QSK (CXRS) - Ausbau - Kühlung für OP2

(Ladungsaustauschspektroskopie am Neutralheizstrahl)

Design Review ??.??.2019/20

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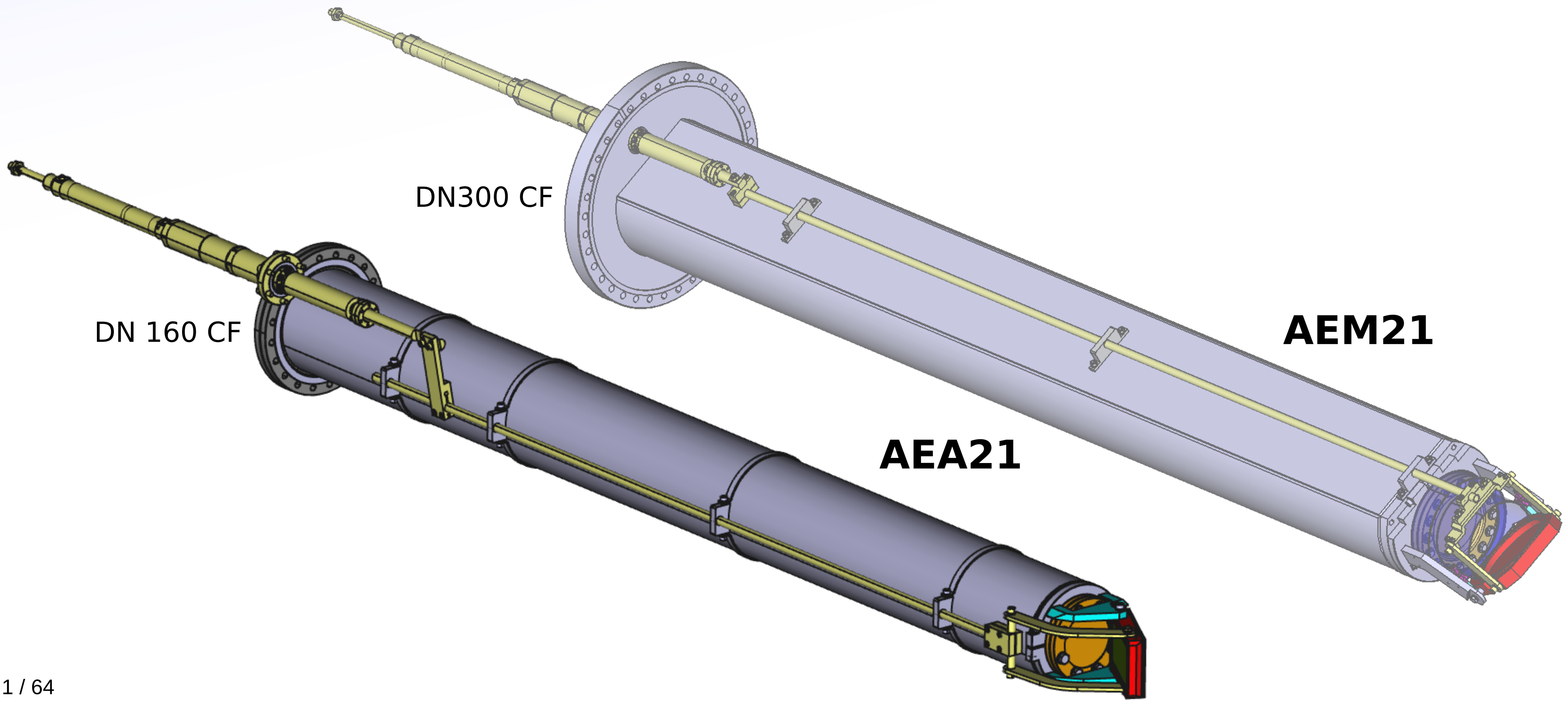
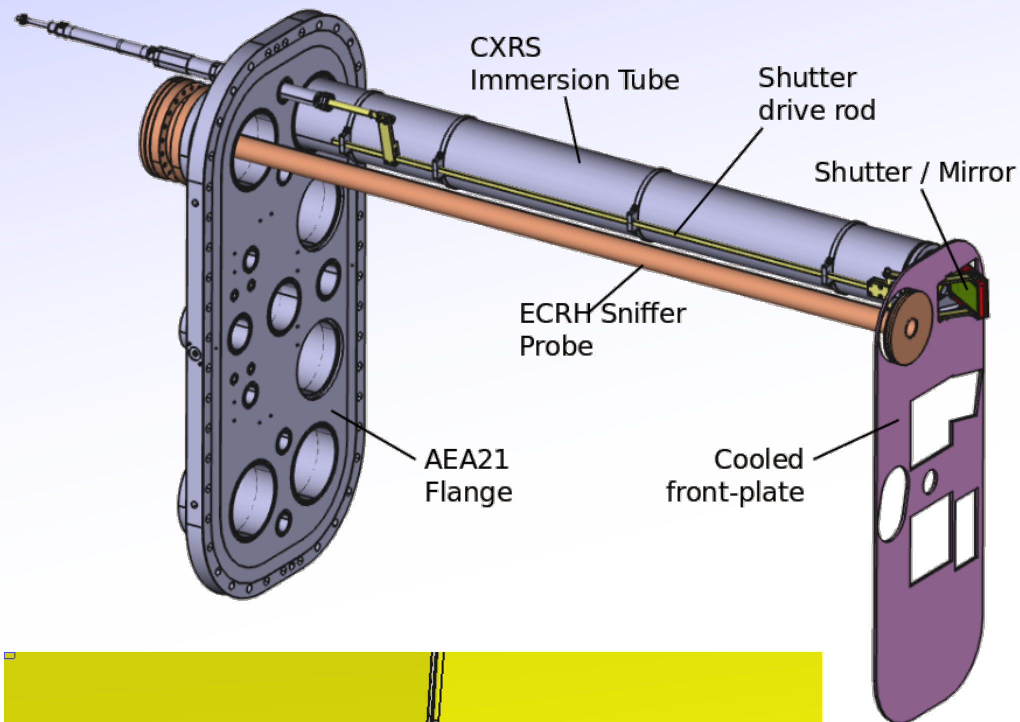
Immersion tube: AEA21 and AEM21

- Two immersion tubes installed for OP1.2b:
- Cooling may need to be added for OP2 long-pulse operation.
- Both systems have an aluminium mirror in a stainless steel shutter block.
    - Shutter only needs to be open for ~10s, so windows and mirrors only exposed for short periods.
    - Back side of shutter block directly faces plasma and may need to be actively cooled.
- AEM21: Port liner will not fit with diagnostic - Need a special solution.
- AEA21: Port protected by common cooled front plate - does not need to be considered here.



AEA21

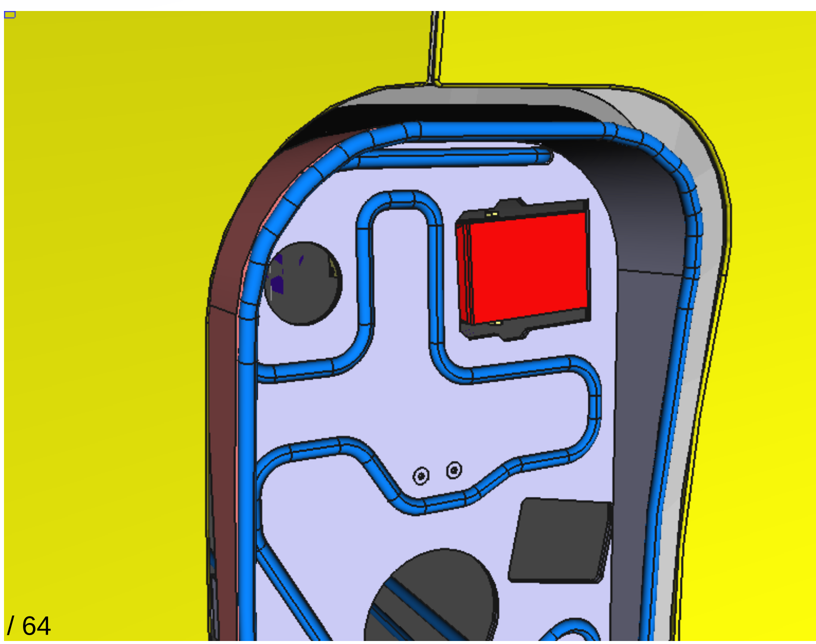


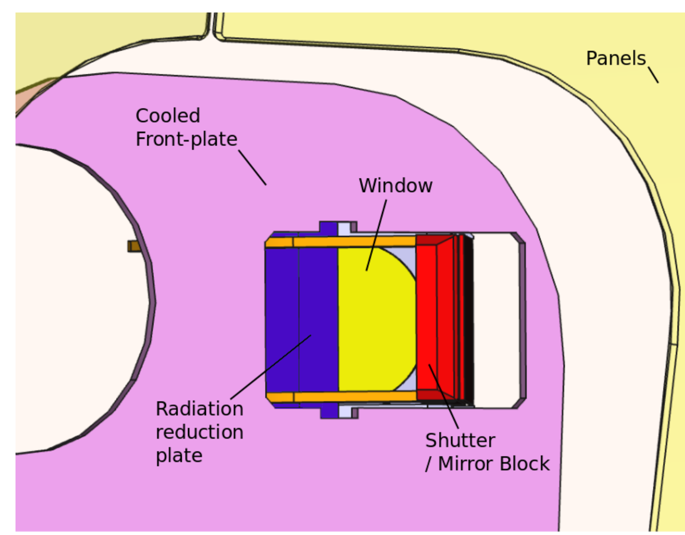
- Cooled front plate provides protection of port wall and most diagnostics parts [QMR2]

- Front plate design finalisation required for thermal calculation and QMR2 DDR.
--> Need to confirm QSK cooling concept.

