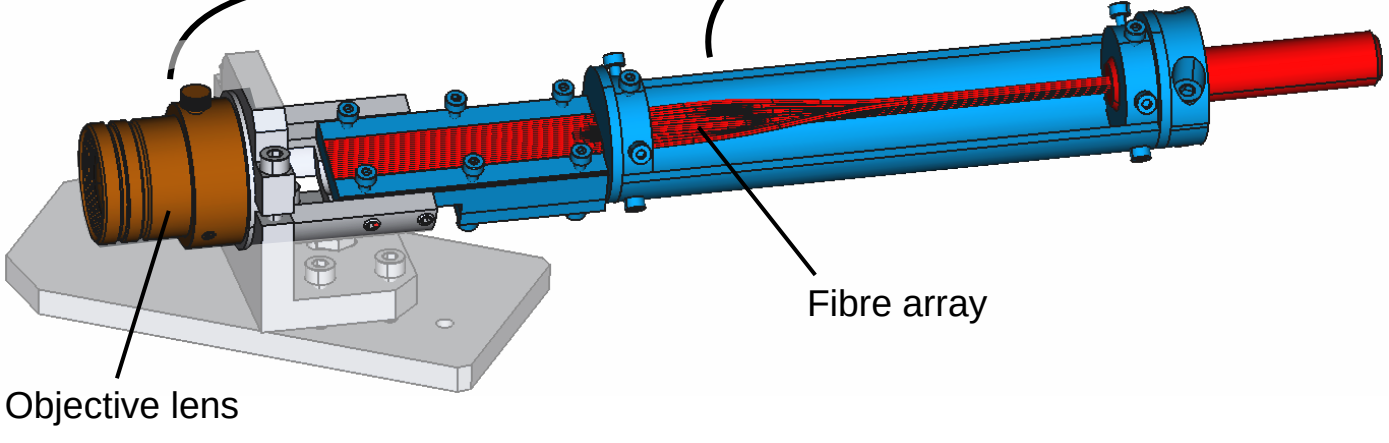


AET20/21 - CXRS 'inner guts'

- Copy of HST optics carriage (a.k.a 'inner guts') for CXRS:
- Design maintains performance of QSK from AET20/21.



- Existing fiber bundle, objective lens and patch panel from OP1.2 fit to new carriage:



Manufacturing

Simple steel fabrication +copper plating:
- Front plate, port shield, cap (TD, Discussed. External supplier found, pending renegotiation with TS)
- Caps for AEM21 and AEA21-O and -U. (TD, discussed)
  -- Copper plating by Galvano-T (in progress, disucssion pending TS)

Steel pipes: cut, bend, weld (TD - AS, discussed)
- AEM21 port
- AEM21 immersion tube

- Studs and panel mounts. (Ready)
- Mouting bracket AEM21 frontplate (TD, contracted, in progress)
- Modifications to AEM21 passring (TD, discussed)

TD packages not yet registered (could pass to ITZ)
- AEM21 immersion tube - bolts welding
- AEM21 window protection collar, cooling block, pipe clamps
- Shutter drive plate cuts for TE, TE clamps and support plates.
- Drive cylinder feedthrough parts for A21-U
- Shutter, shutter mount, drive, drive cylinder parts for A21-U

Other:
- Bendable gap protection foils - E3.
- AEM21 pipe connectors (x4)

Purchasing

AEA21-U Tube (Delivered, checked. I.O.)
RSA-905 Mirrors (ordered, expected ~April)

To be ordered after DDR:

- Vacuum windows without ITO - 2x DN63-CF, 1x DN100-CF
- CF 16 daughter flange for M21 TE feedthrough
- Sigraflex pads/strips
- Glass for protection windows
- Manual cut-off valves for AEM21
- Bellows for A21-U shutter. (Repeat order).
- Pressure cylinder for AEA21-U. - (Repeat order)
- Thermocouples (Repeat order)

Documentation

1-QSK-Q0018 DDR Checklist - (Also covers all documents)

Project Documentation:
- 1-QSK-S0002.1 Project specification - Cleared
- 1-QSK-T0003.1 Safety Analysis - Accepted and signed (minor corrections pending)
  - 1-QSK-T0004 Thermal Analysis
  - 1-QSK-Y0006 Port protection thermal report (EN)
- 1-QSK-P0000 WBS - Up to date

Relevant change notes:
- 1-QSK-C0008 AEM21 Front plate - Cleared
- 1-Q-C0010 Additional shutter for AEA21-U - Accepted and implemented (formal clearance pending)
- 1-ACK60-C0002 KKL Users lists - Updated to include AEM21 front plate and diagnostic.

Special allowances:
- 1-QSK-Q0002 Mirror AEM21 - Obsolete
- 1-QSK-Q0009 Mirror AEA21-O - Cleared
- 1-QSK-Q0016 Mirrors AEM21, AEA21-U - (*After delivery, replaces Q0002)*
- 1-QSK-Q0017 Copper Straps - (*After delivery)*
- 1-QSK-Q0019 ECRH Compatibility - Cleared

QAAPs:
- Lab assembly of AEA21: 1-QMR-xxxx, 1-QSK-Q0020,21,22, 1-QRI-Q0014.
- Installation/calibration AEA21 - Copy 1-EGG21-Q2418
- Installation AEM21 Port Protection and Tube - 3 QAAPs in preparation with AS.
- Calibration AEM21, AET2x - Copy 1-EGG21-Q2383.

Technical specifications:
- 1-QSK-S0007 - Manufacture and welding AEM21 port protection - Accepted
- 1-QSK-S0008 - Copper plating AEM21 port protection - In preparation.

Backup slides...

Tungsten

- W in SOL will have a significant impact on all spectroscopy diagnostics:
- Some baffle tiles to be replaced with W already in **OP2.1.**

Example from CXRS on JET with tungsten wall:

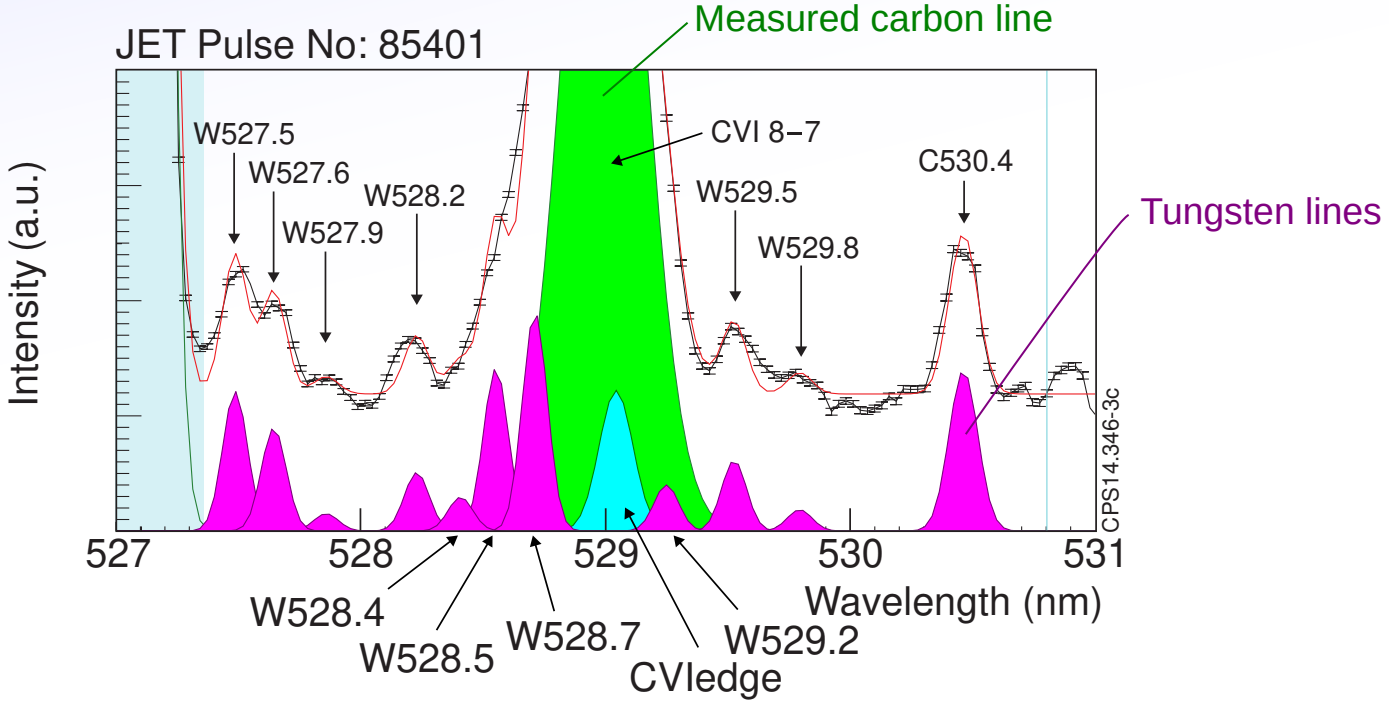
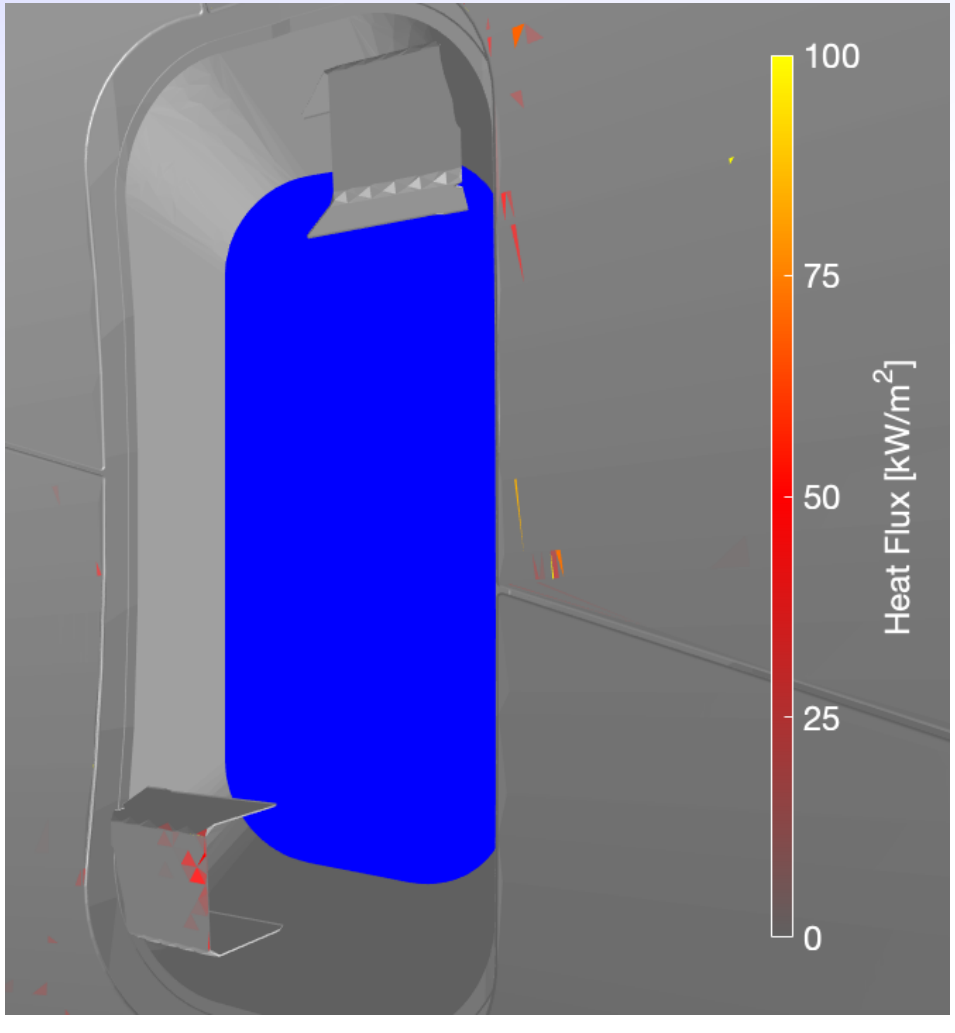


FIG. 3. (JET pulse #85401) An edge track example of the f t (red) and individual lines (green) close to the CVI 8-7.

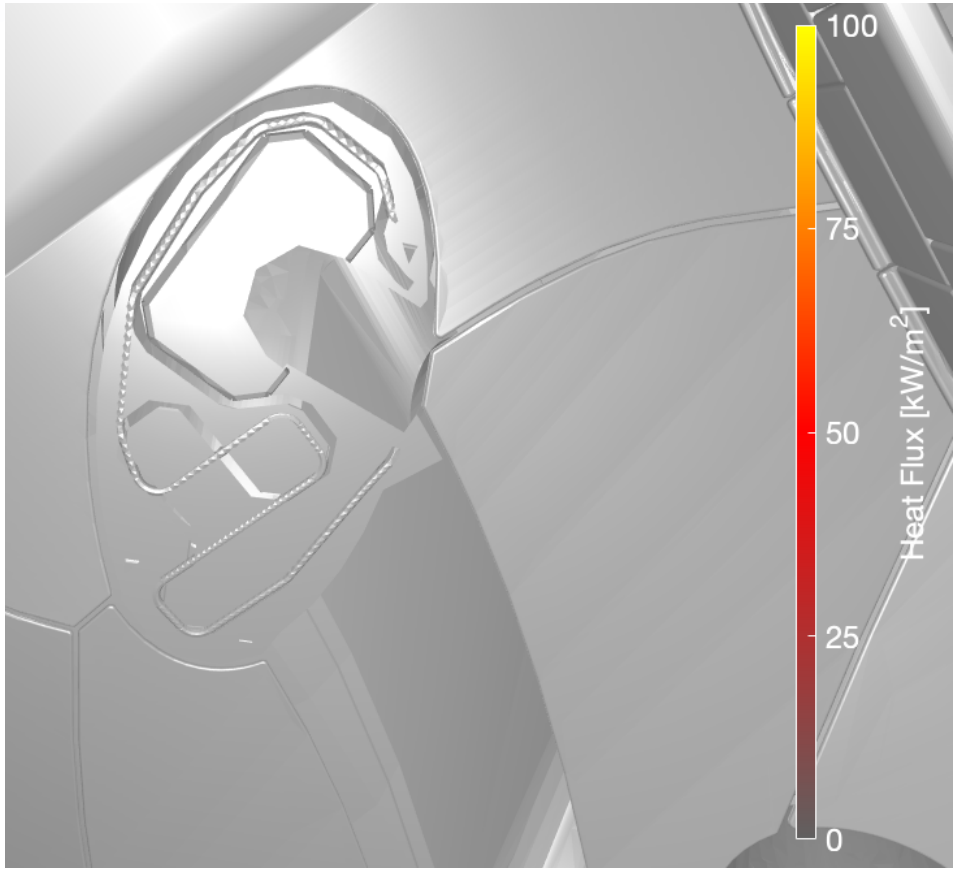
- Expected and unavoidable with W wall, but what will be the effect of W tiles as NBI beam dump?
- CXRS HFS measurements near beam dump may be strongly effected if beam dump is replaced with tungsten tiles!

Fast ion losses

AEA21: Some local hot spots on CXRS housing, but total load only ~50W

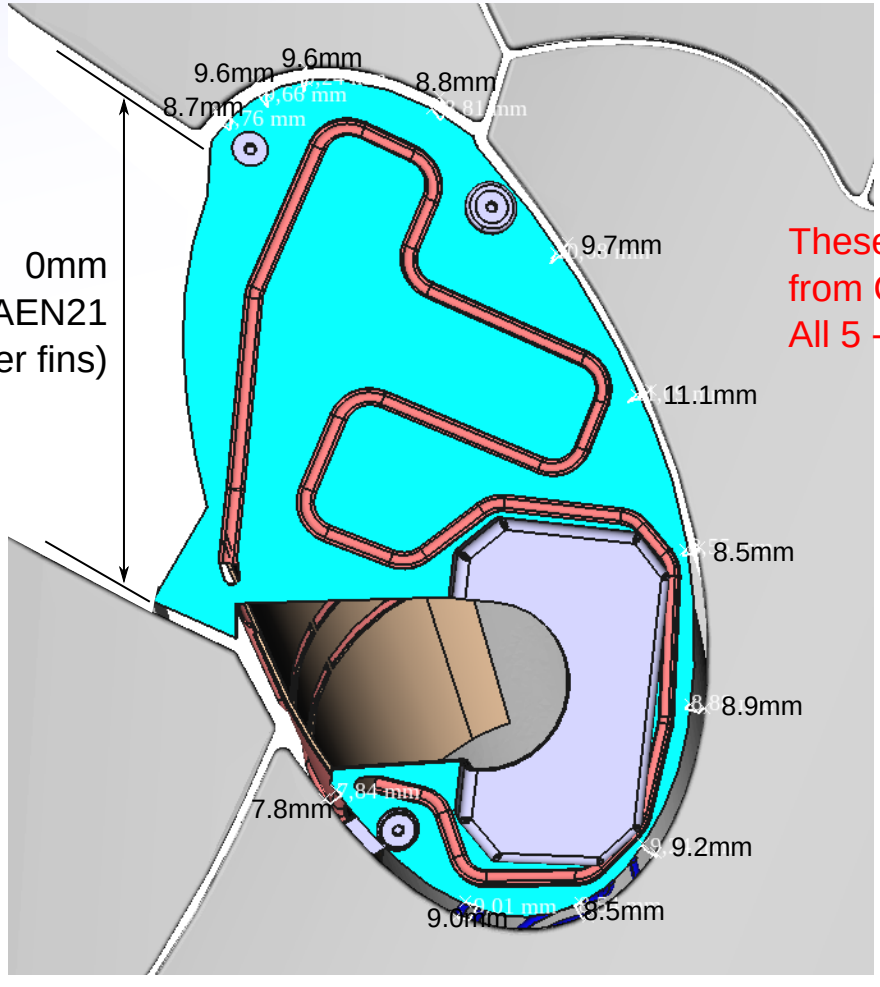


AEM21: Zero load



AEM21 port protection - Gaps

Front panel is effectively a panel, which gaps are required to be < 10mm (1-AC-T0004).
- As-designed gaps meet this requirement.
- As-designed gaps used for thermal calculations --> tolerable loads on vessel and port walls.
- Panel is adjustable via mounts up to ±2mm adjustment in all directions.