- QSK Shutter only open during NBI operation ~20seconds.

- Shutter contains aluminium (RSA905) mirror and must remain < 350°C.

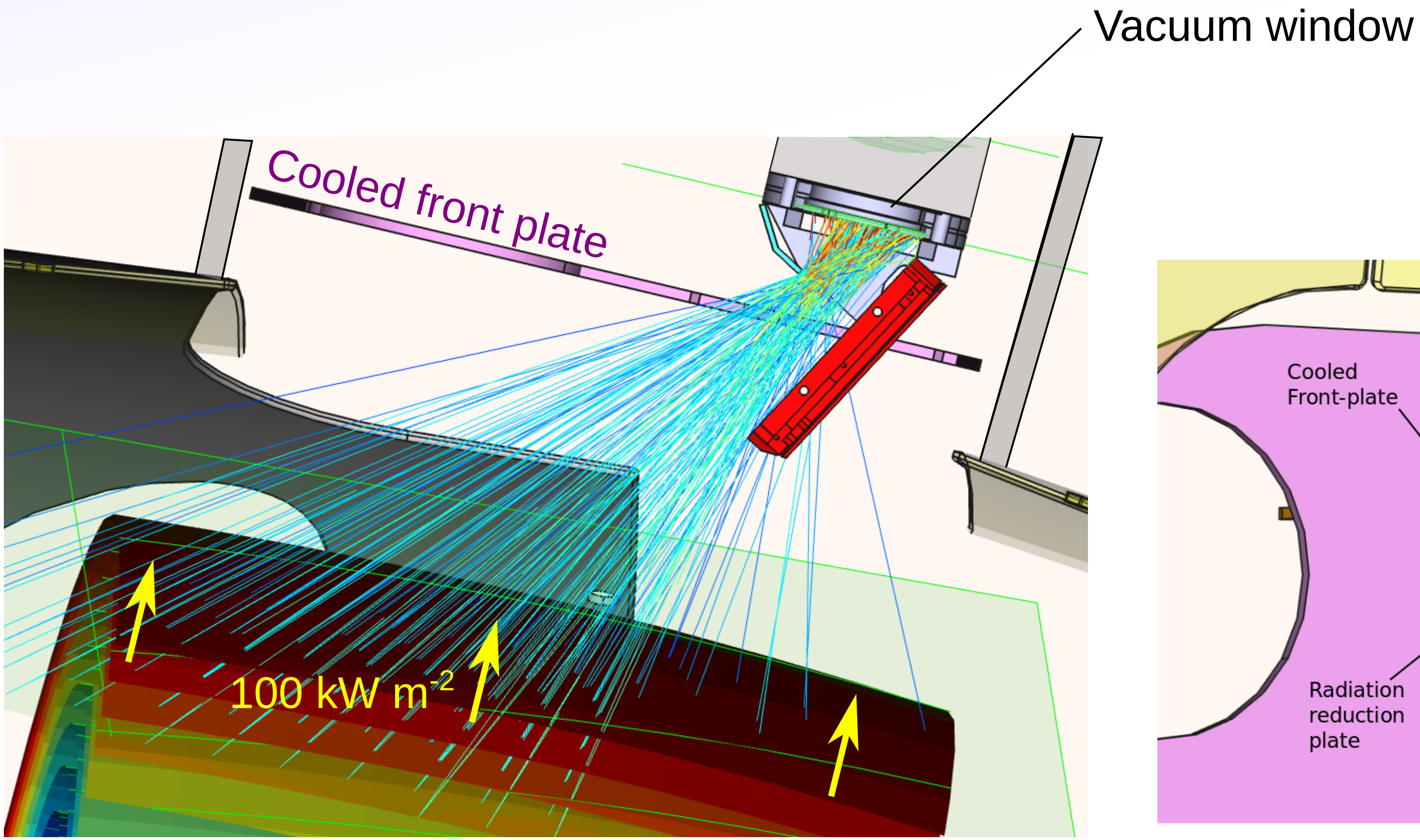


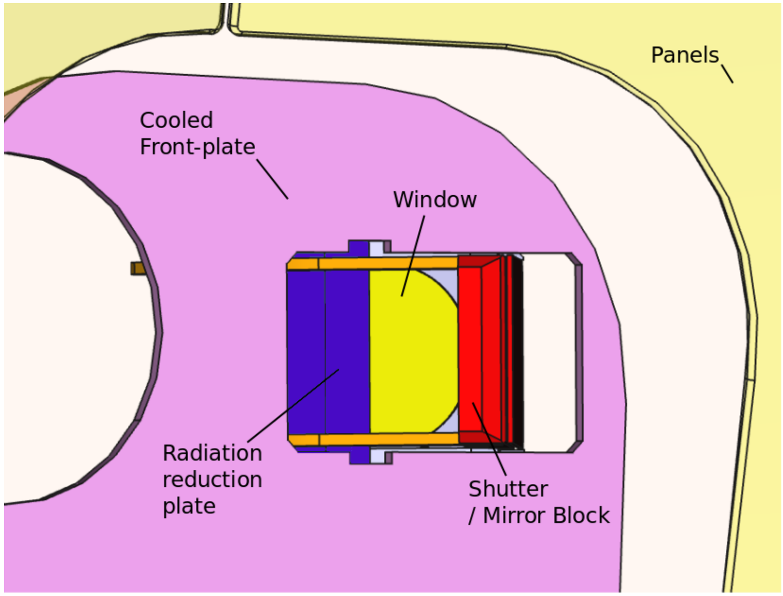


AEA21 - Vacuum window

- Vacuum window only exposed during **20s** open period.
- Shutter, cooled front plate and added structure limit exposure to **40W.**
- Cycle time of NBI ~20 min - enough time to cool by conduction through weld to CF flange.

- *Possible to add 'sacrificial window' (glass plate) in front of vacuum window.*

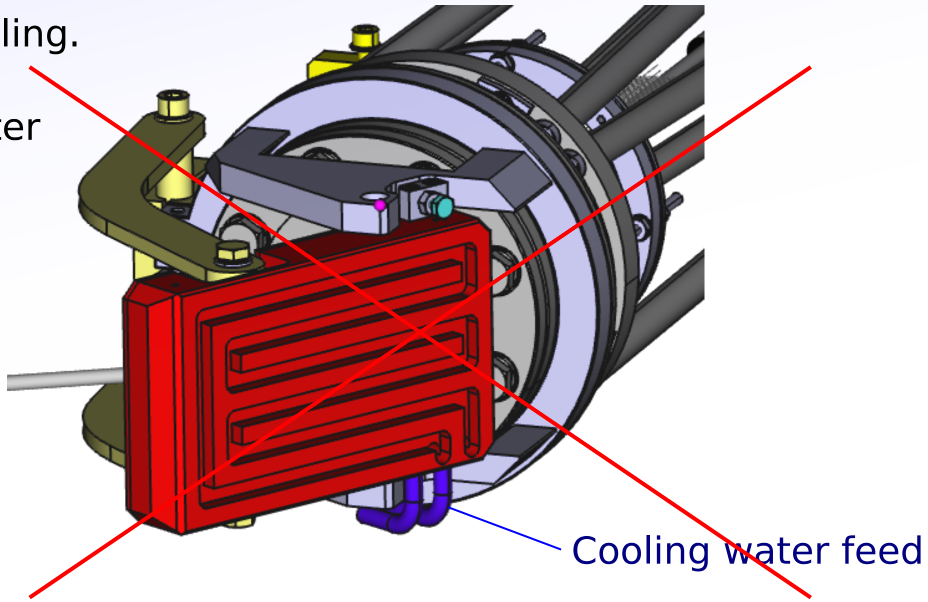




AEA21 - Shutter - Water cooling?

Back side of shutter exposued to full 100kW m^{-2} x 30min.
Shutter hold RSA905 aluminium mirror --> requires cooling.

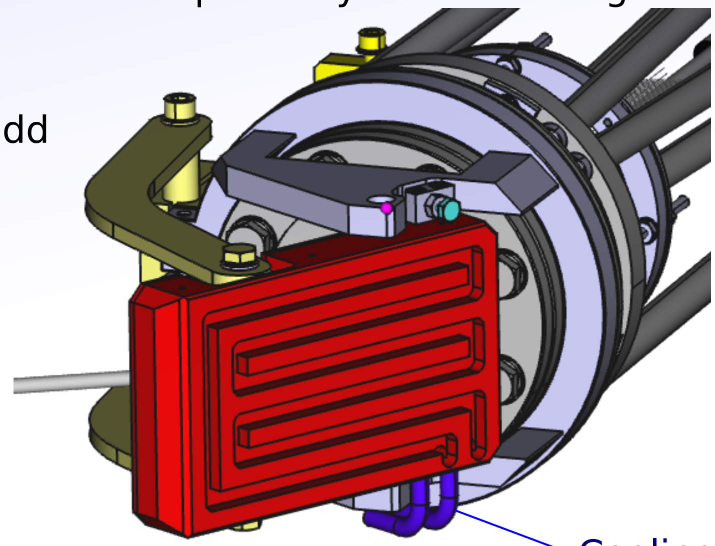
Originally planned to add flexible cooling tubes to shutter but space is too limited.
+Involves risks of water leak.



AEA21 - Shutter

Back side of shutter exposued to full 100kW m^{-2} x 30min --> probably needs cooling.

Either:
1) Machine water channels into mirror block and add flexible cooling tubes to mirror.