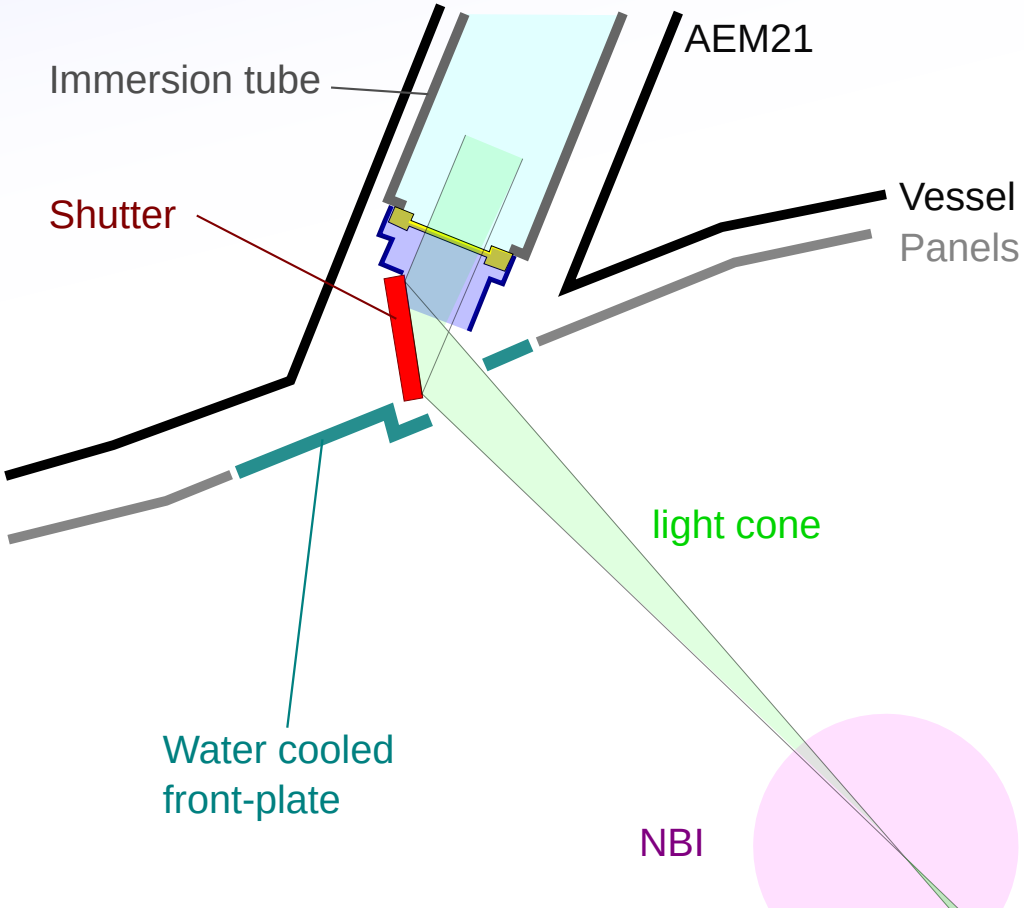


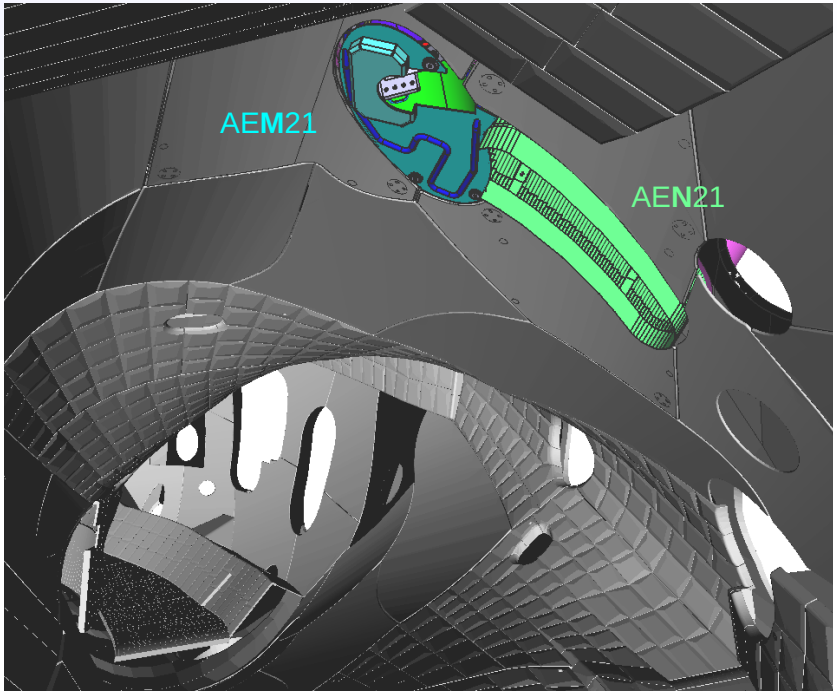
0mm
(Covered by AEN21
Portliner fins)

These are documented properly
from CATIA in 1-QSK-K0000
All 5 - 9mm

AEM21 port protection - concept

- Water cooled front-plate covering most of port.
- Small cut-out to allow necessary diagnostic view.

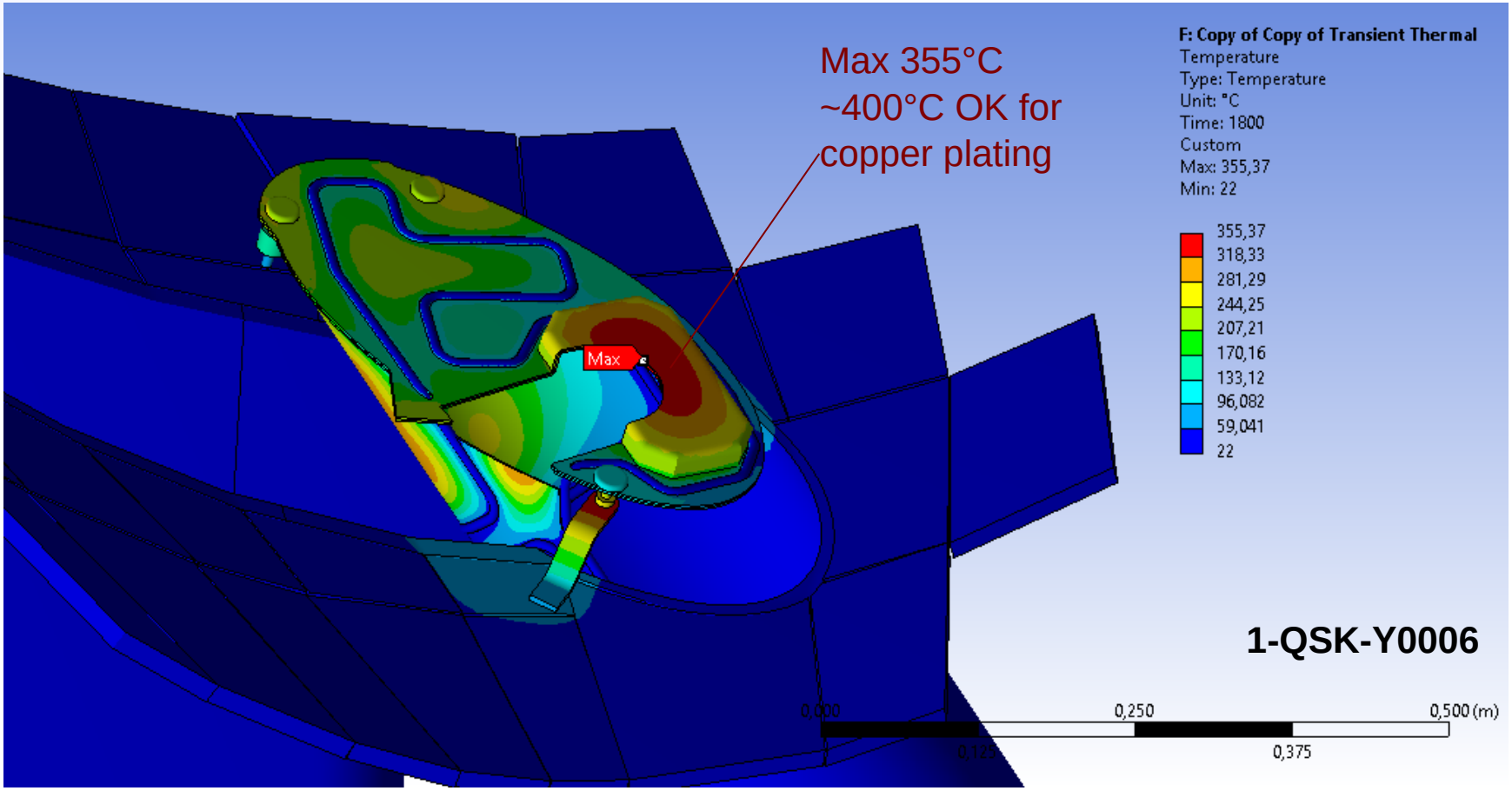




View including neighbouring AEN21 Portliner,

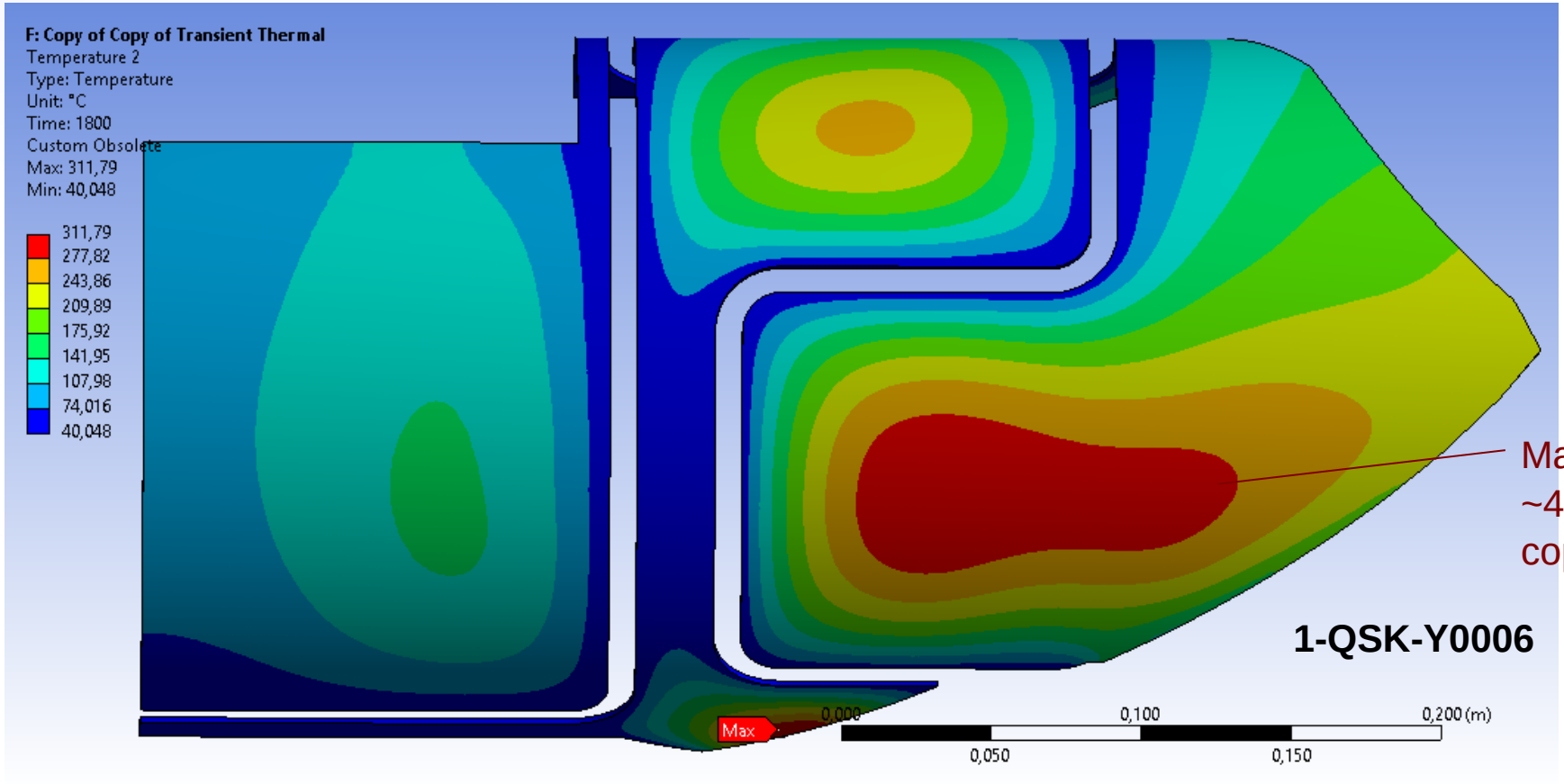
AEM21 port protection - thermal analysis

Thermal analysis of the final port protection shows acceptable temperatures:
- Power loads calculated from 100kW/m^-1 at plasma boundary using ray tracing.
- 1800s or steady-state temperature evaluated by EN (M. Khokhlov).
- Radiative cooling ignored.
- Good conduction via copper plating assumed.
- No copper plating on rear shield assumed.
  (but it will be plated anyway --> even lower temperatures)



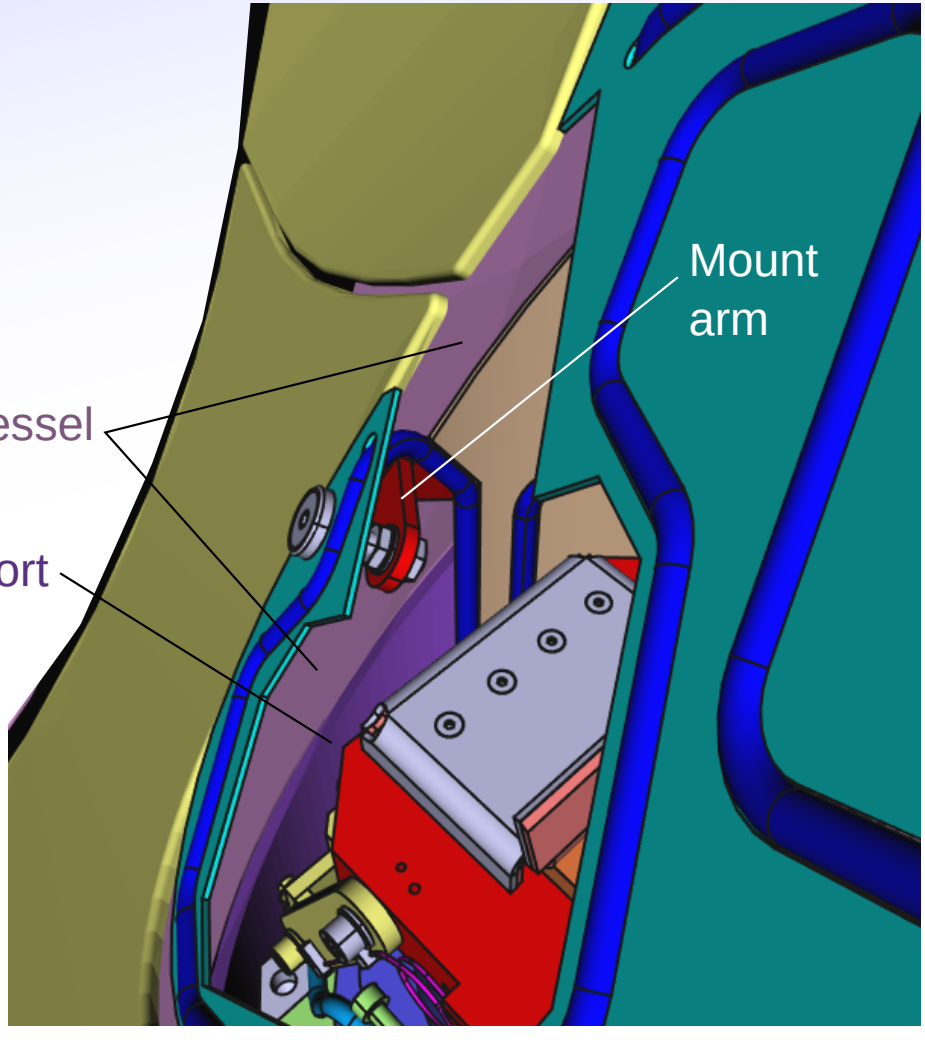
AEM21 port protection - thermal analysis

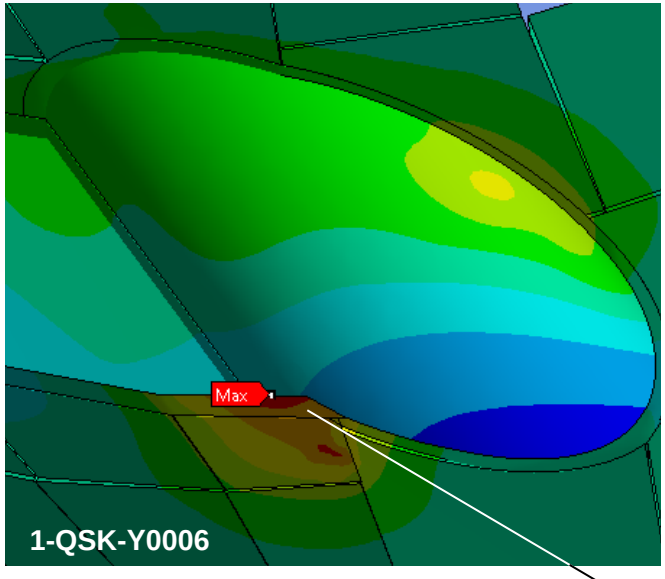
- Max temperature of rear shield calculated as 311°C.
 - This was calculated with no copper plating as we wanted to avoid it but it is required anyway to conduct the pipes to plate sufficiently. The real temperatures will therefore be far lower.