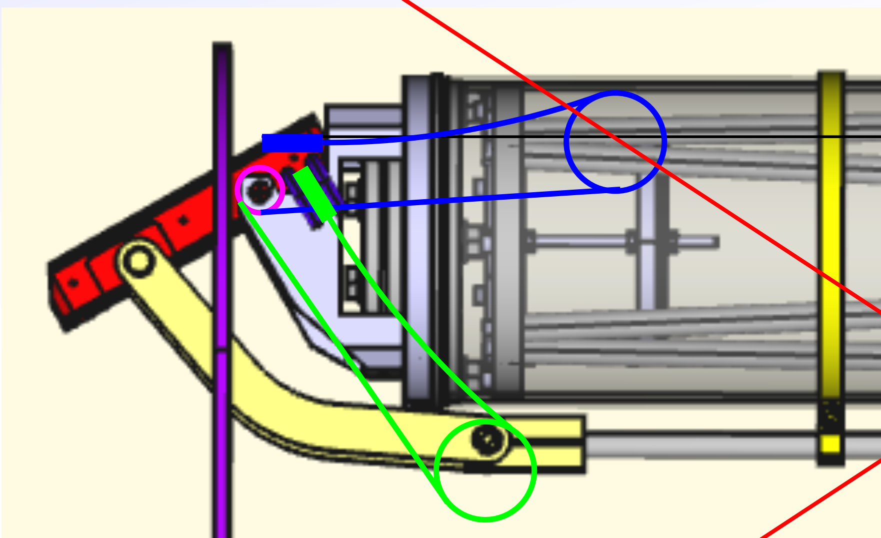


Mirror pivots by large

AEA21 - Shutter

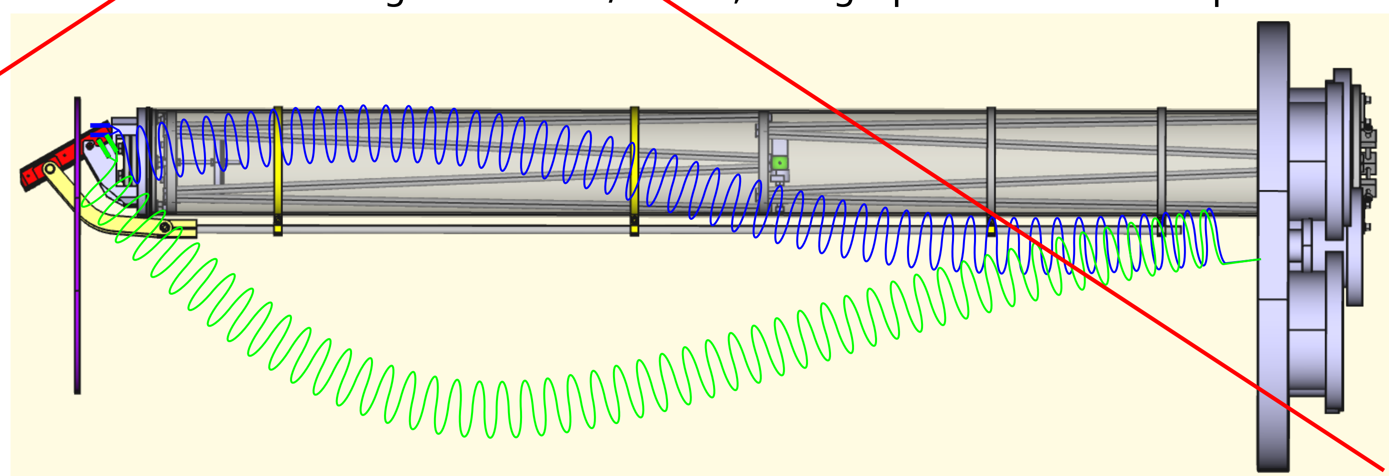
1) Machine water channels into mirror block and add flexible cooling tubes to mirror.

Mirror pivots by 60° and shifts by a few cm - difficult to allow sufficient movement to water cooling pipes.



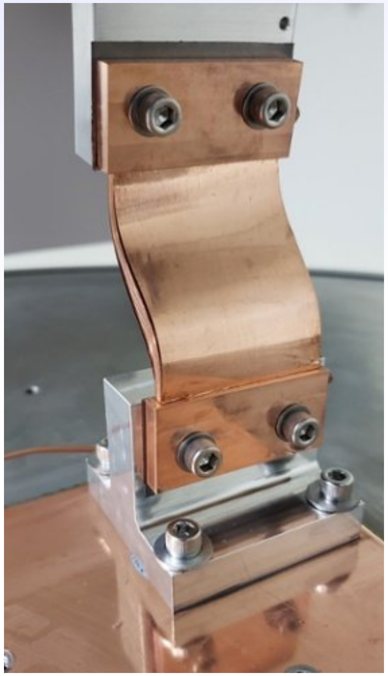
Two coils of pipe required to deal with offset as well as rotation.

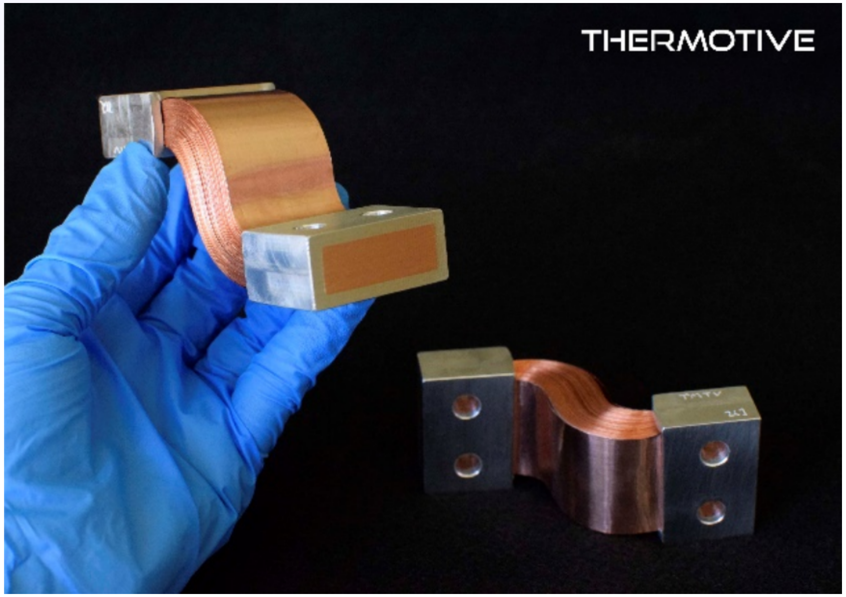
Alternative Idea:
Long coil above/below, using up whole width of port.



AEA21 - Thermal straps

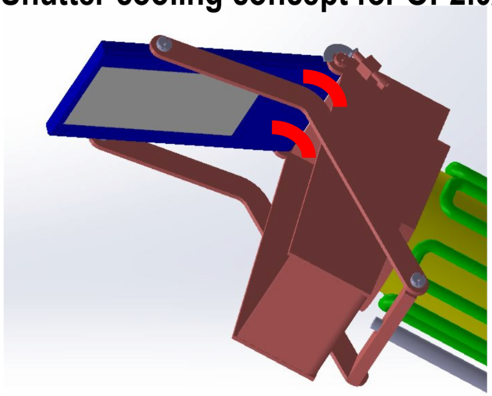
Alternatively, we could use thermal straps:





Thermal conductivity:
- Aluminium: 225 $Wm^{-1}K^{-1}$
- Copper: 450 $Wm^{-1}K^{-1}$
- Graphene: 2500 $Wm^{-1}K^{-1}$