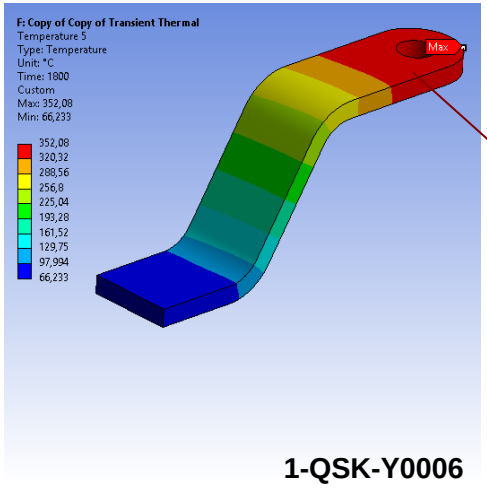
AEM21 port protection - thermal analysis

- The mount arm and a small part of the vessel and port are exposed to the plasma.
- Mount arm can heat up to max 350°C - OK for stainless stell component.





Max 85°C OK for vessel.
(Not on welds).



Max 350°C
OK for steel component.

AEM21 port protection - flow rate

(1-QSK-Y2008, M. Khokhlov)[5248]

- Due to the 7mm inner diameter (usually 11mm), the flow rate/pressure drop relation is more critical.

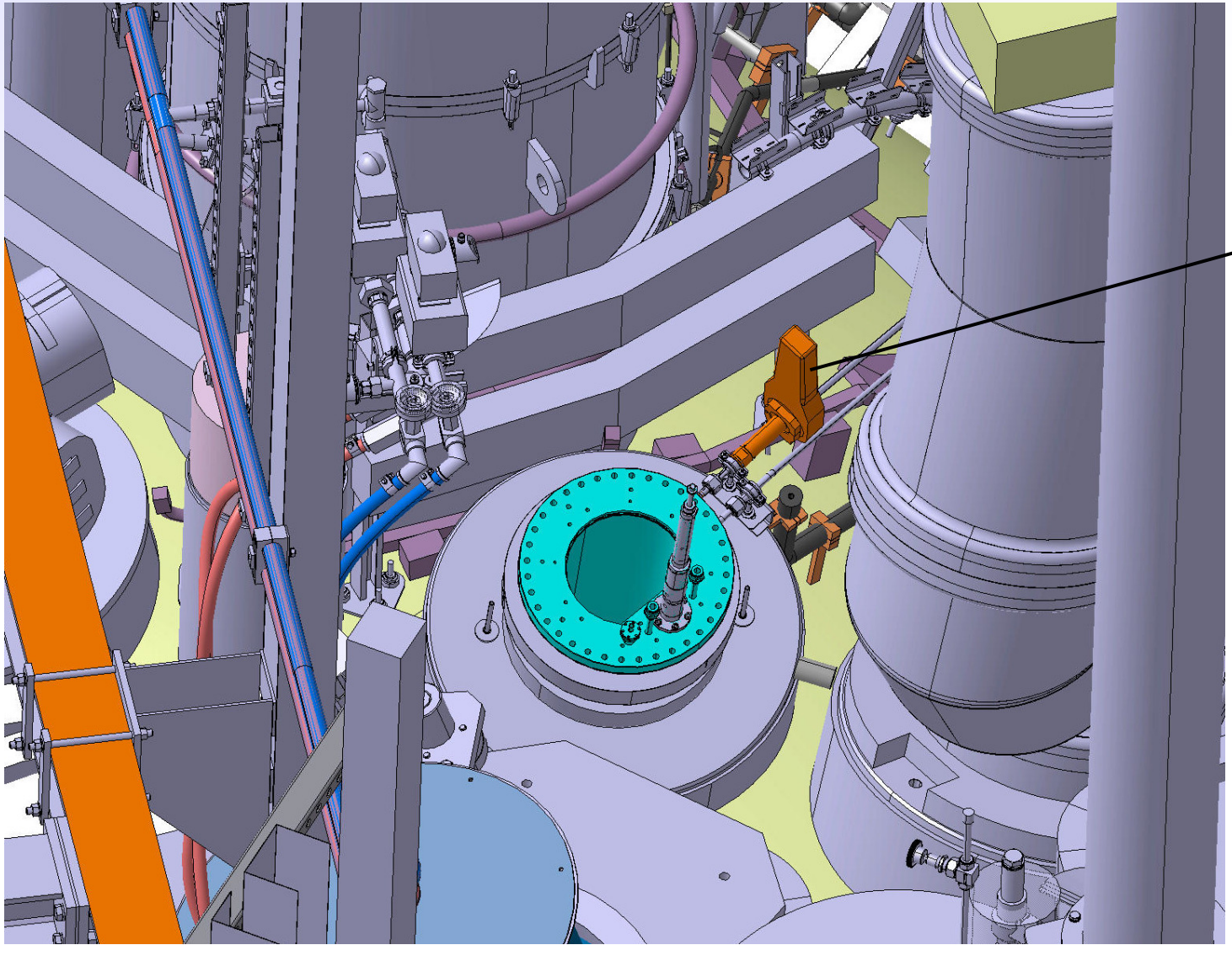
0.2 l/s = 9.2bar (> 6 bar limit)

0.1 l/s = 3 bar (< 6 bar limit)

At 0.1l/s the temperature rise due to the 5kW = 15°C. --> OK

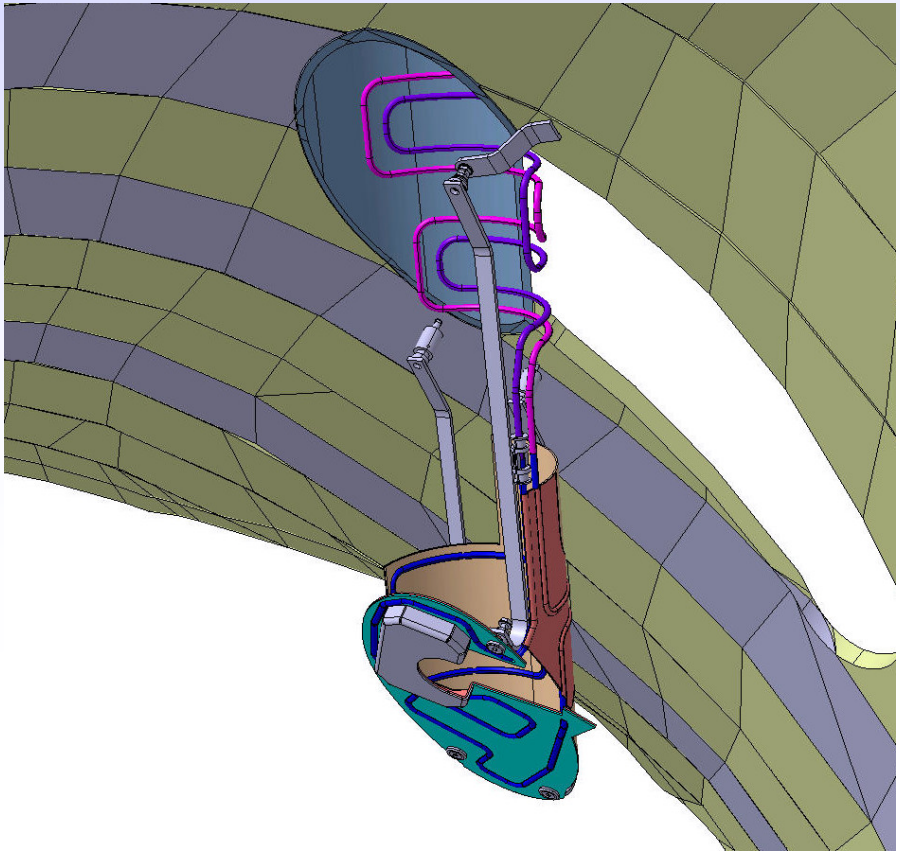
AEM21 port protection - pipes to passring

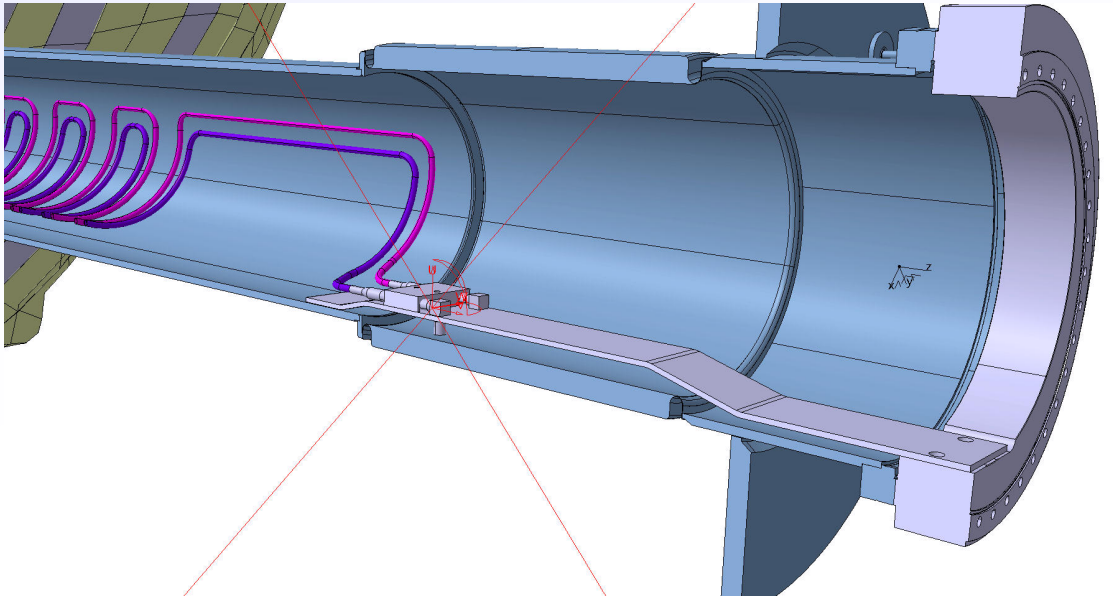
Sufficient space for welding pipes to passring:

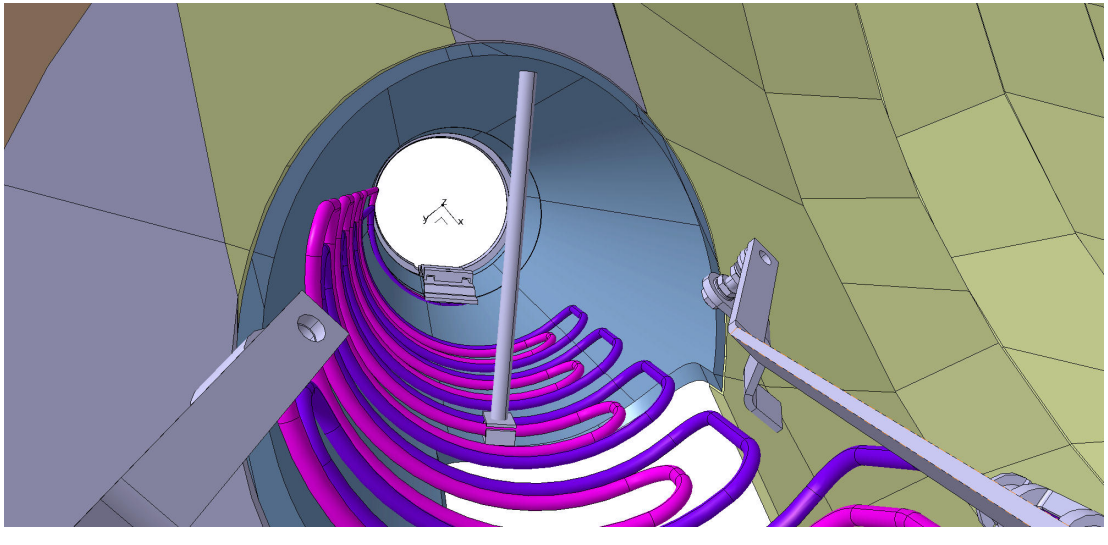


AEM21 port protection - Installation

Support devices for port protection and pipes during in-vessel welding:

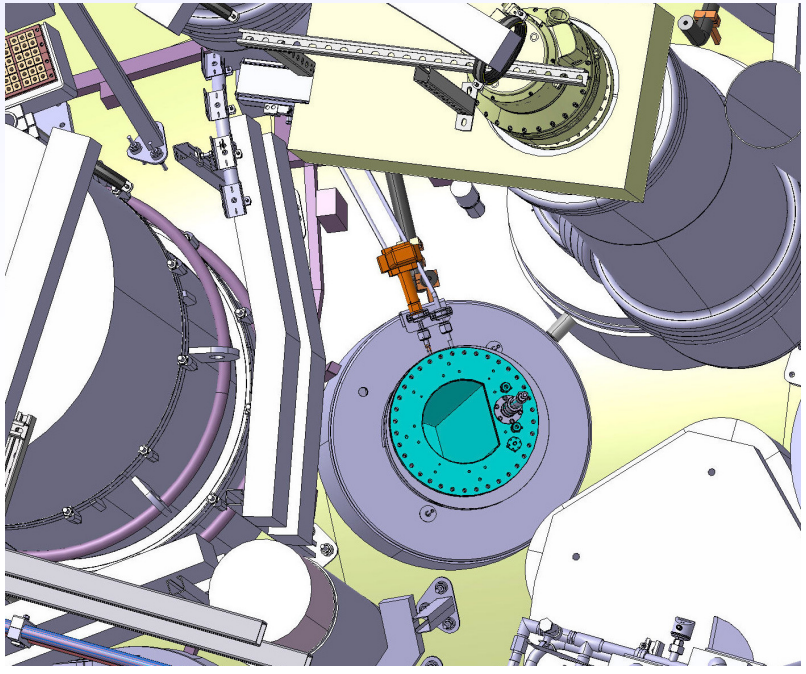


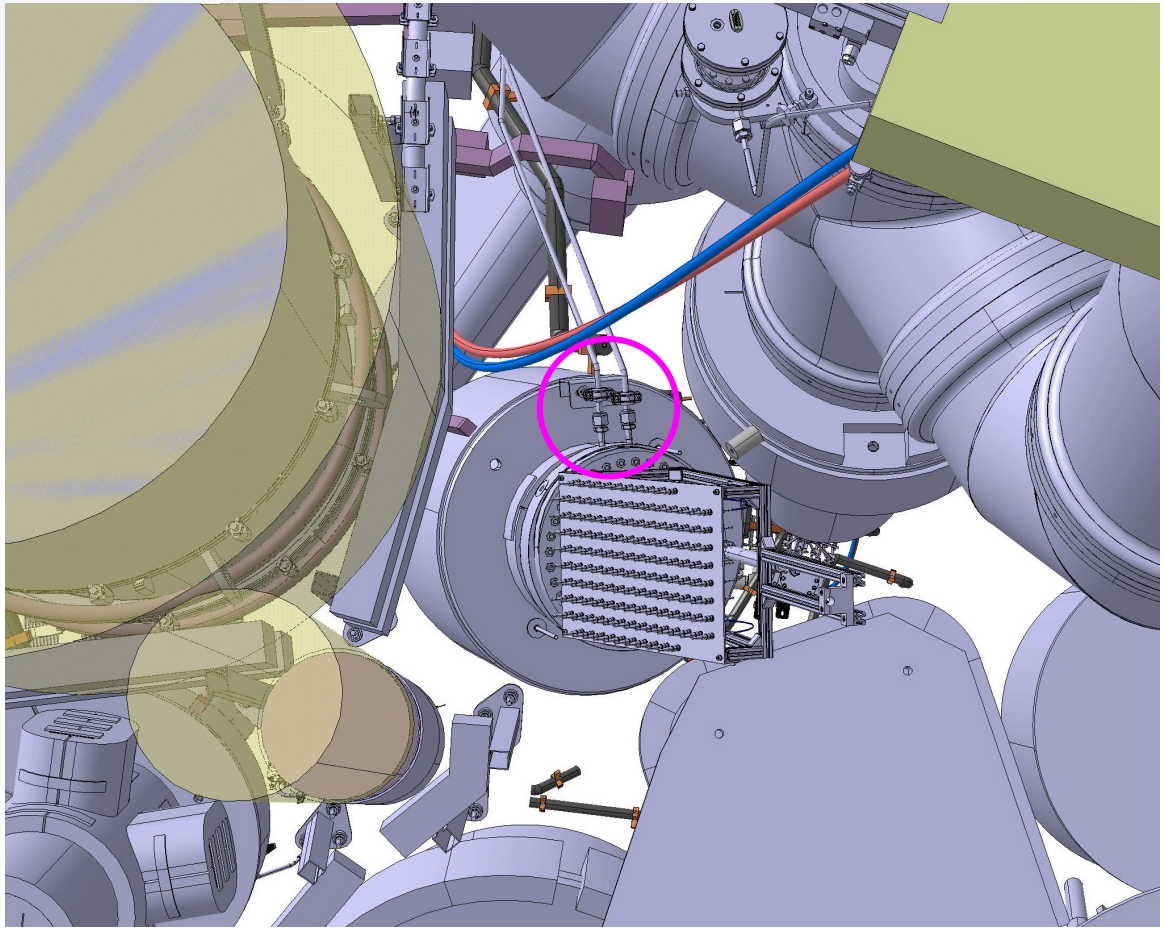


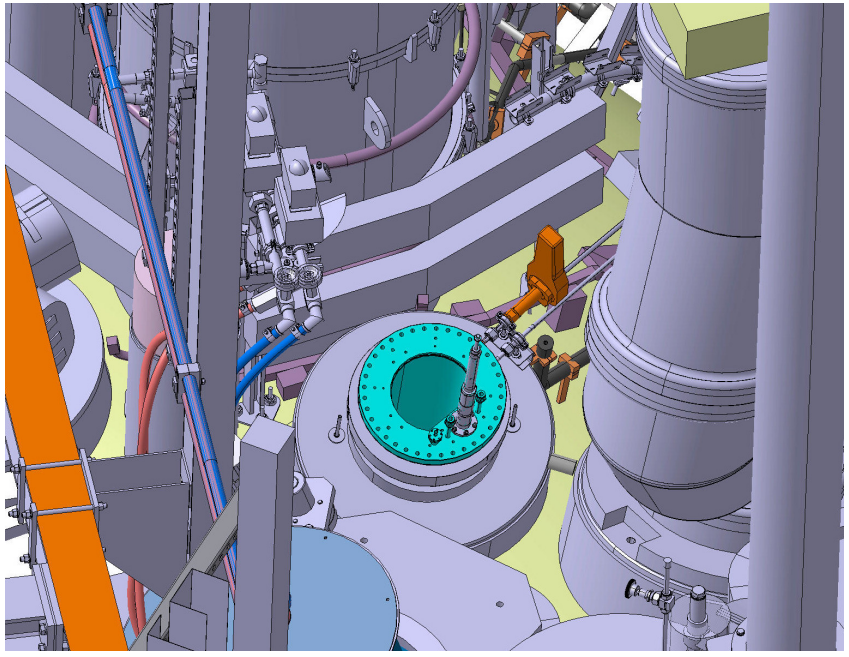


AEM21 port protection - Step protection

Is step protection required for pipe connections to port protection?