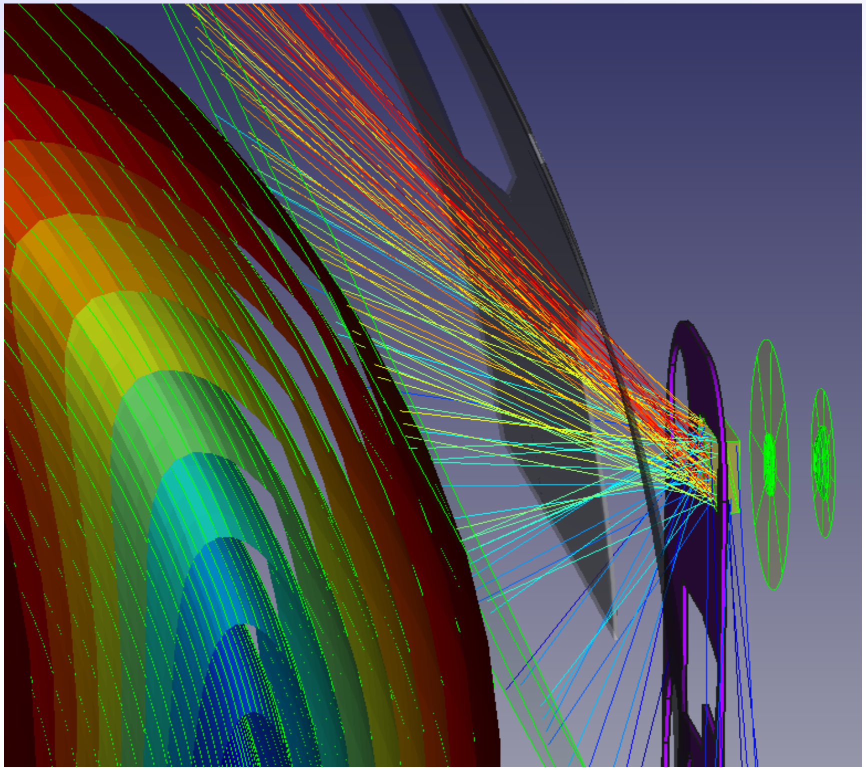
Shutter cooling concept for OP2.0/2.1

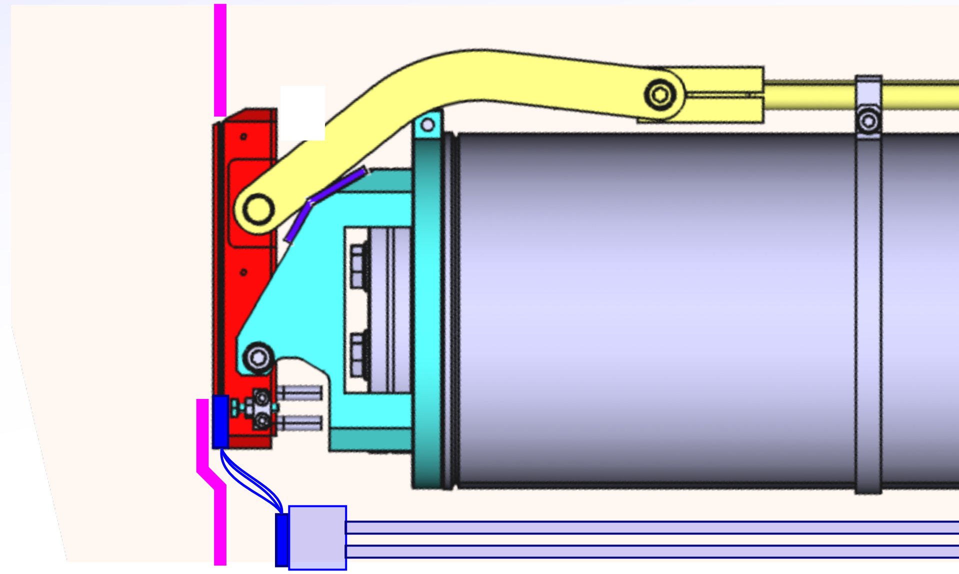


Also planned for Gas Puff Imaging mirror (A. von Stechow)

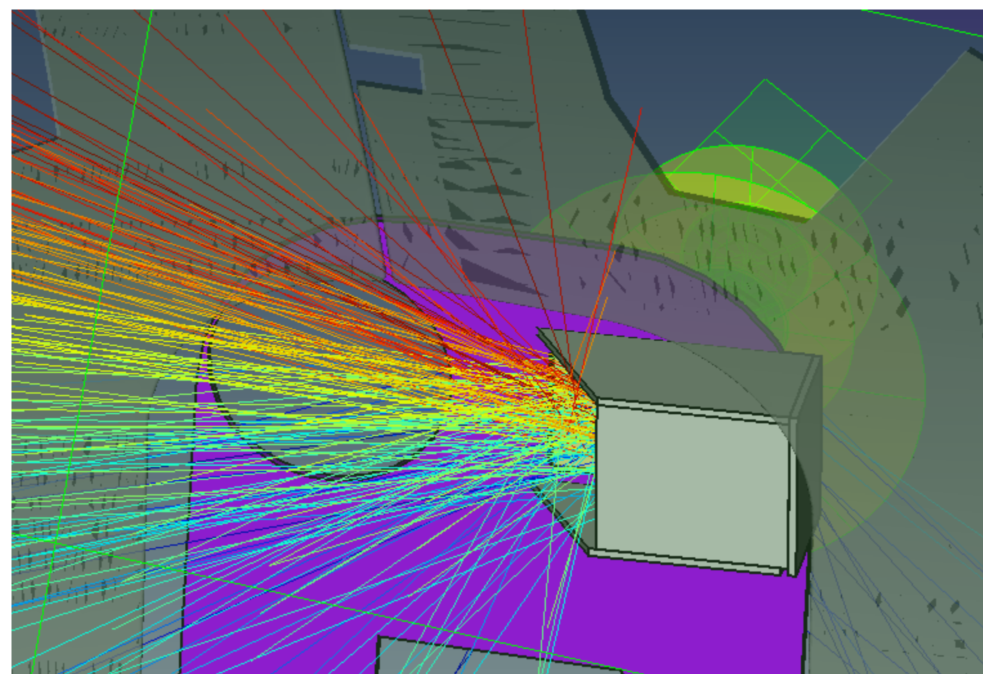
AEA21 - Heat load (closed)

Calculation of heat load to closed shutter from 100kW m^{-2} at LCFS is 660W



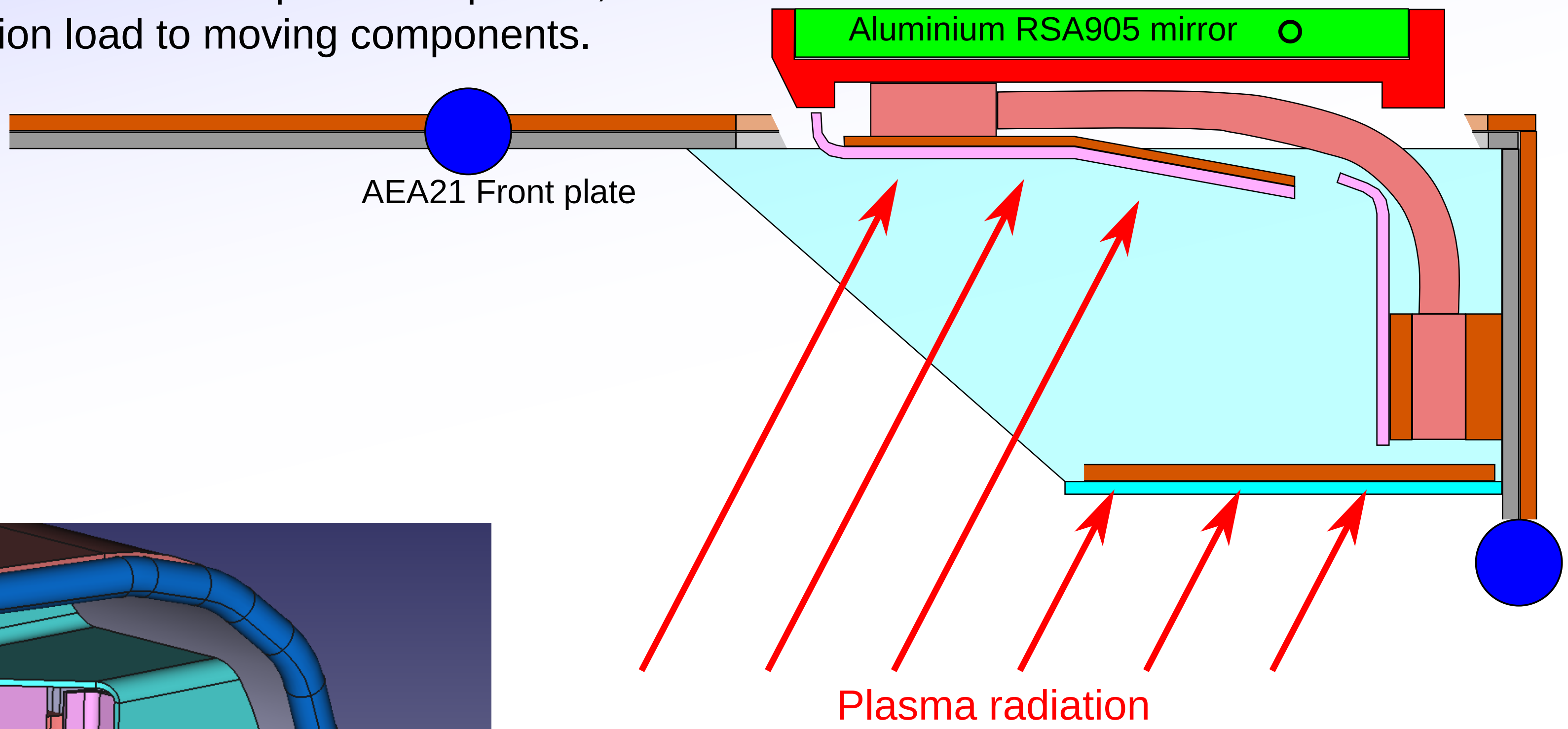


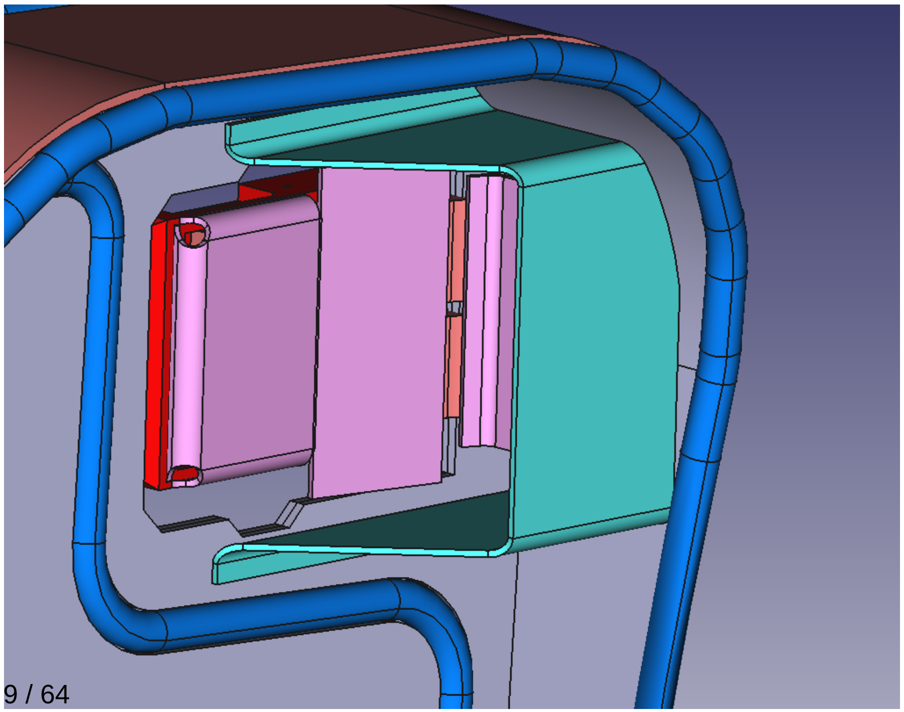
Including an outer cover as part of the front plate reduces this to 250 W



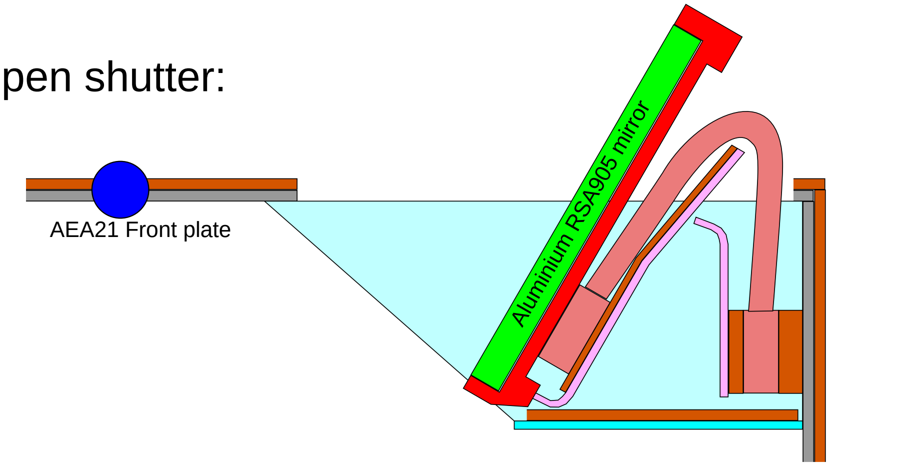
AEA21 - Concept

Copper straps to be shielded from plasma exposure, also reducing radiation load to moving components.



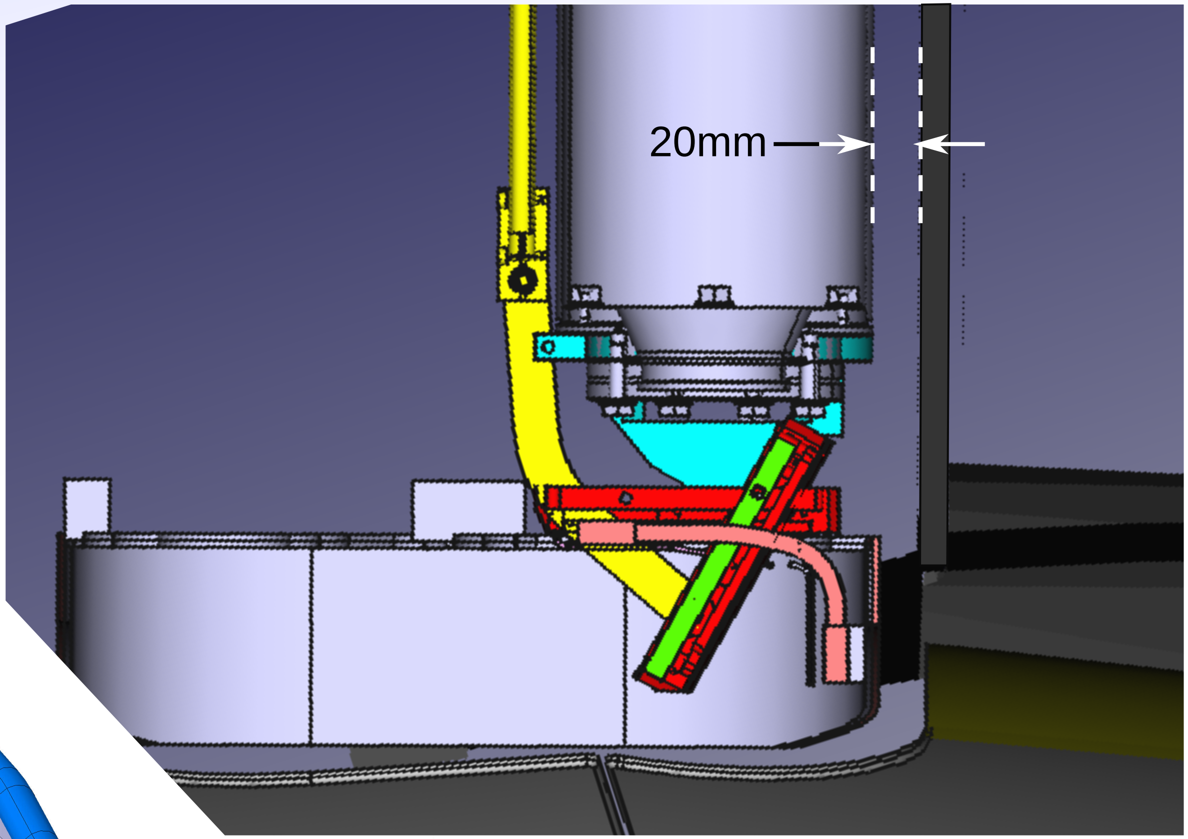


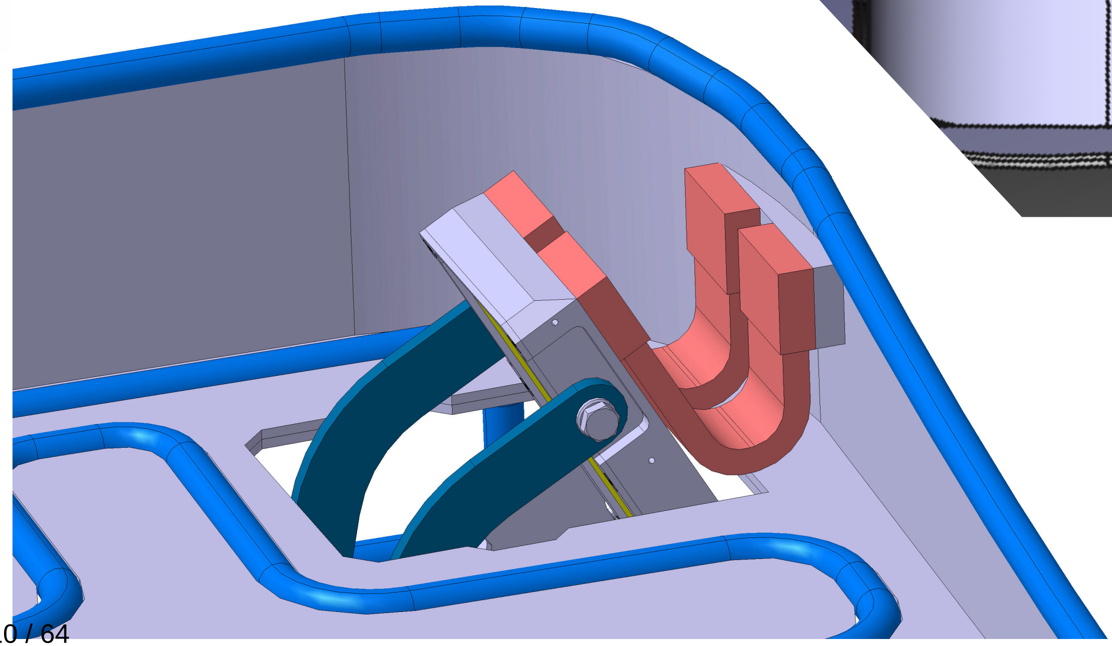
Open shutter:



AEA21 - Thermal straps

There is not sufficient space for the thermal strap on the inside of the cooled front plate.

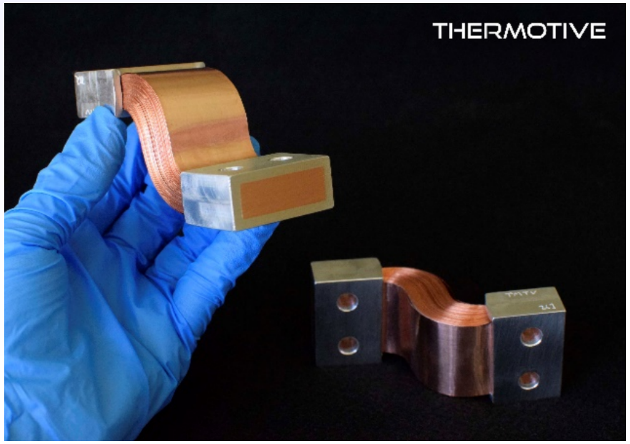




Sufficient space to attach on outside of cooled front plate, but copper straps exposed to plasma.