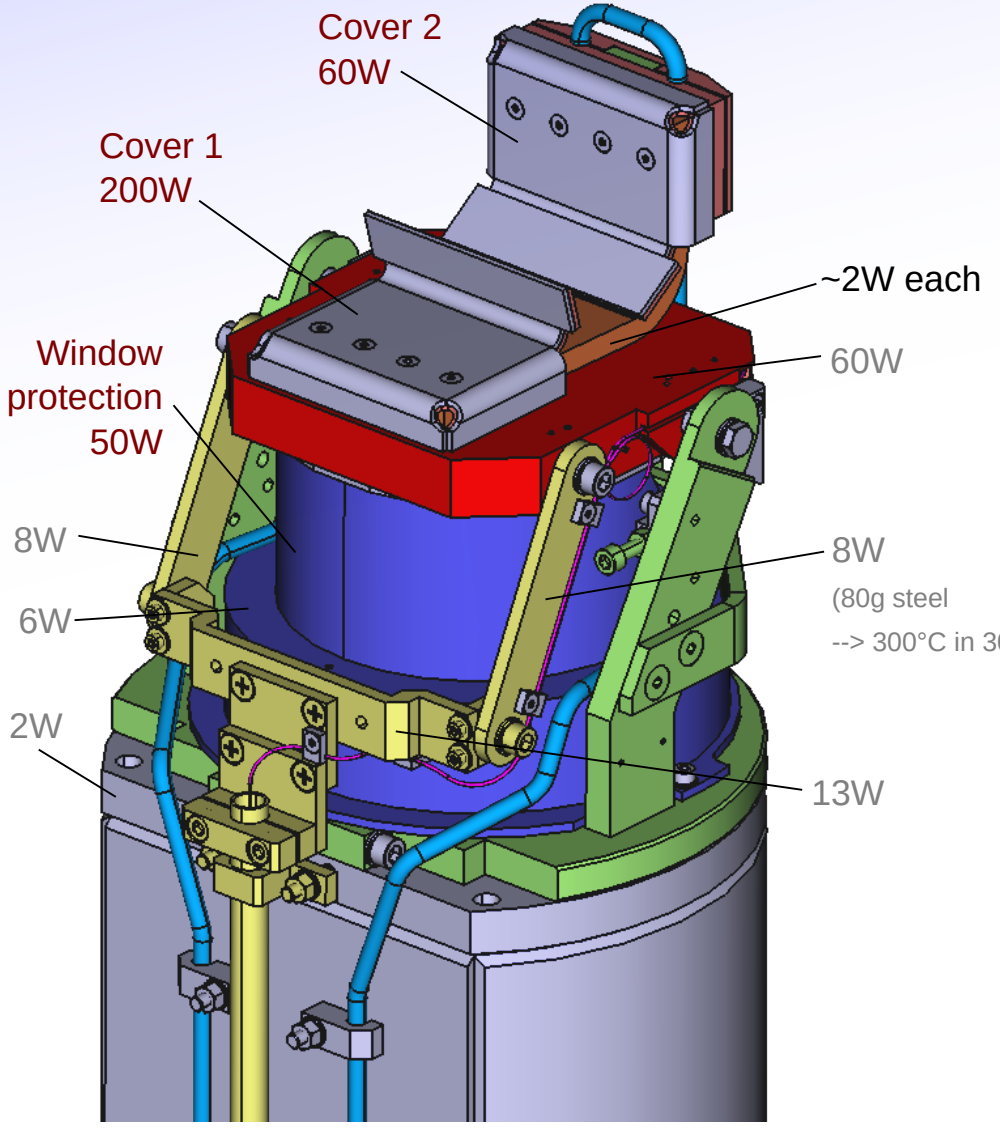


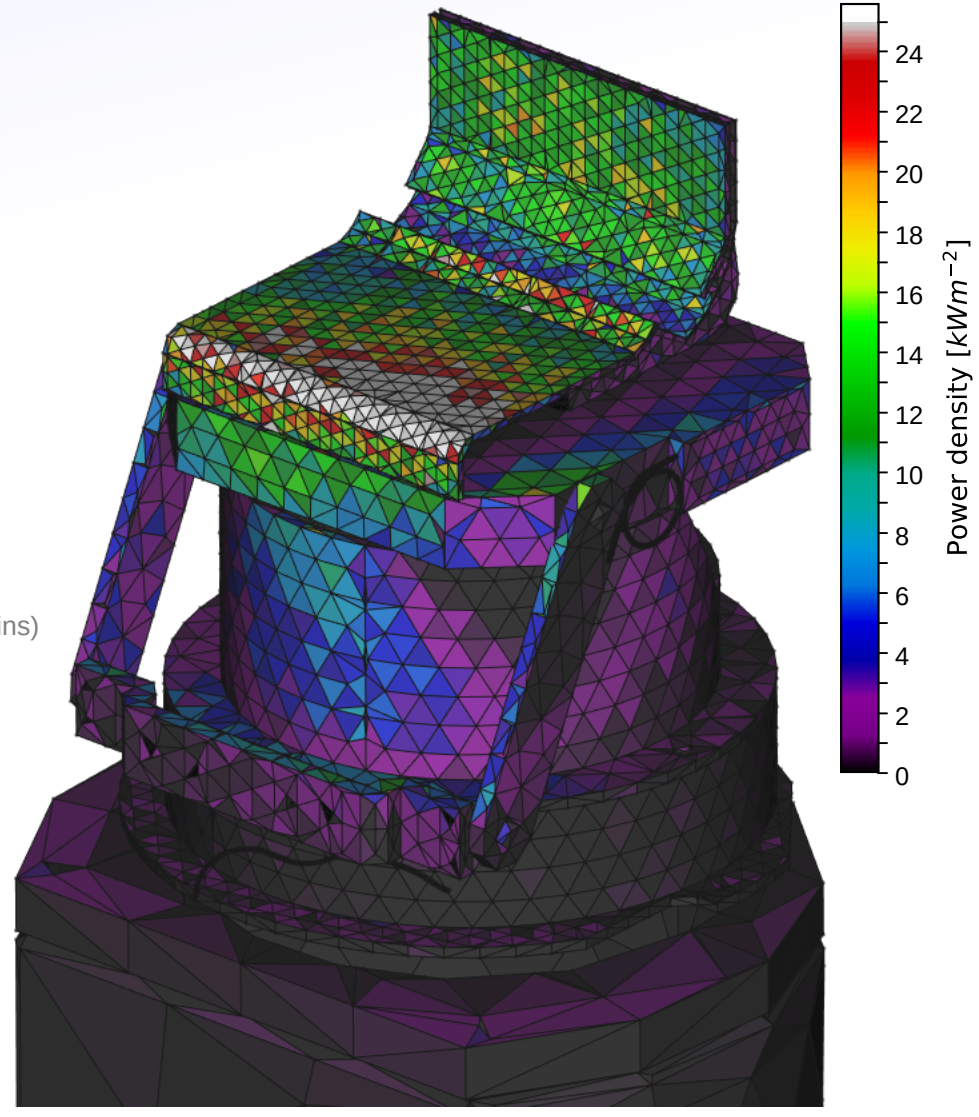


AEM21 Immersion Tube - Thermal

Calculated direct radiation to immersion tube components, through the main hole in the front plate:

All parts other than shutter, covers and window protection have negligible ΔT.



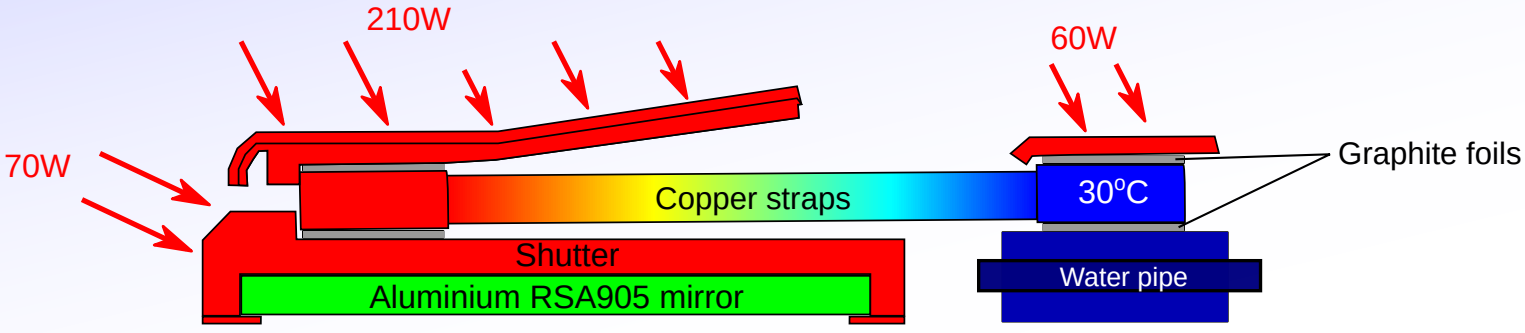


Reradiation of the front plate at 350'C gives an additional ~20W to shutter and cover, otherwise most goes to port shield.

AEM21 Immersion Tube - Thermal

In total, 280W falls on components connected to hot end of straps.

Worst case for aluminium mirror: Heat spreads uniformly through all of them.

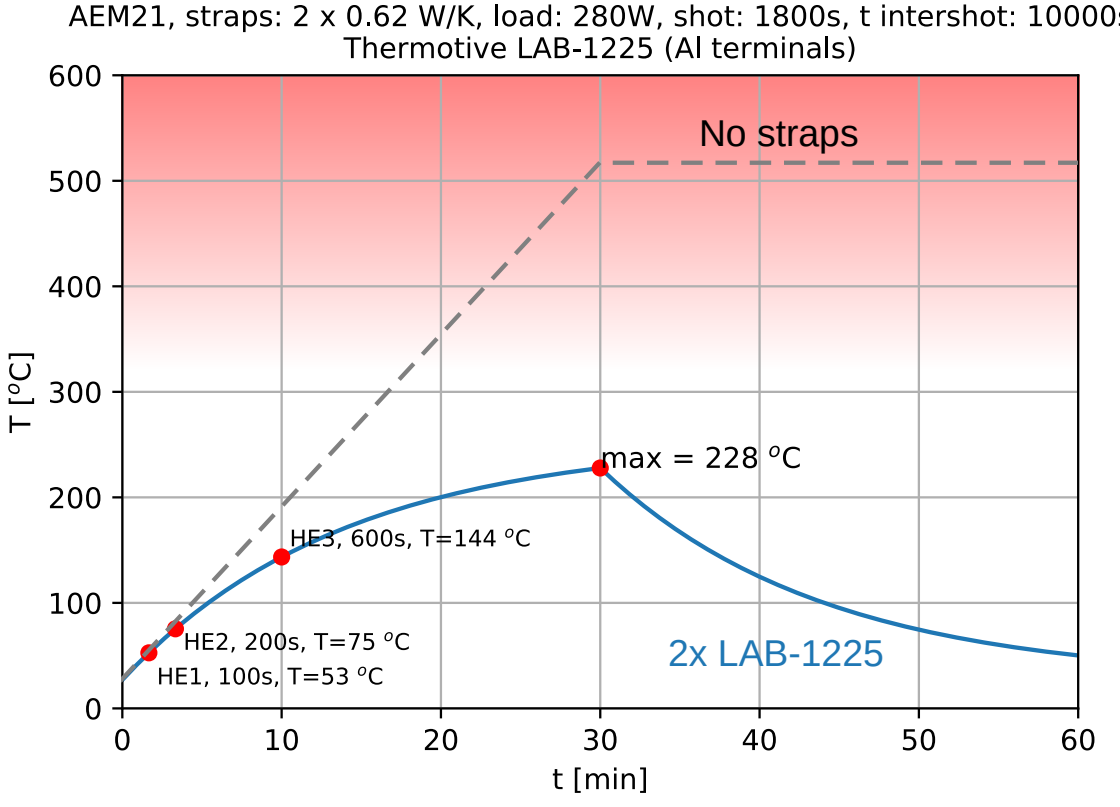


Initial tests of thermal straps + interfaces from gas-puff-imaging diagnostic:
- Achieved ~55% of advertised 'ideal' conductivity due to extra interfaces.

2x Thermotive LAB-1225 'standard' straps
--> max 230°C

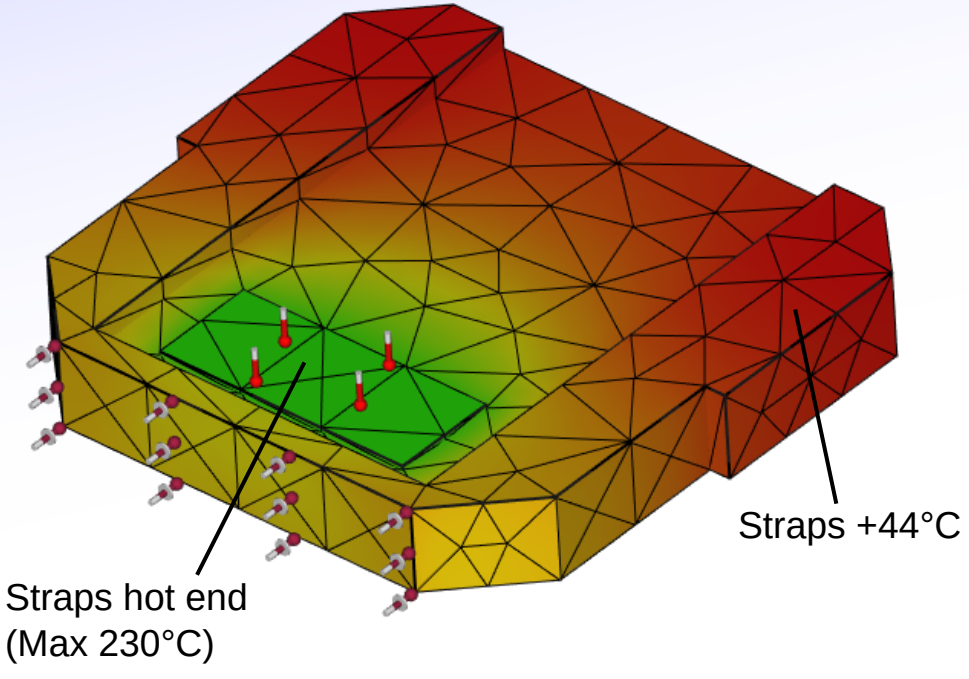
*Temperature solution is a balance of strap conductivity and the heat capacity of the steel shutter.

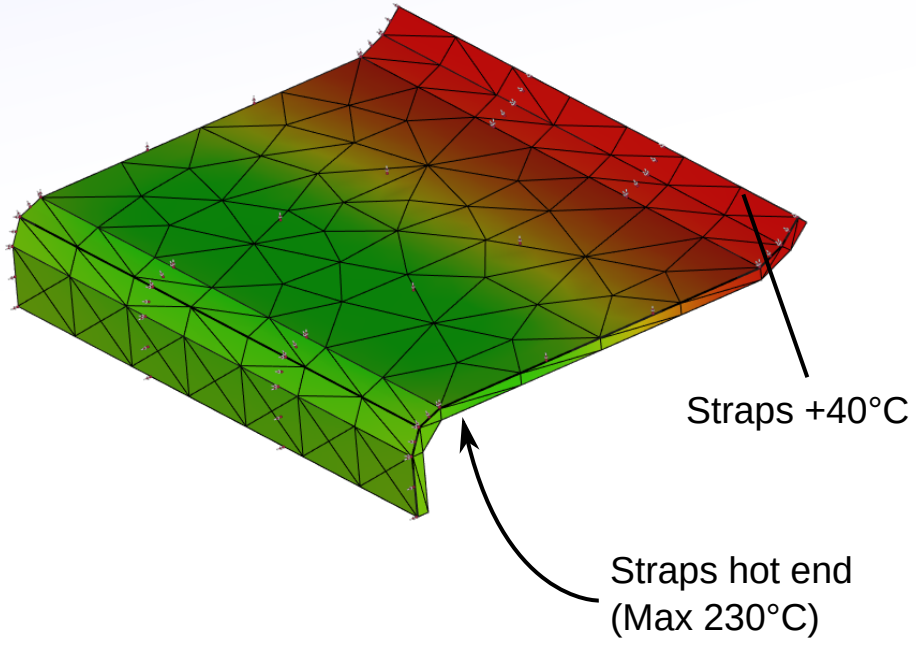
With no straps, 520°C is reached.

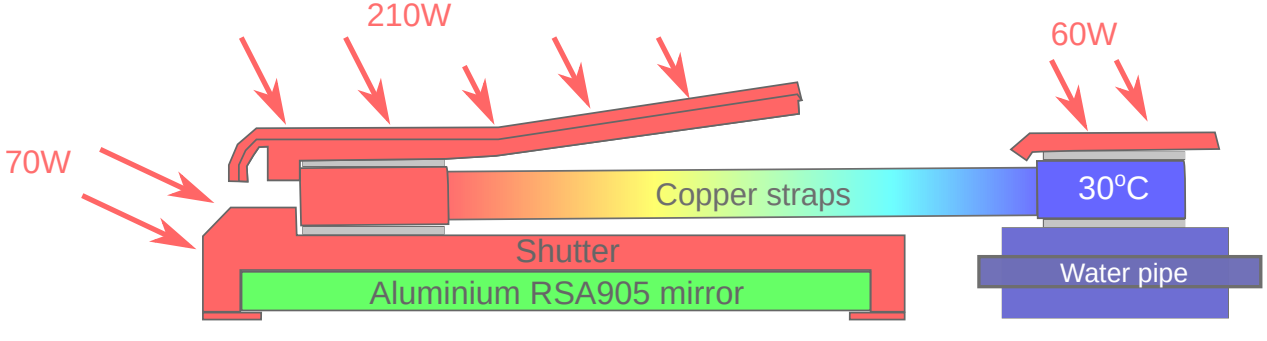


AEM21 Immersion Tube - Thermal

Thermal conduction of shutter (steel) and cover (copper-plated steel) leads to only slightly higher temperature than strap ends.

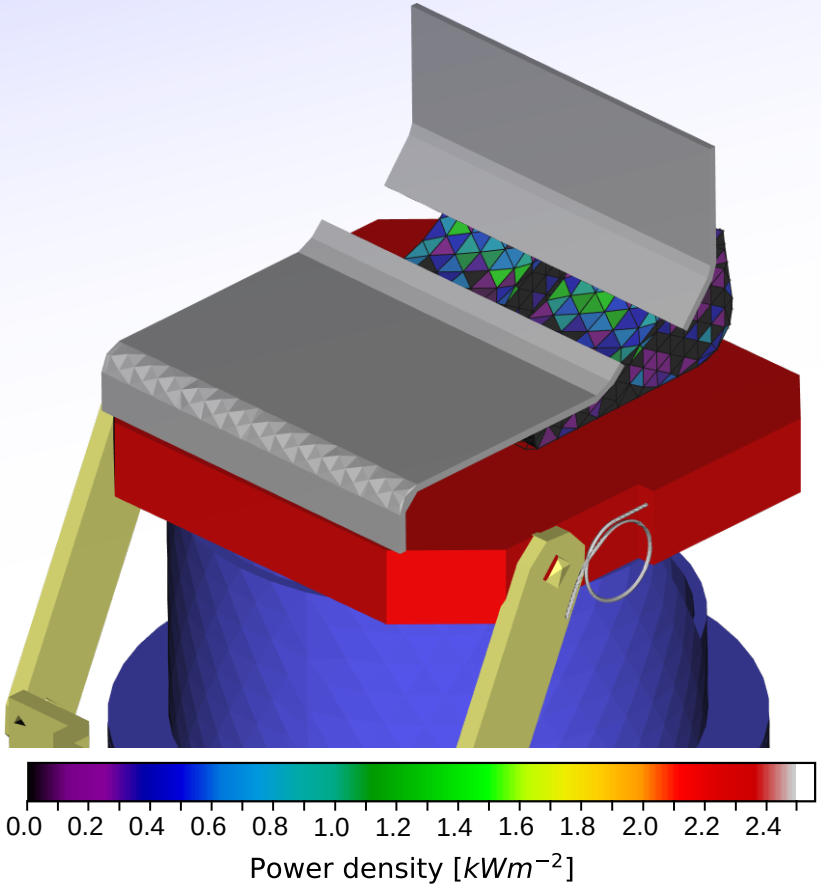




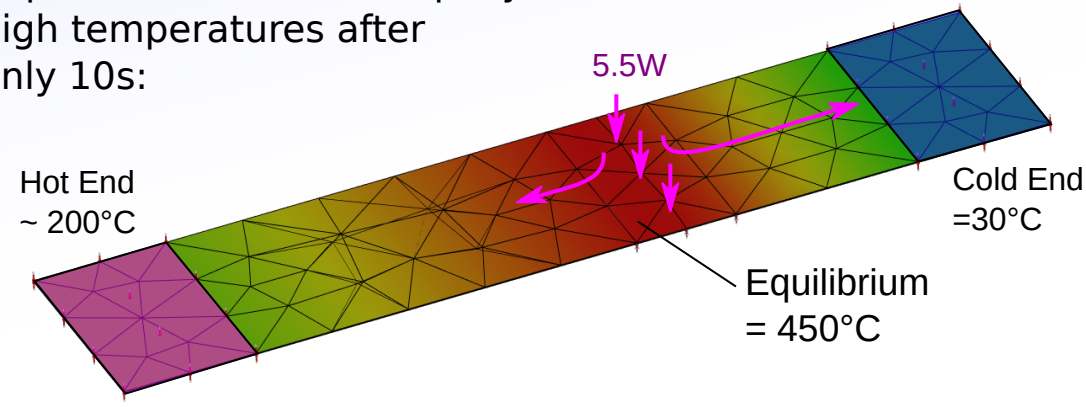


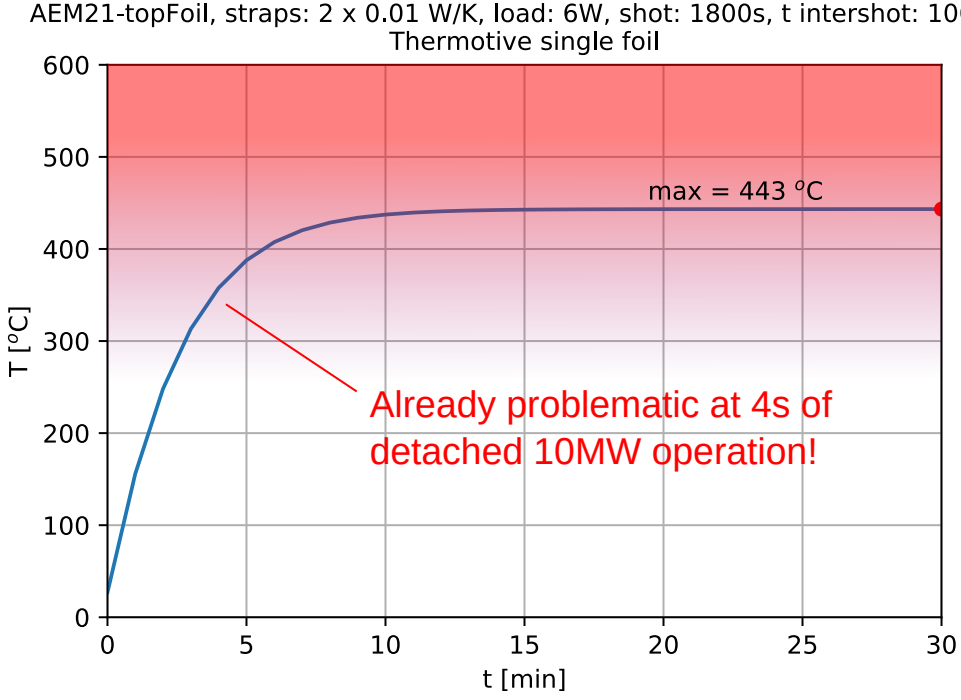
AEM21 Immersion Tube - Thermal

5W falls directly on the top foil of each strap through the ~10mm. The gap is unavoidable in the cover design.



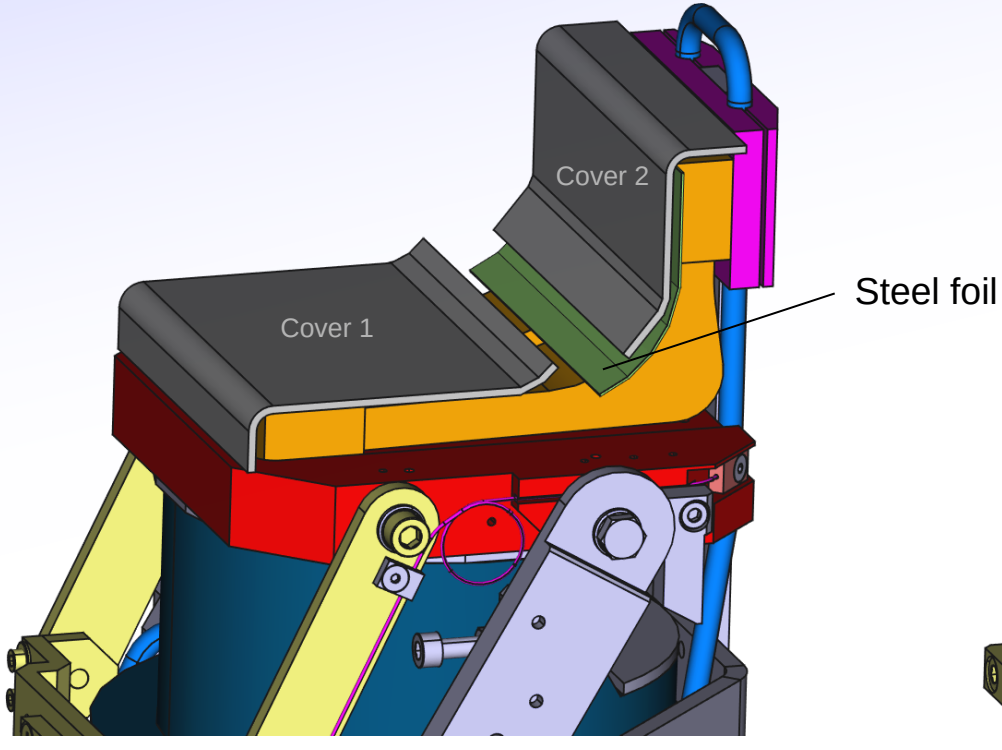
The top most foil has very low thermal inertial (only 25µm thick), so heats rapidly to high temperatures after only 10s:

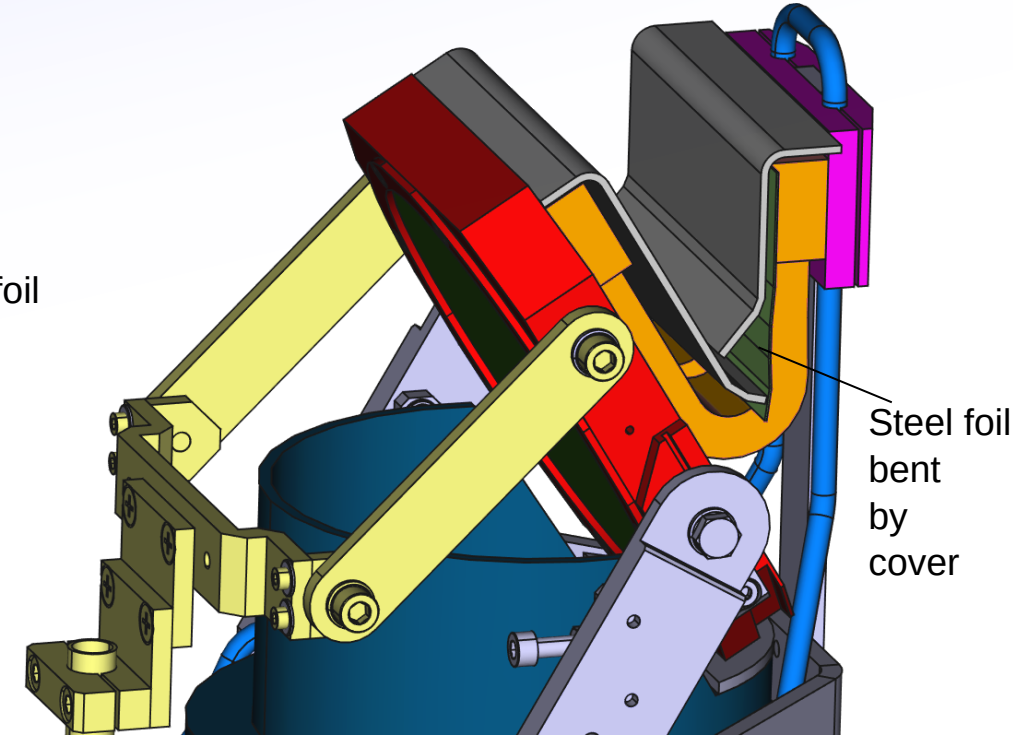




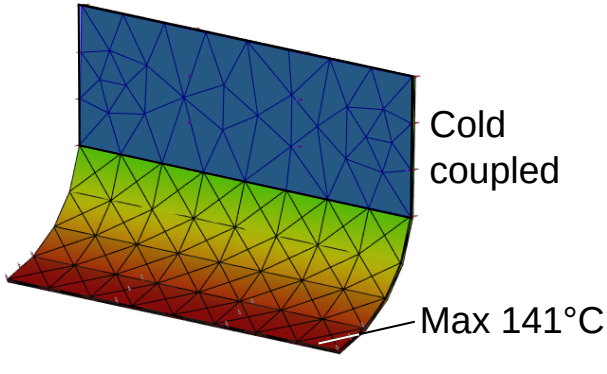
AEM21 Immersion Tube - Thermal

To protect the straps, a 0.5mm steel foil will be added.
- Thin and flexible enough to be pushed back by the moving cover
- Thick enough to provide sufficient heat conduction of the 5W, or to tolerate the resulting temperature.





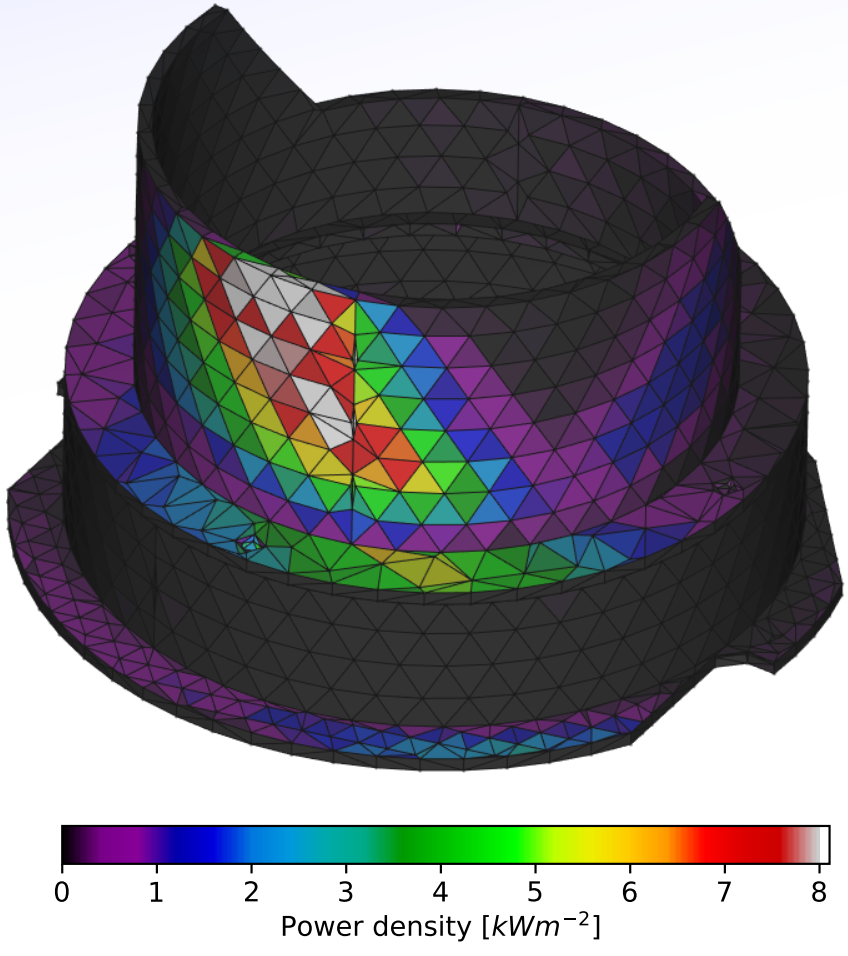
Maximum temperature of steel foil = 140°C

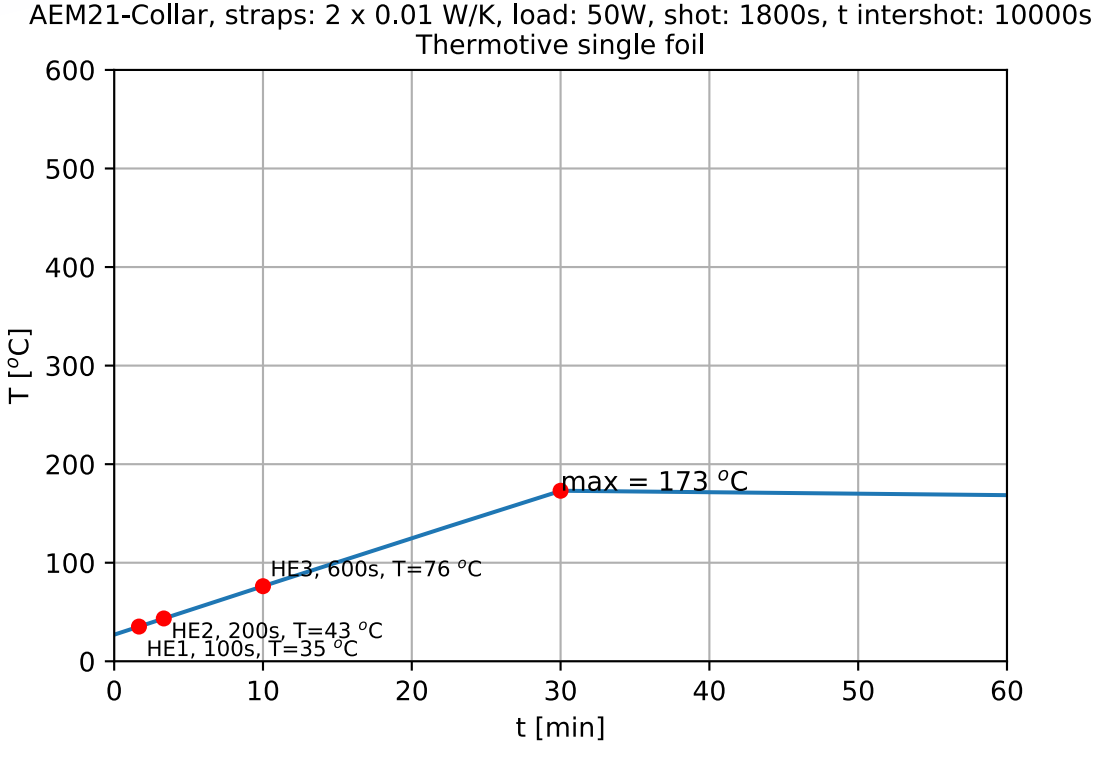


AEM21 Immersion Tube - Thermal - Collar

The protection collar, with sacrificial window, also gets ~50W.