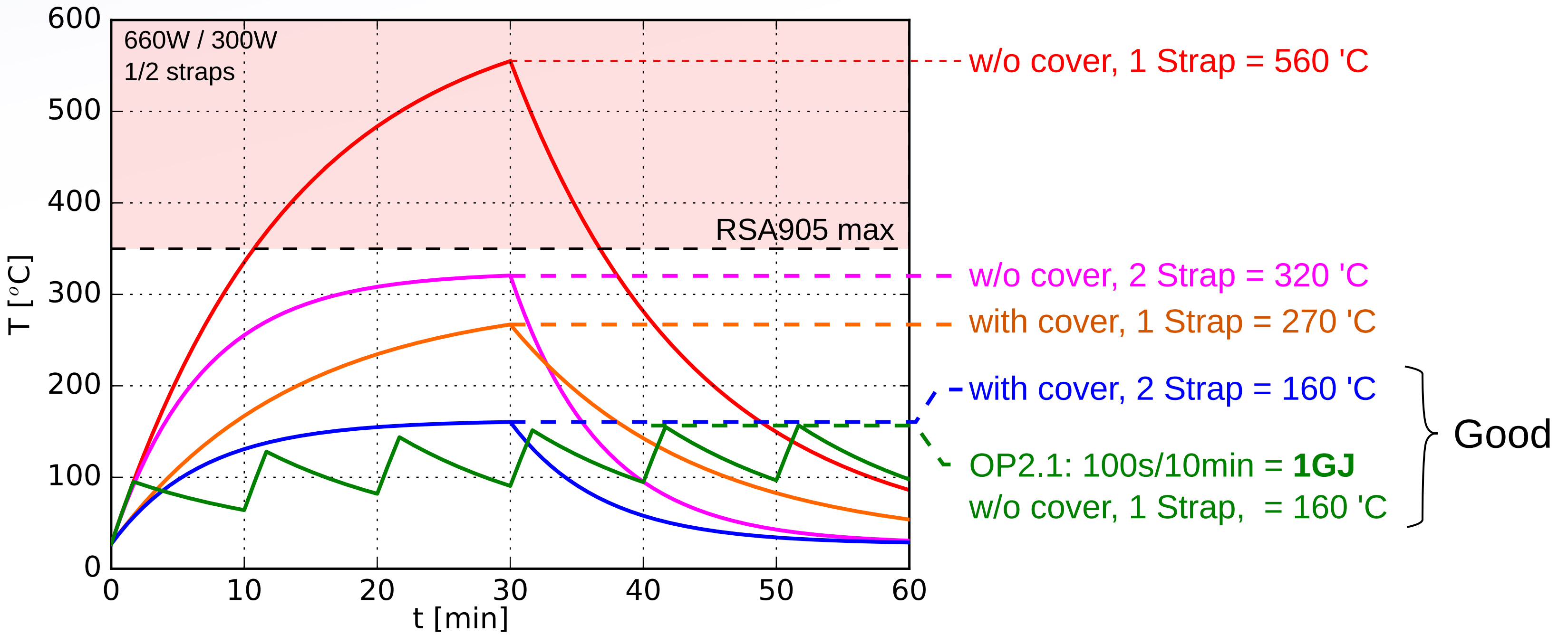
AEA21 - Thermal strap

Ray-traced loads to shutter from 100kW m^{-2} at plasma boundary.
Without cover: 660W
With cover: 300W



Largest copper strap has 111/L W/K conductance.

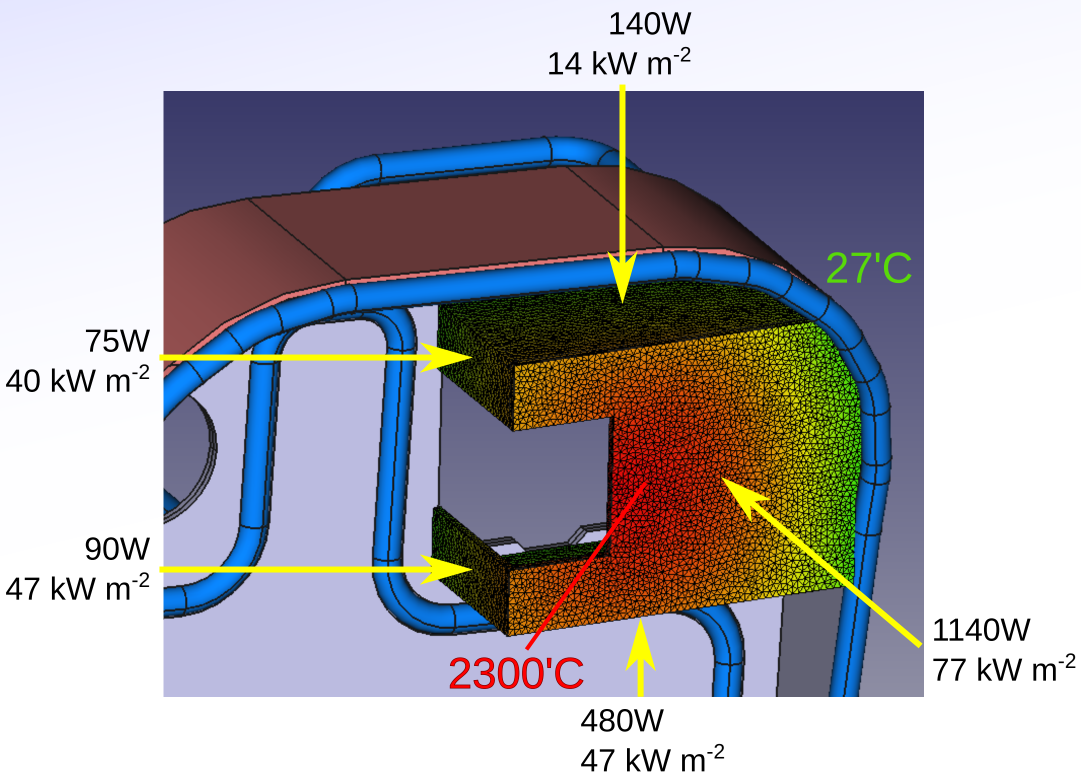
Direct performance calculation:

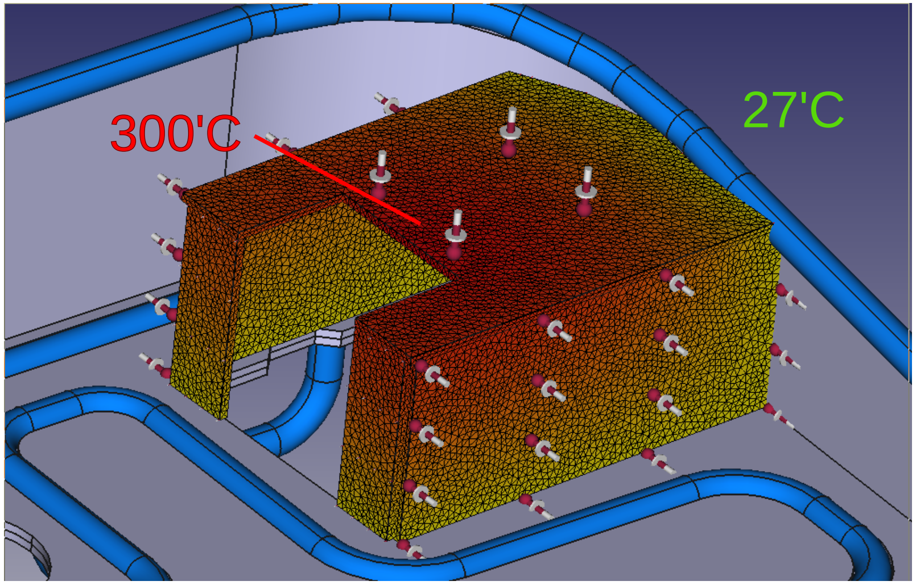


1) With 2 straps and cover, 18GJ is OK by x2
2) 1GJ is OK even with no cover and only 1 strap

AEA21 - Cover

Ray traced 100kW m-2 at LCFS to cover.
FEM model for 3mm thick SS --> Too hot, needs some kind of copper layer or water pipes.