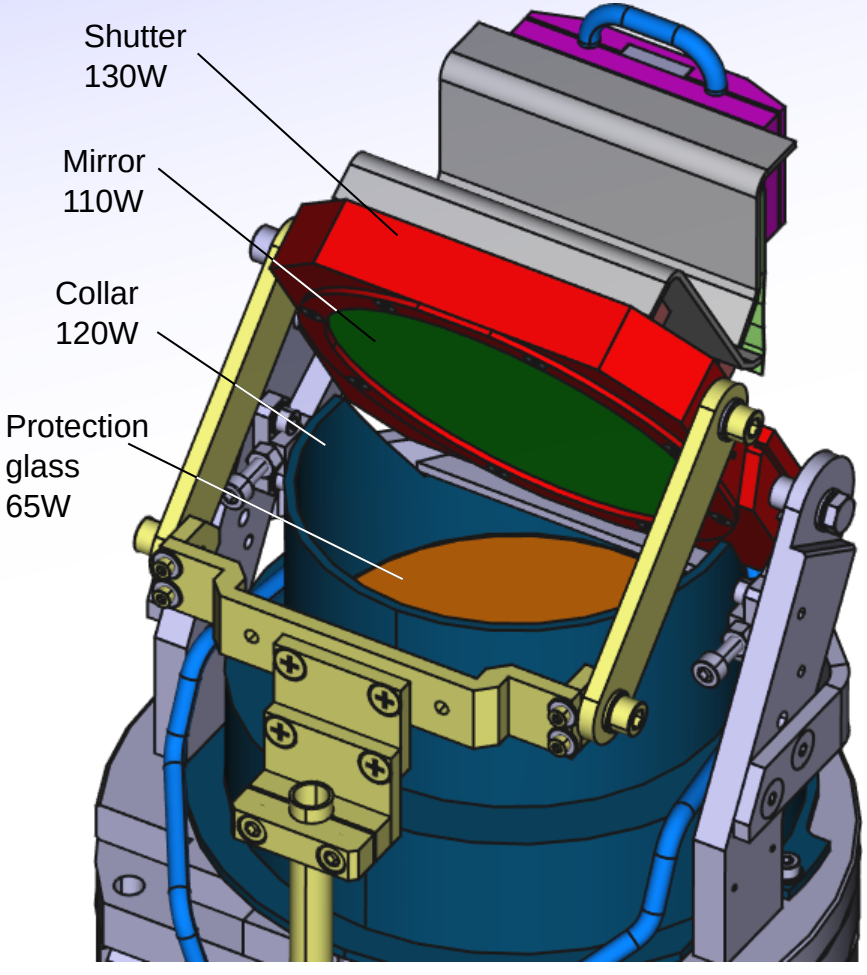
Copper press contact with water cooling pipe to mitigate, but even without water or radiation cooling, only ~180°C would be reached even for HE4.



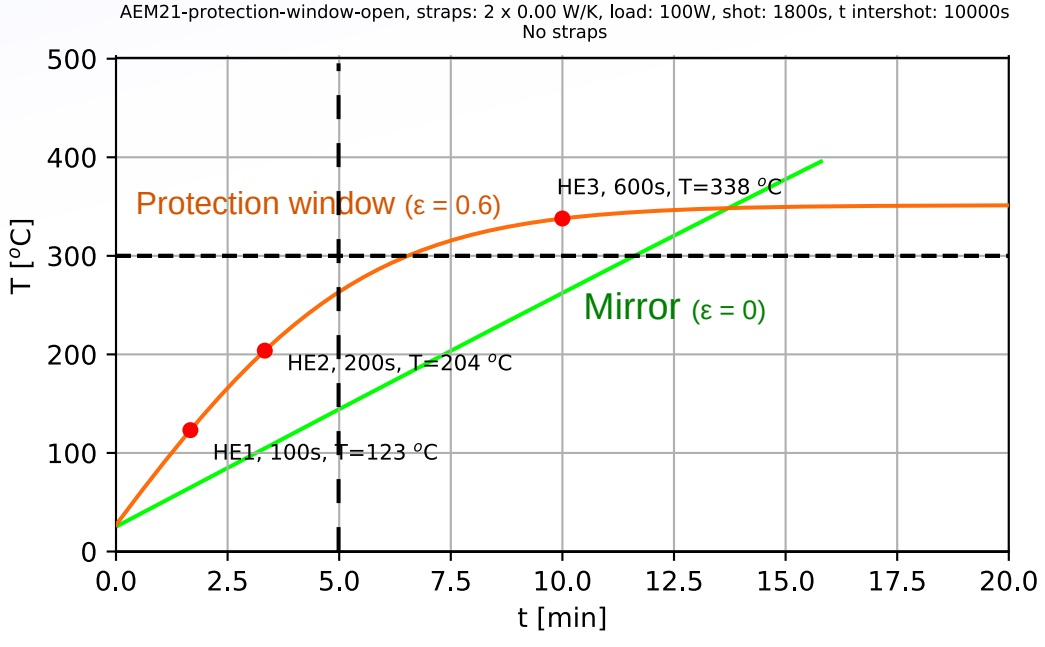


AEM21 Immersion Tube - Thermal - Open

With open shutter:



Even without any heat transfer through contact with shutter, mirror can be safely exposed to full heat load for several minutes (once):



Window would get 65W --> 20°C/min which is above maximum allowable 2°C / min.
Instead, protection glass can easily handle up to **~5 minutes** --> Sets maximum shutter open time.

Soft X-ray / VUV --> Captured by protection glass
Visible / IR --> Passes protection glass and window

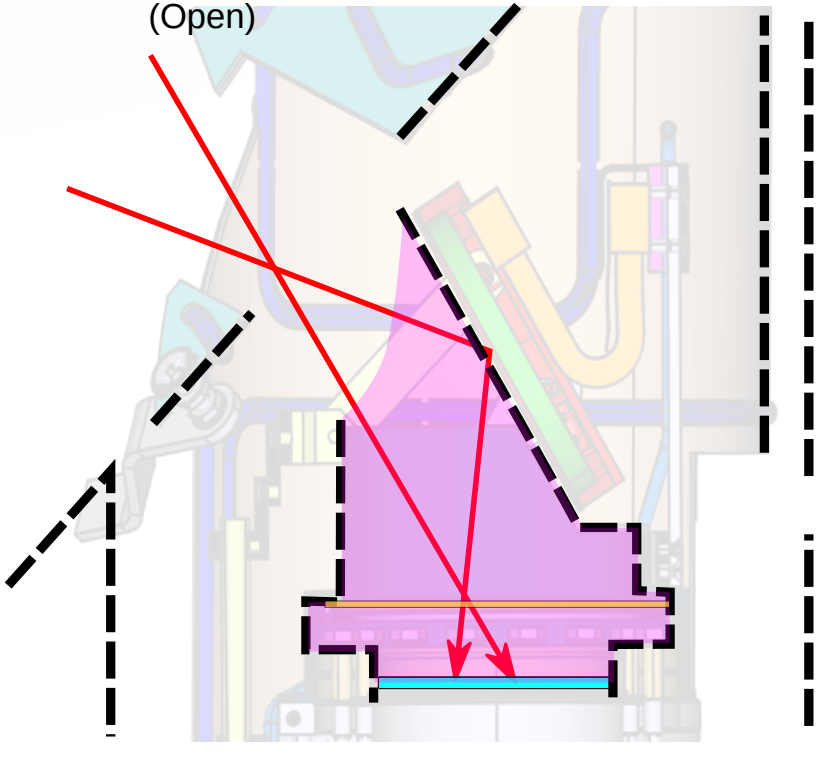
AEM21 Immersion Tube - ECRH stray radiation

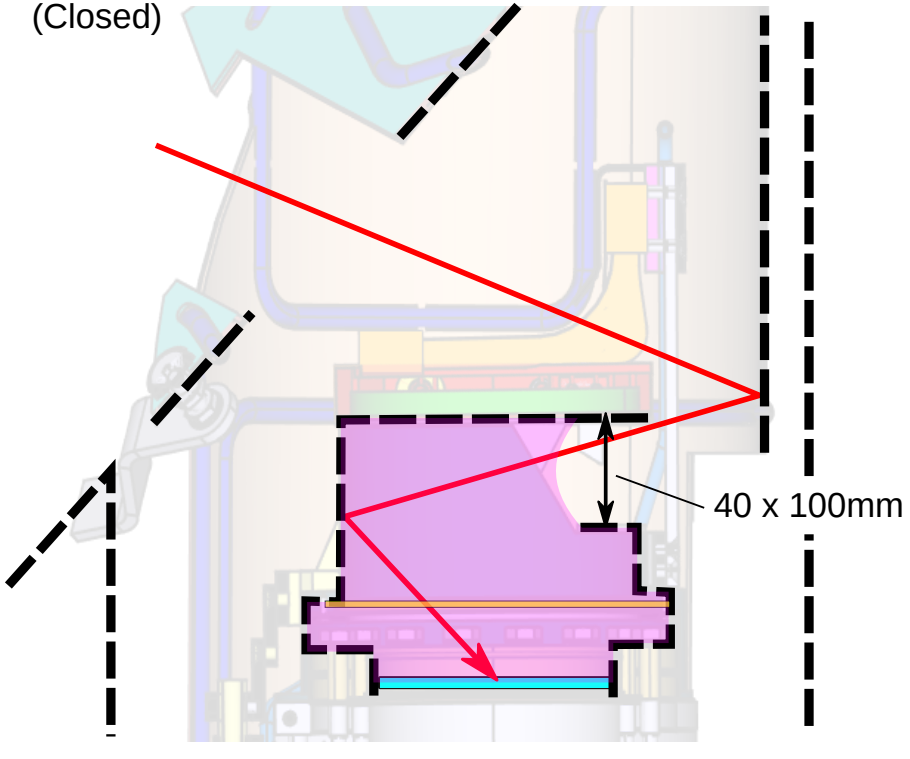
Stray radiation in HM21 is expected to be max 12kW m^{-2} [1-ACH-T0088 A.Carls].

Window used in OP1.2 was ITO coated but test in MISTRAL showed incorrect layer and strong absorption:
- At 12kWm^-2 --> ~25 °C/min >> 2 °C/min MAX

- Window did not break in MISTRAL tests at 50kWm^{-2} up to 15 minutes, where >> 300°C was reached.
- In operation, open-shutter time could be limited to 30seconds, where only 60°C would be reached at 50kWm^-2. Actual power is at most 1/4 of this.

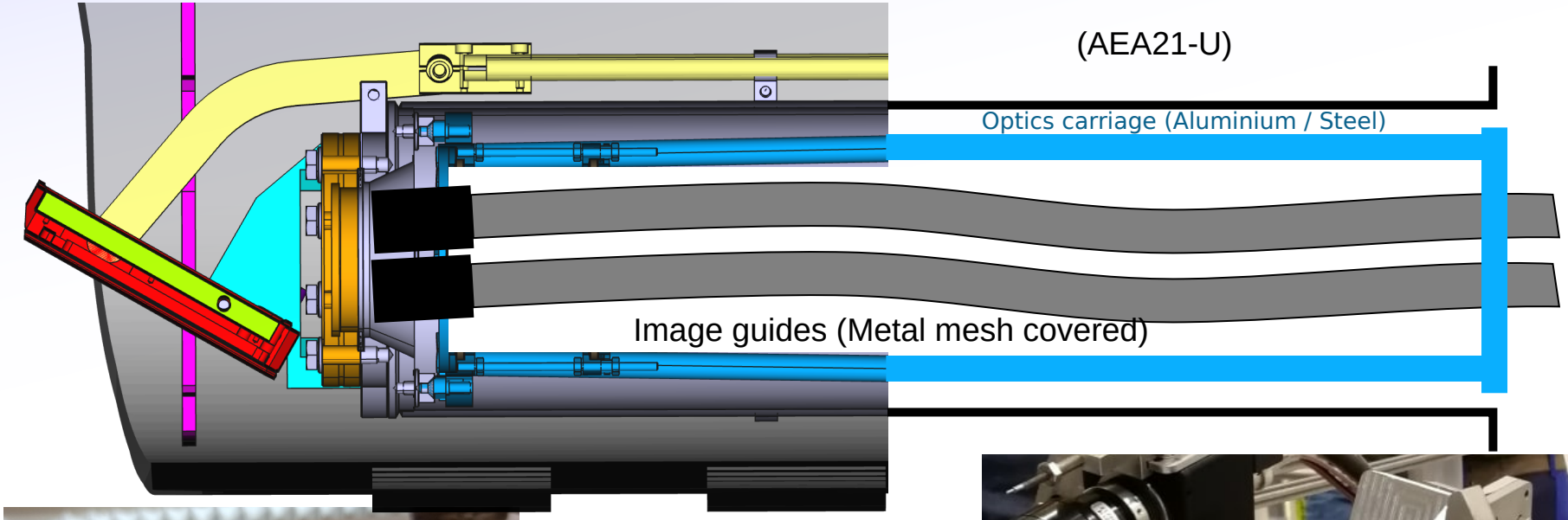
With closed shutter, window exposure is only via 100x40mm gap behind shutter, but no absorber inside window enclosure, so EC radiation can build up:

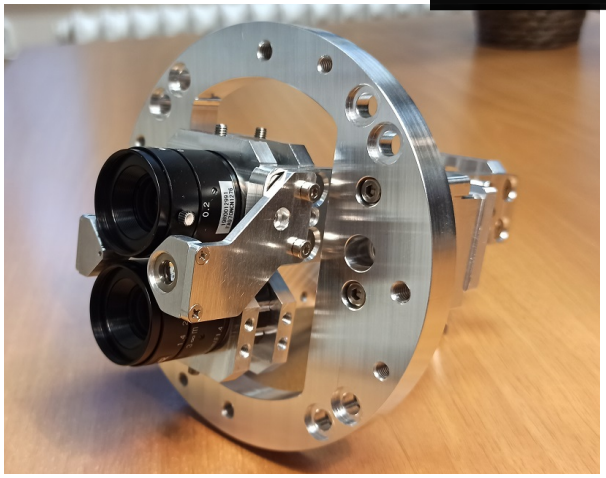


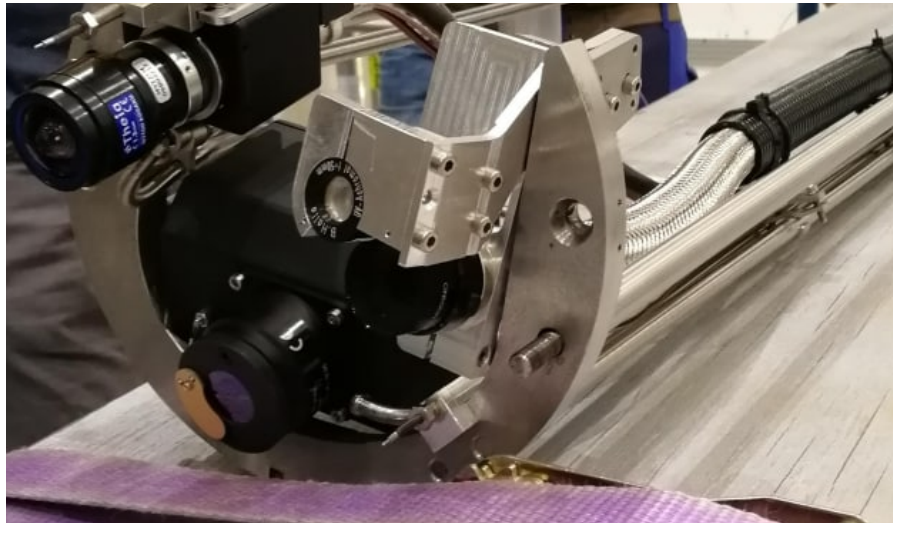


ECRH stray radiation - AEA21-U

Contents of tube:
- Stainless steel and aluminium mouting components.
- Objective lenses - Unknown glass
- Image guide - covered in wire mesh.



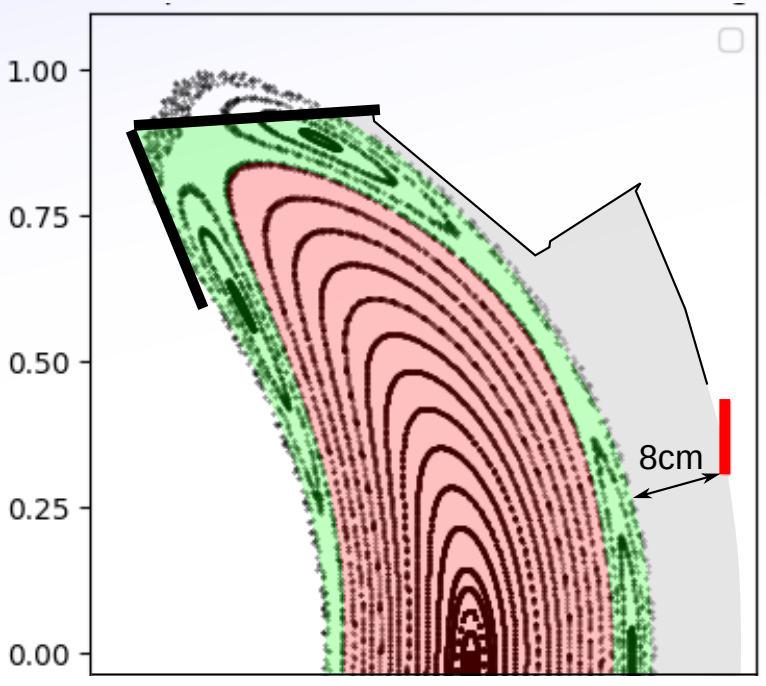


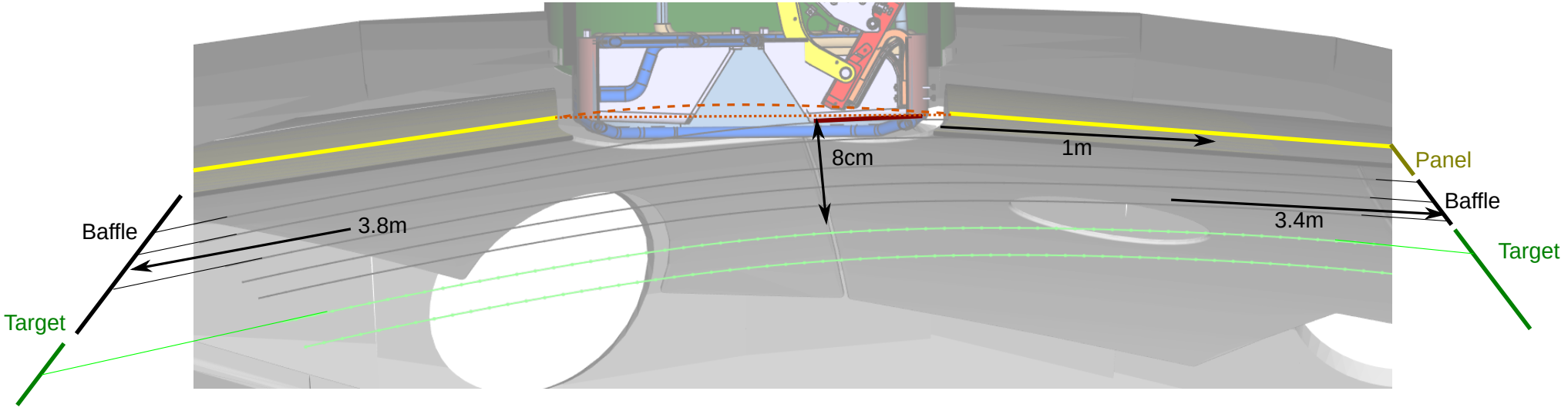


AEA21 Immersion Tube - Housing

Lower corner of CXRS Housing protrudes ~8mm beyond panel level, but still 8cm deep in SOL shadow:

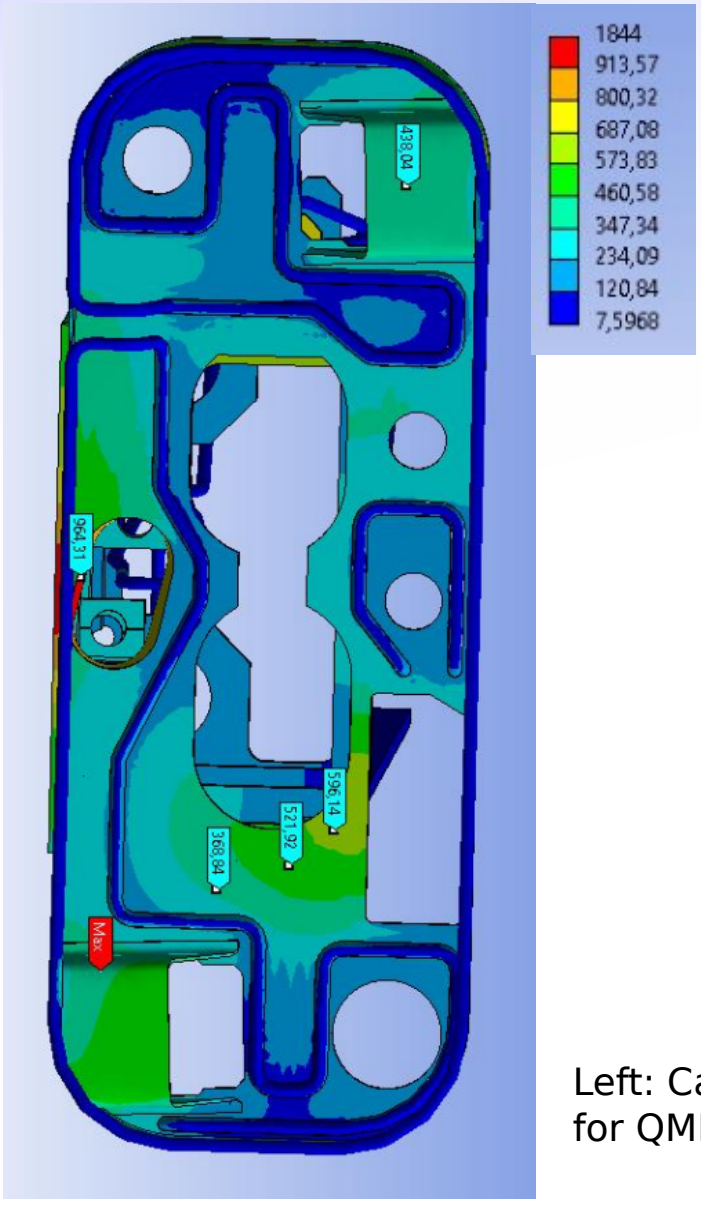
Housing is a copper-plated steel with connection to cooling

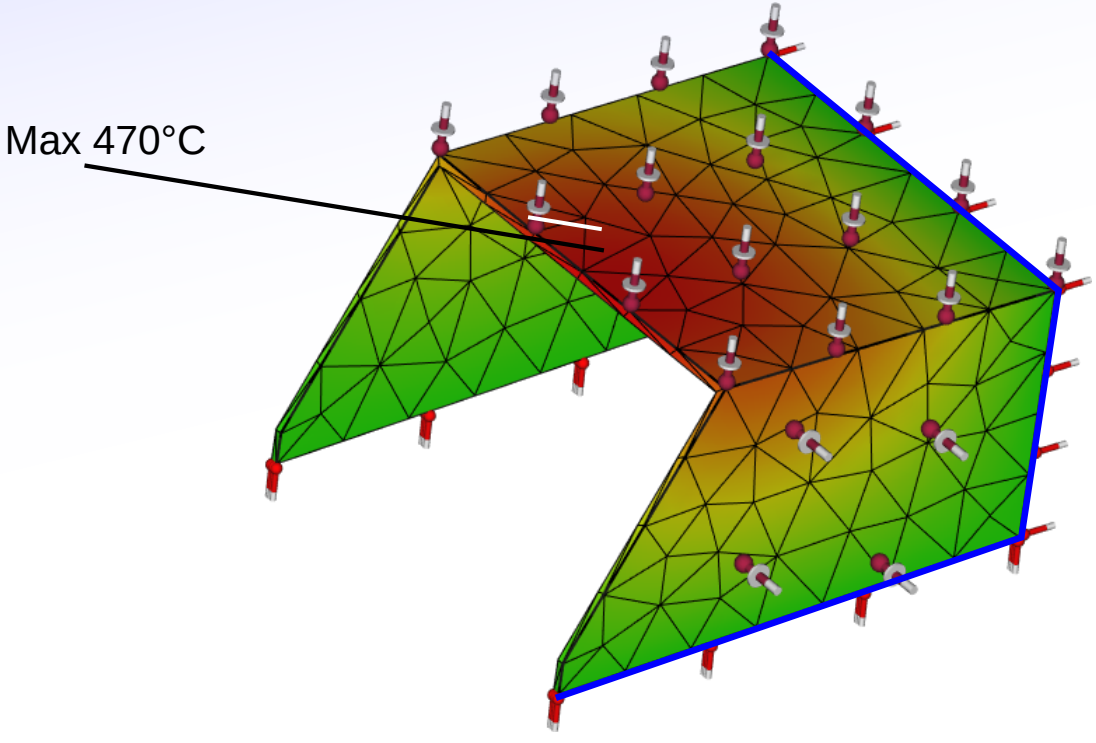




AEA21 Immersion Tube - Housing

Radiation load to housing:



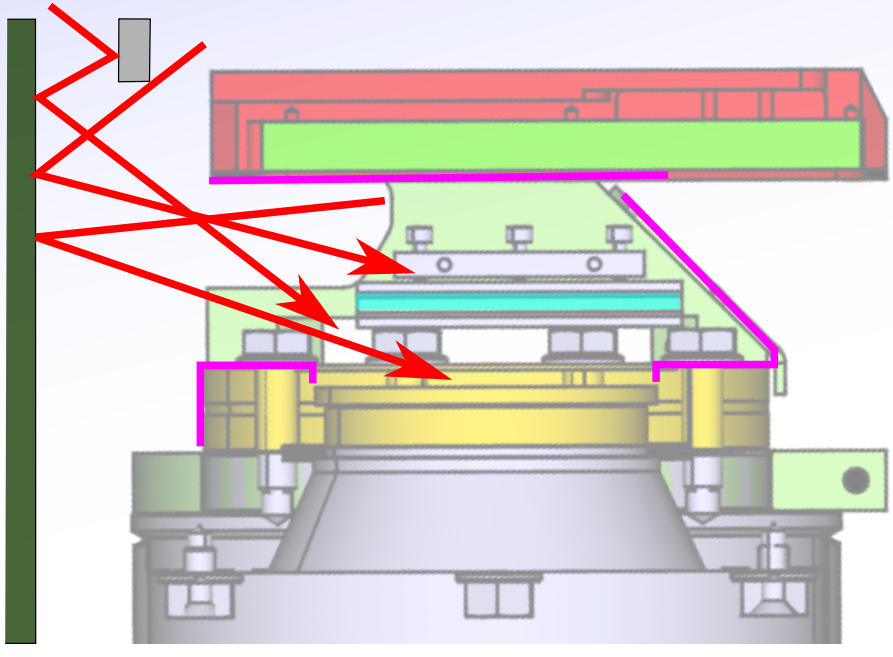


Simple thermal model gives max as 470°C.
This is acceptable for copper plated stainless steel.

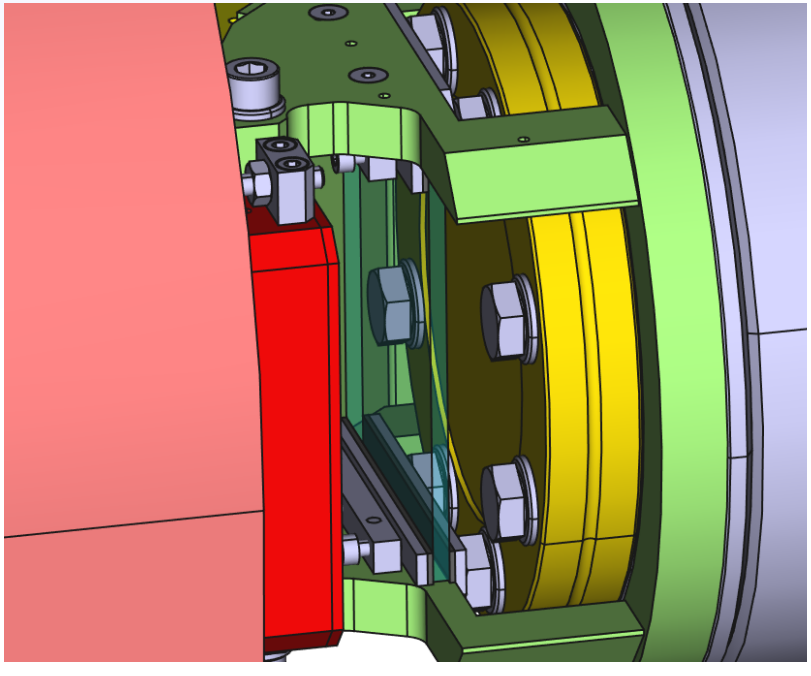
Left: Calculation by A. Carls for
for QMR-K3 DDR gave ~450°C

AEA21 Immersion Tube - ECRH

~35 x 80mm gap to window that could pass EC stray radiation.

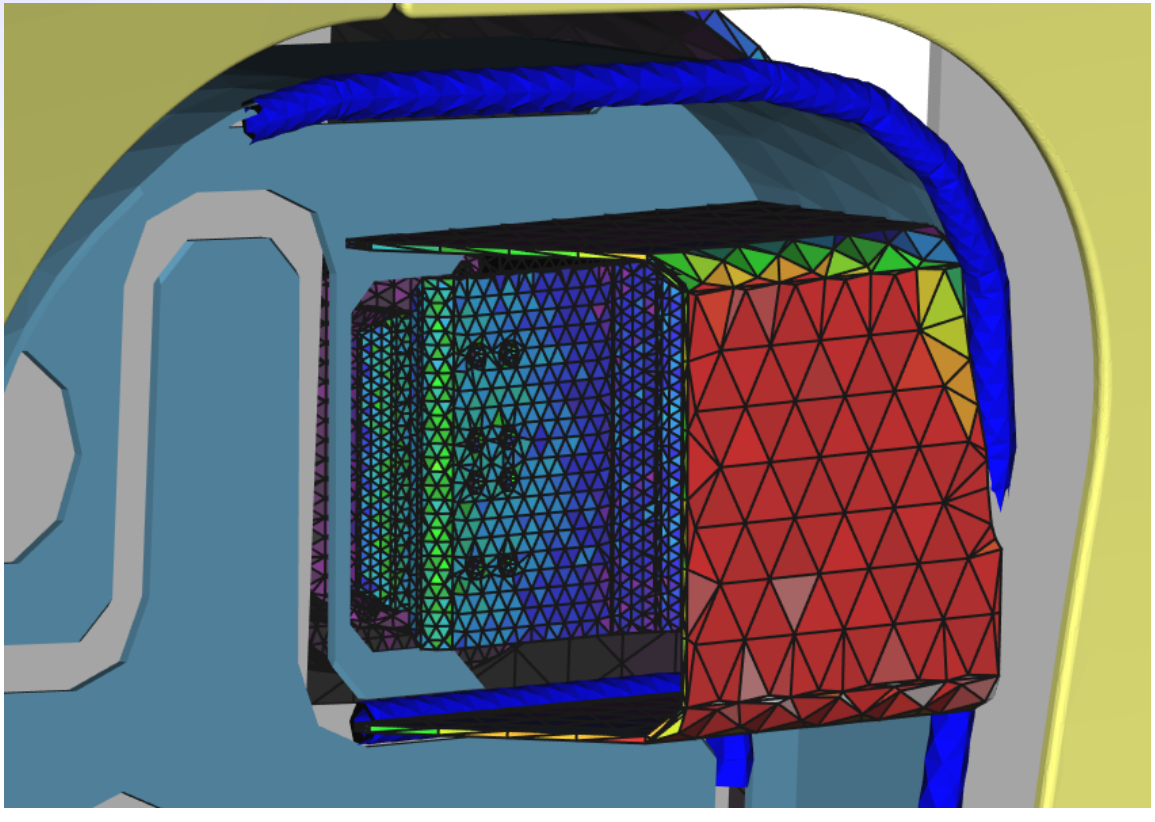


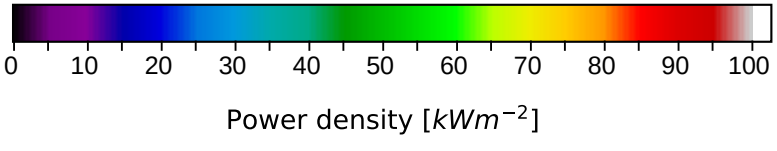
Port wall

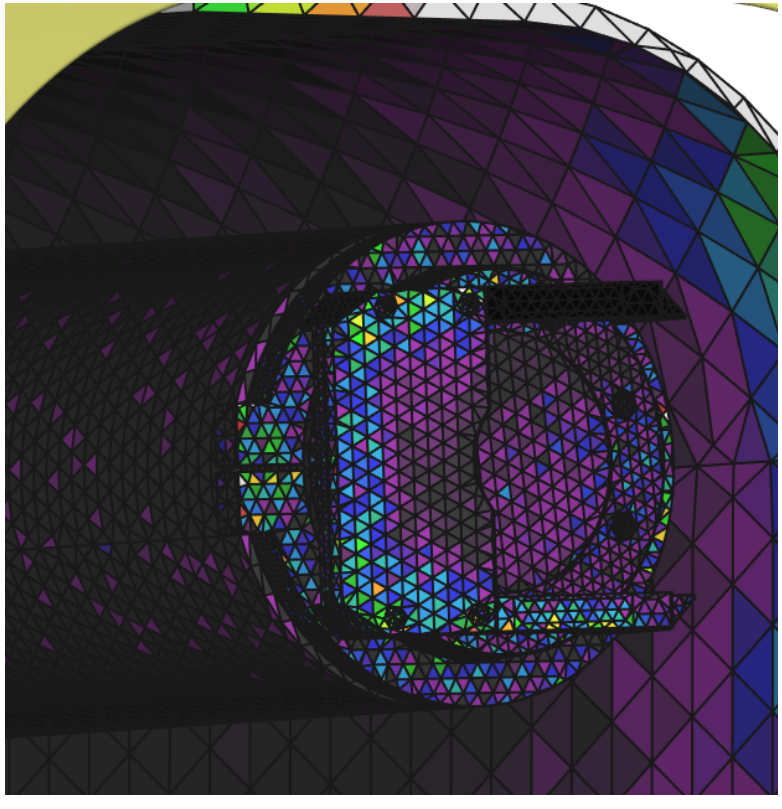


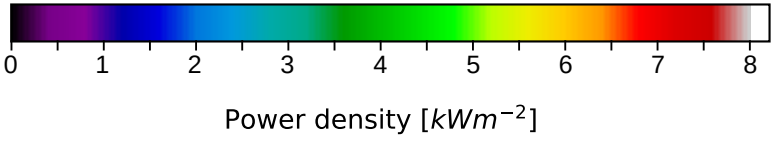
AEA21 Immersion Tube - Radiation loads

Radiation loads from final shutter/cover structure:
Cover sees almost full ~100kWm-2 (validation check).
Loads to port wall and immersion tube through gaps negligible (as in QMR K3 calculation).