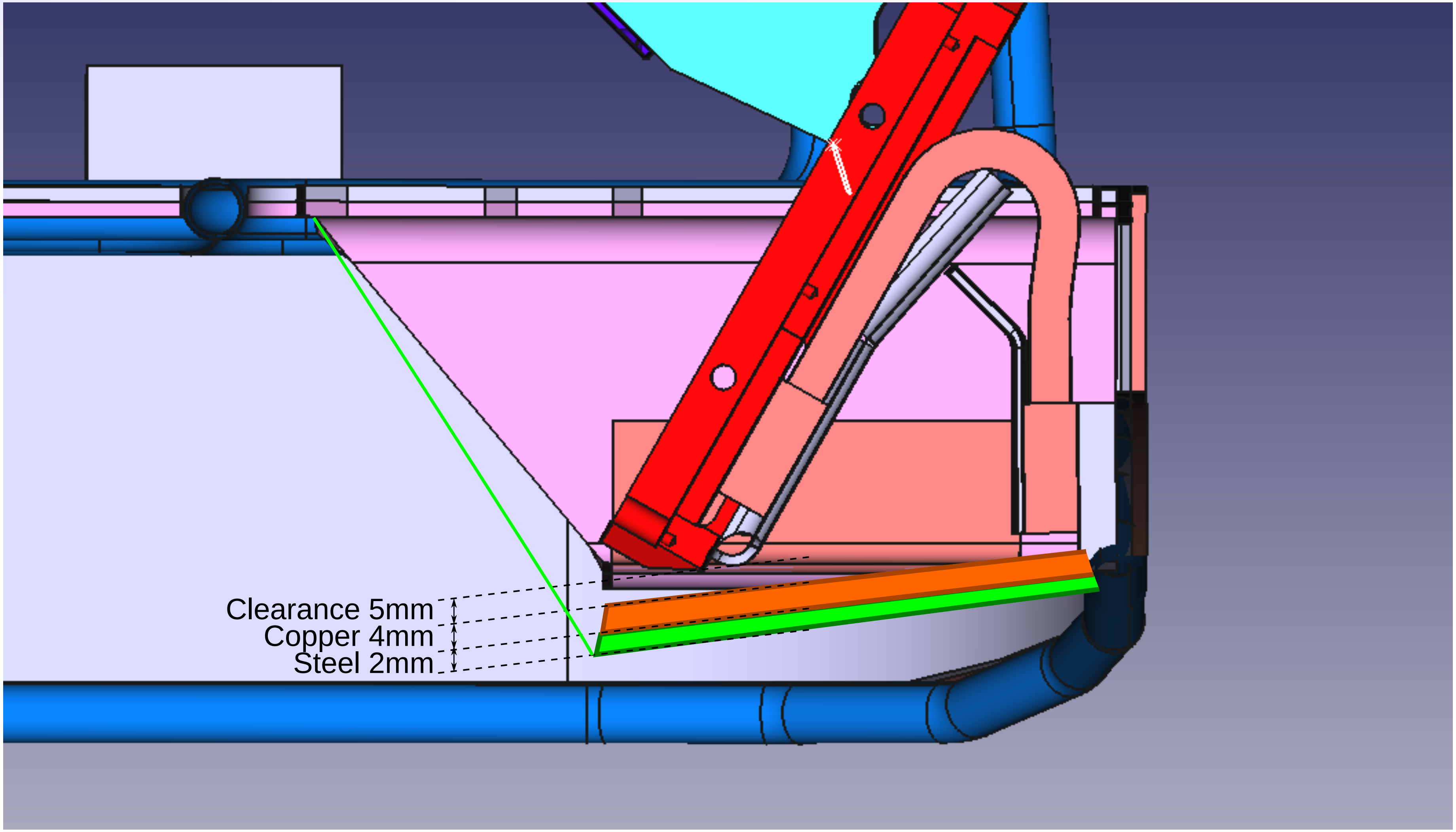


3mm SS: 43 W m^{-1} K^{-1} --> 2300'C

3mm Copper: 300 W m^{-1} K^{-1} --> 300'C

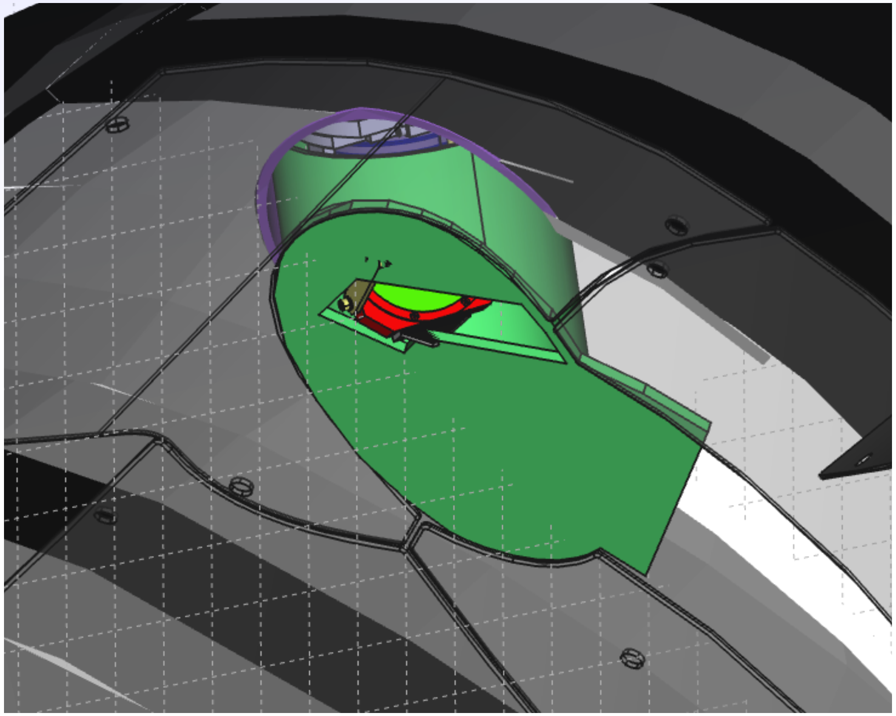
AEA21 - Space under cover

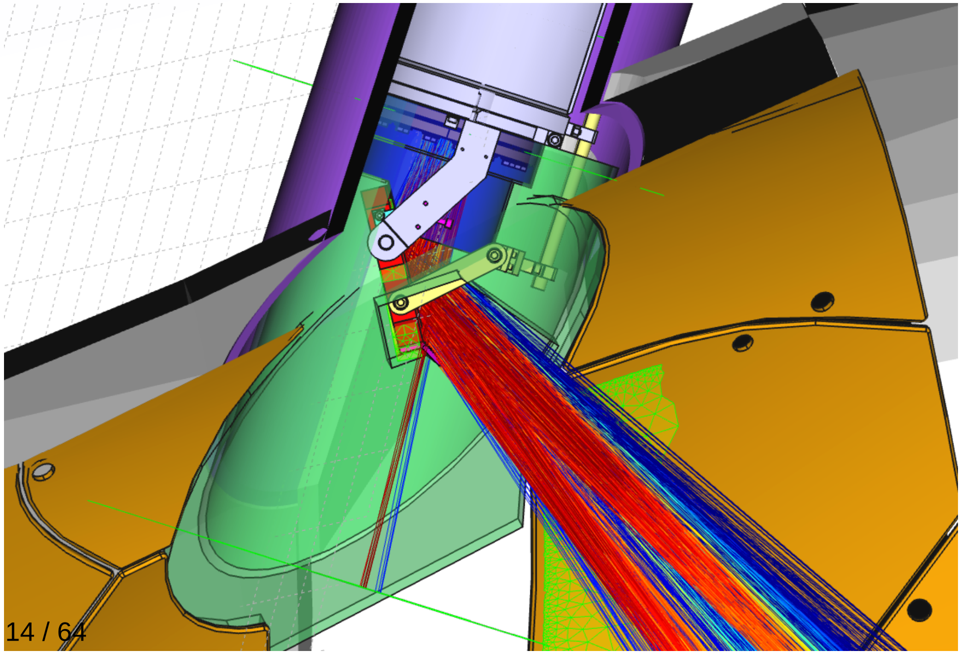
We need a little more space behind the cover for adjustment of the mirror and for possibly thicker copper.

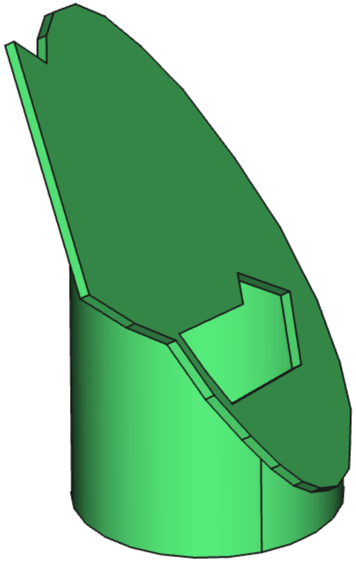


AEM21

- AEM21 requires protection for port.
- Basic concept is some kind of steel 'pot' with cut-out for required view