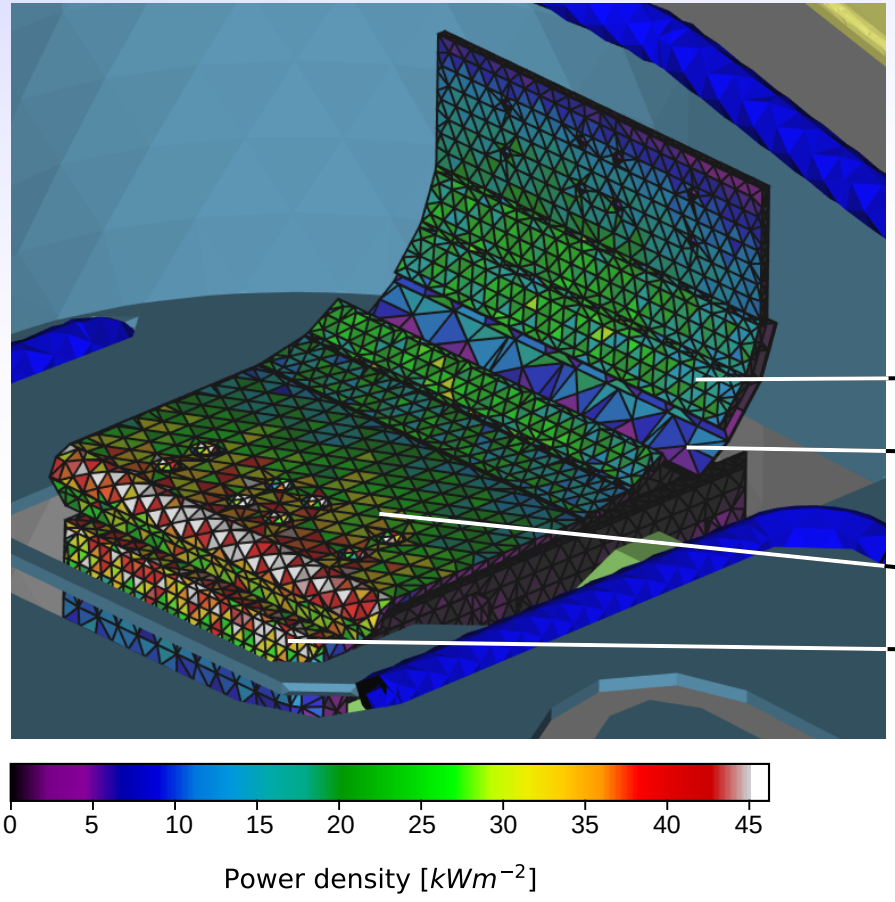


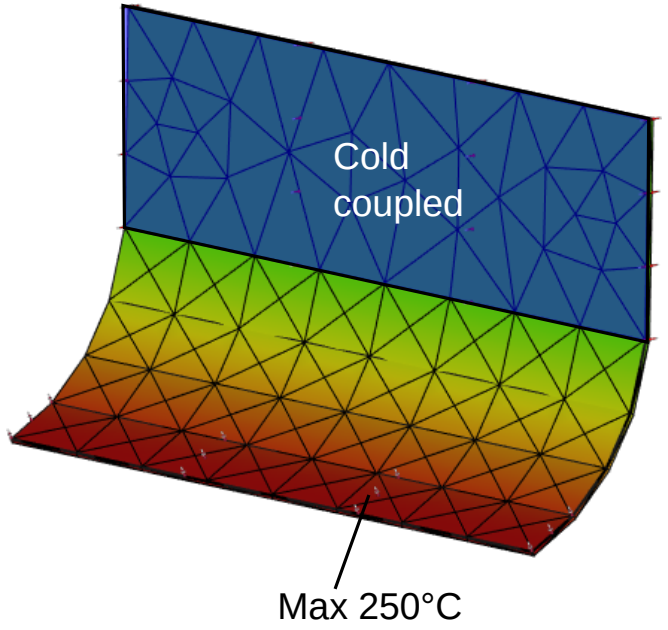




AEA21 Immersion Tube - Radiation loads

Loads to covers and shutter are somewhat higher than for AEM21

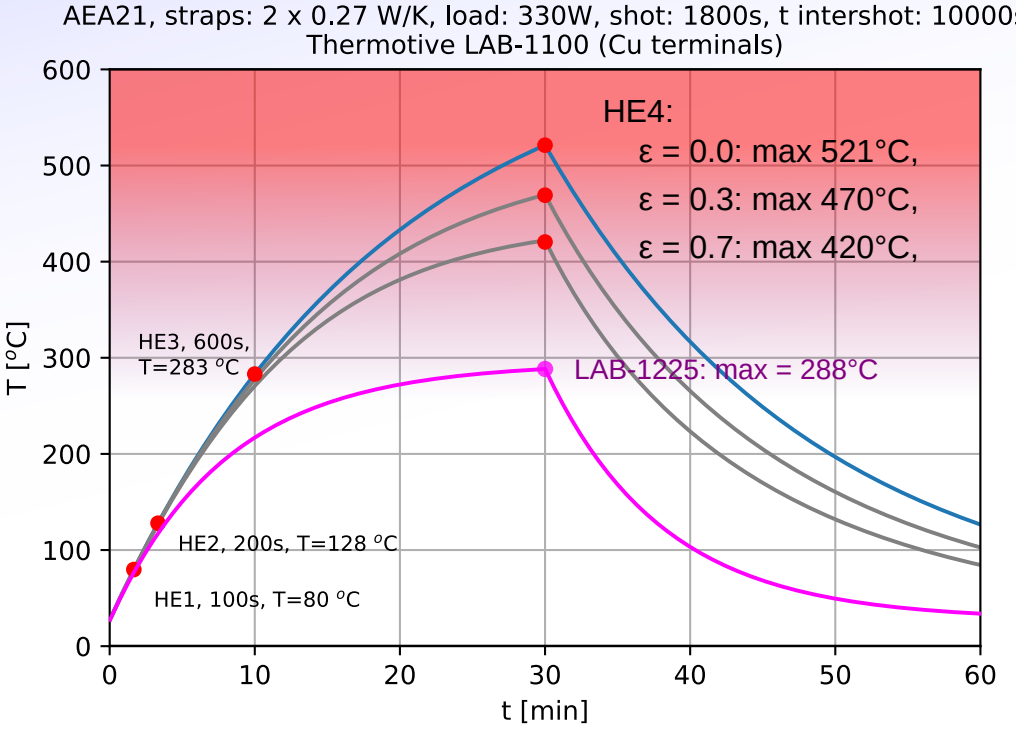


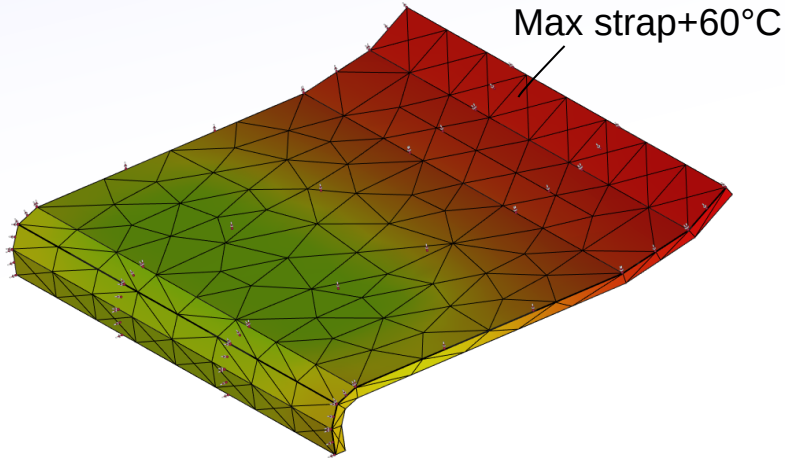


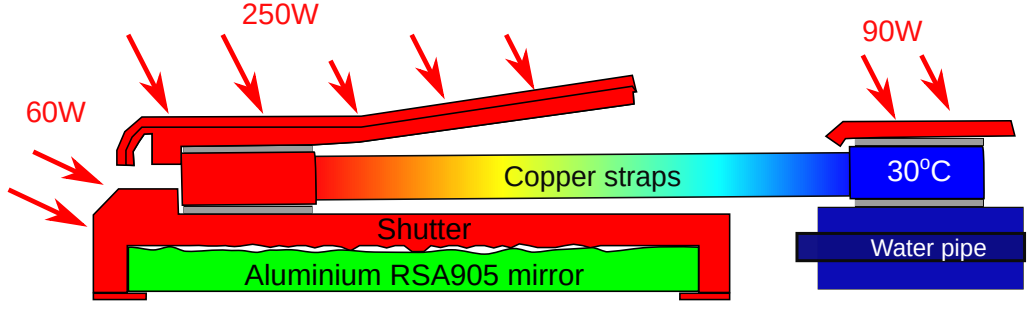
- Gap foil solution definitely required to protect straps.
- Foil reaches max 250°C (acceptable)

AEA21 Immersion Tube - Radiation loads

P = 250 + 60 + 20W max re-radiation from housing
Temperature evolution of shutter is faster due to larger heat flux and smaller LAB-1100 straps.





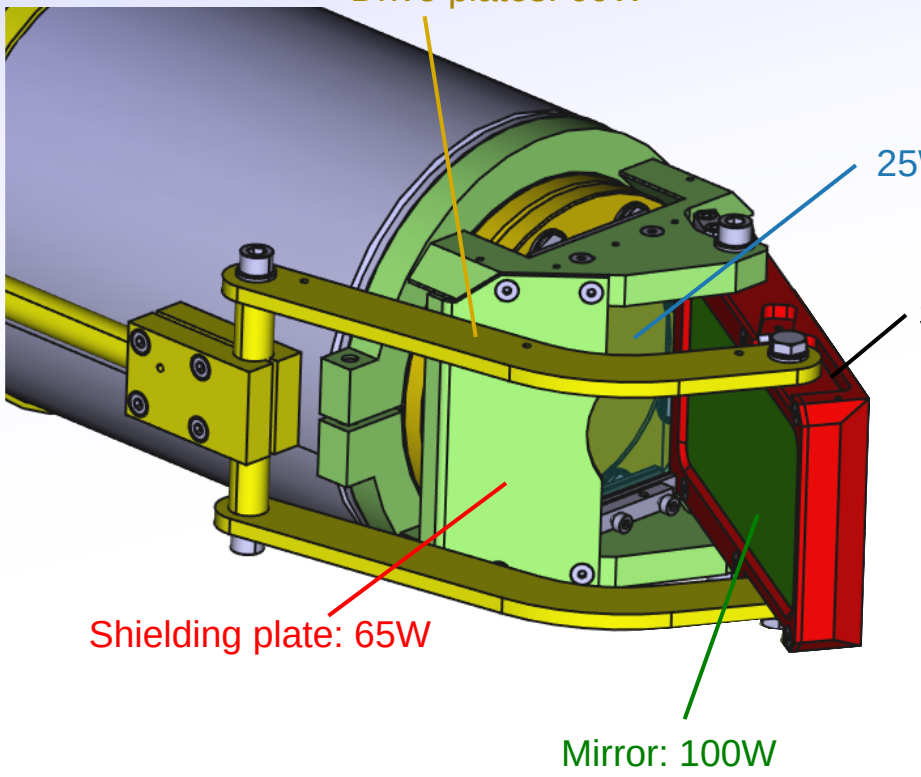


- Acceptable up to HE3.
- At HE4, max temperature critical but depends on assumed emissivity.
  - 450°C is acceptable for shutter and covers (steel + copper).
  - Aluminium not OK at 450°C, but thermal conduction from shutter poor, so there is little real risk.
  - Redesign using LAB-1225 not possibly now, but maybe after OP2.1.

--> Accept this design for HE3 and monitor real temperature evolution of shutter with thermocouple during OP2.1-.3 detachment experiments.

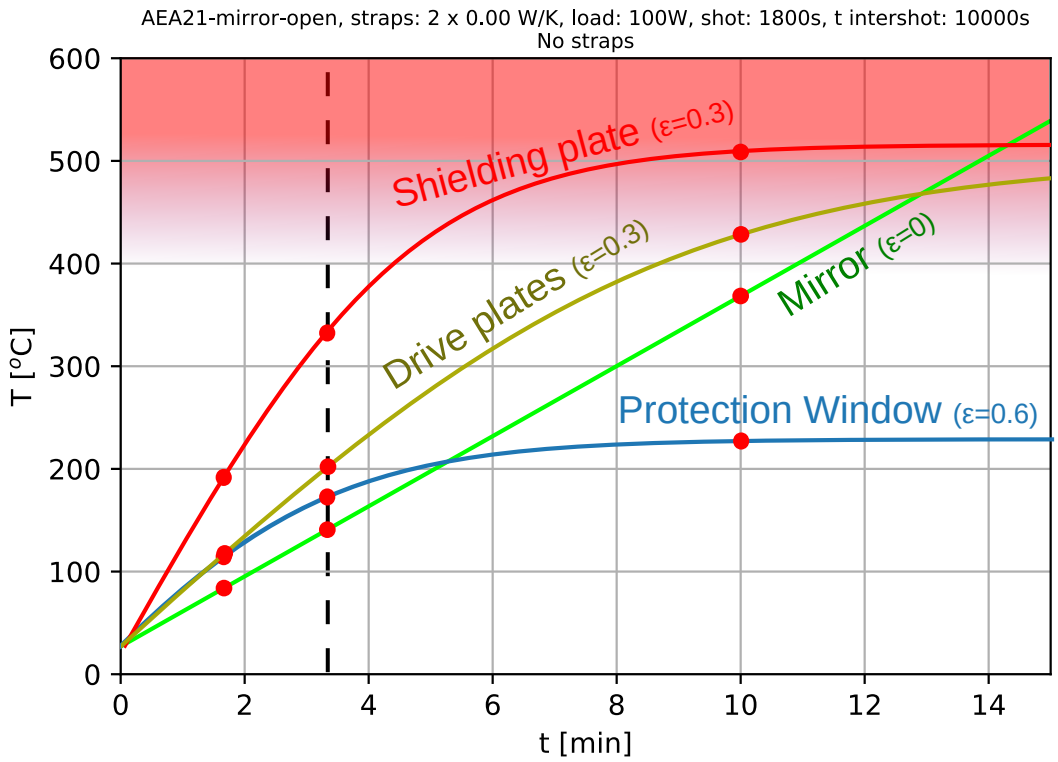
AEA21 Immersion Tube - Radiation - open

With shutter open:



As AEM21, mirror and protection window loads benign up to several minutes.

Thin steel shielding plate sets limit of ~200s (HE2) max **open** shutter time.



AEA21-U - Video, CIS, CXRS-CIS

- Extension/change of *existing* projects (QSV, QSK, QRI).
- Separate projects by physical components:
 1) QSK: Immersion tube, optics carriage and optics.
 2) QSV/QRI: Image guides, soft-iron boxes and contained components.
  - Including routing of image guides.
 3) All: Respective racks and lab components.

"*CXRS-CIS*": - Design and purchase of optical components by University of Seville in 2021.
- Approximately copy of QRI components installed inside QRI soft-iron box.
- Data acquisition in QSK racks (LWL connection).