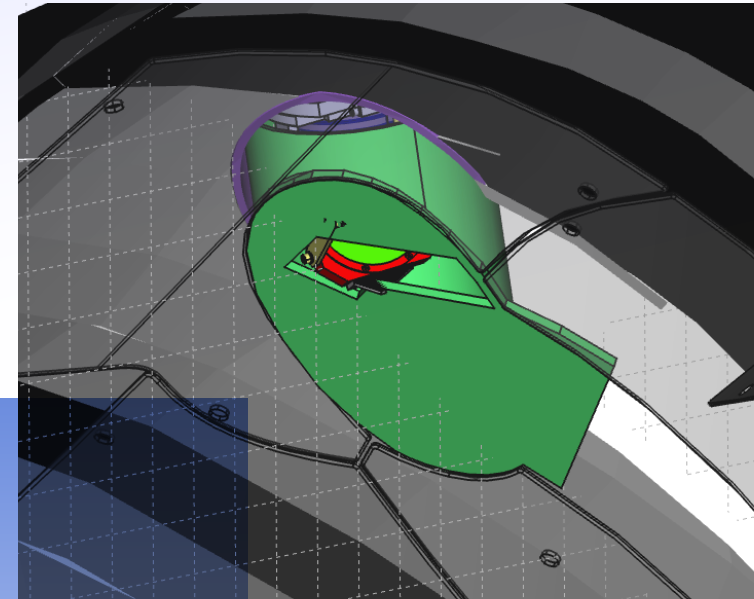


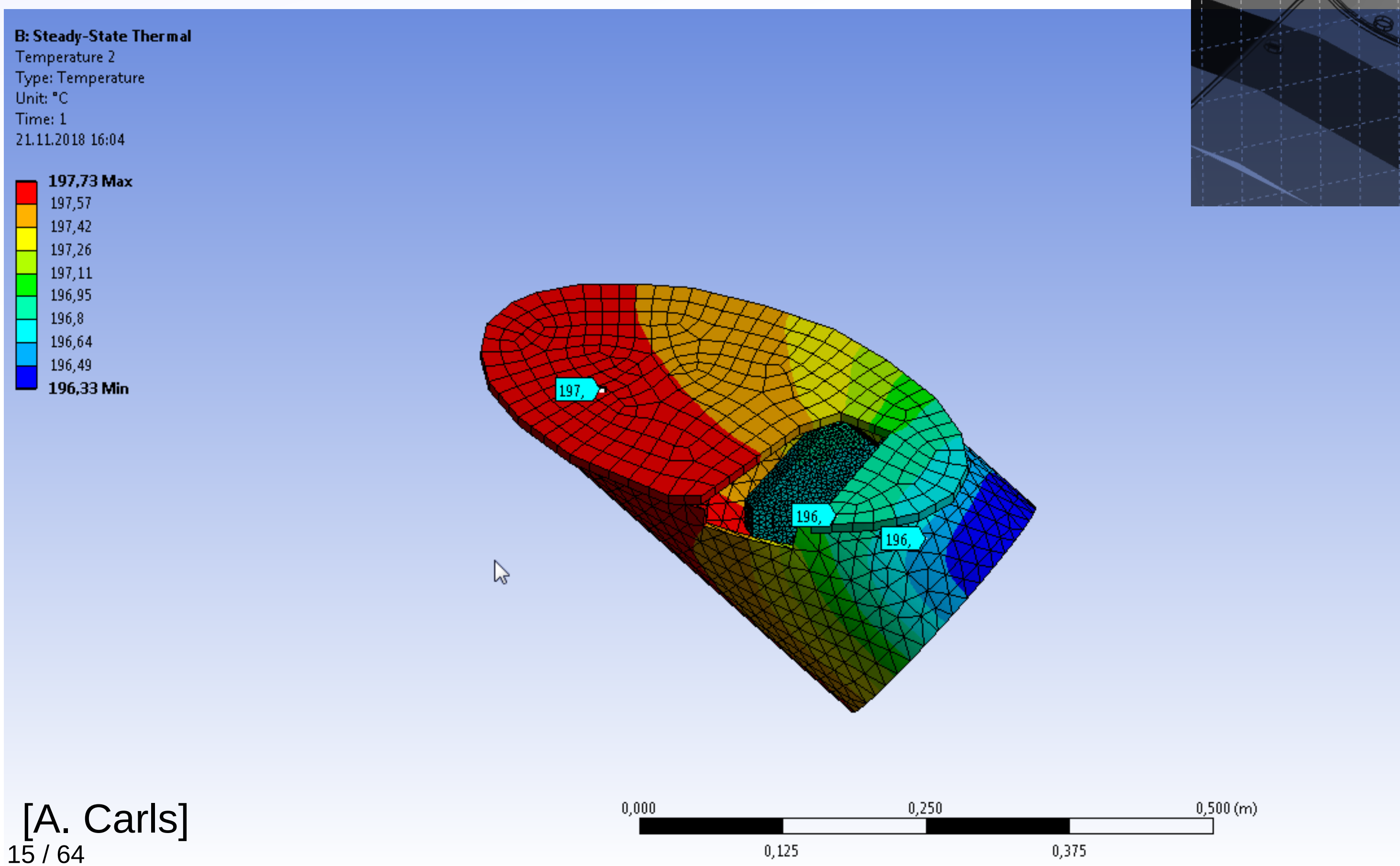




AEM21

- Thermal calculation with free floating pot and mirror shows both rising to 200'C in steady state radiation exchange.
- Probably too much heat exchange from pot to port.
- 200'C on mirror is acceptable, although lower would be better for optics if easily possible.

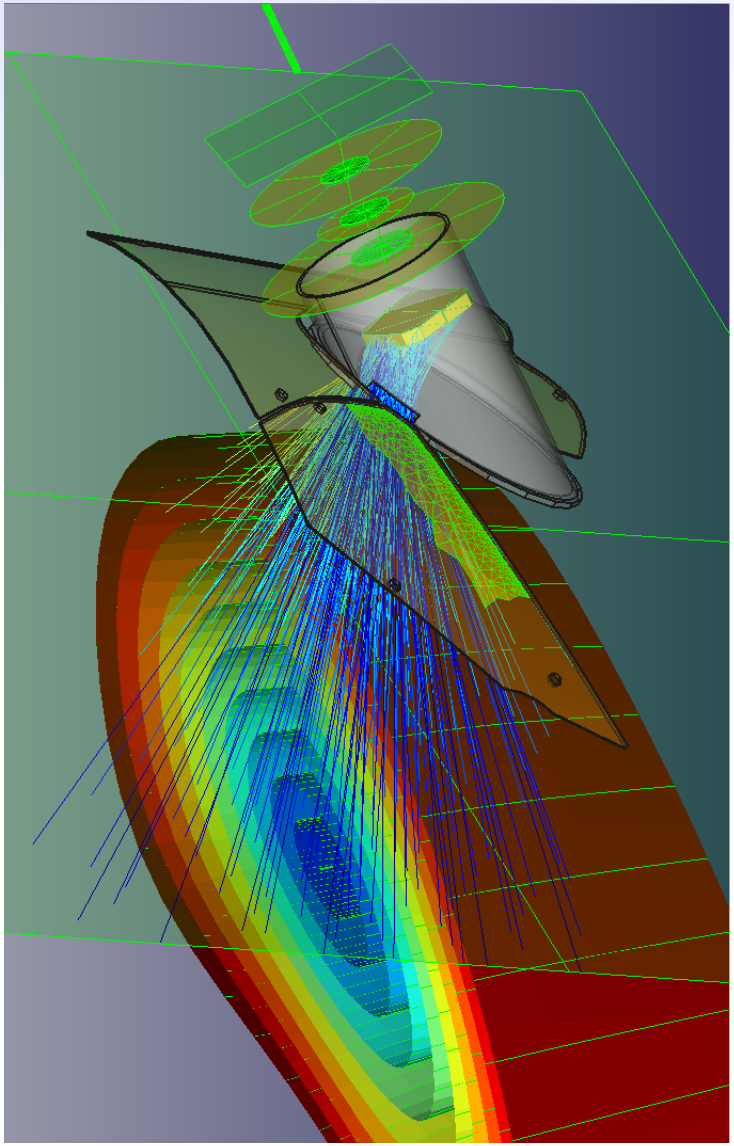


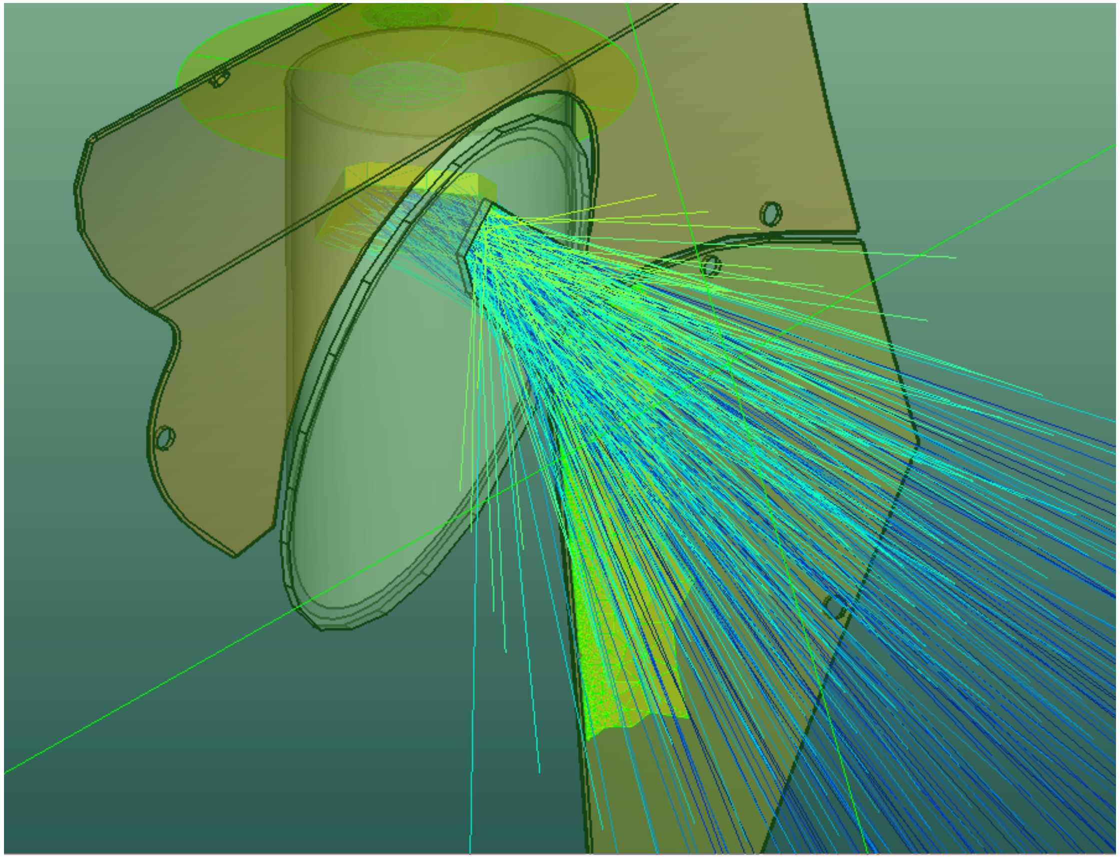


[A. Carls]

AEM21

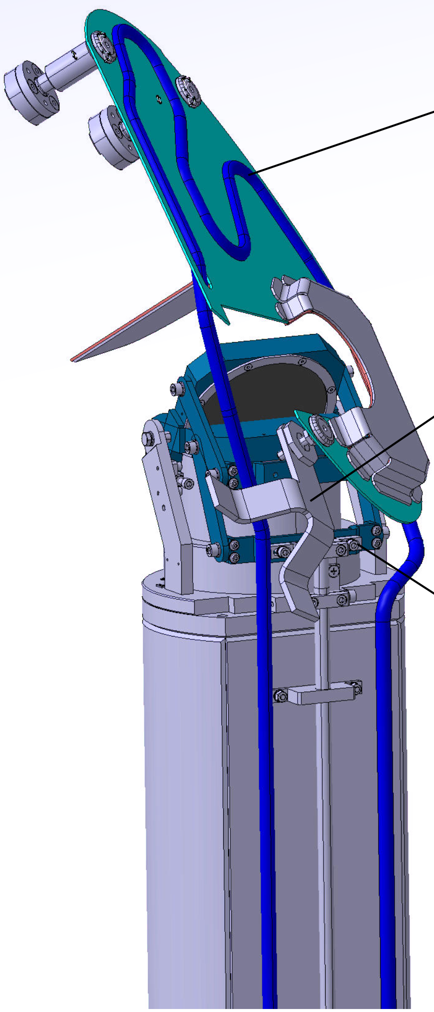
- Heat load from ray-tracing with basic pot comes out at ~200W from $100kWm^{-2}$ at LCFS.



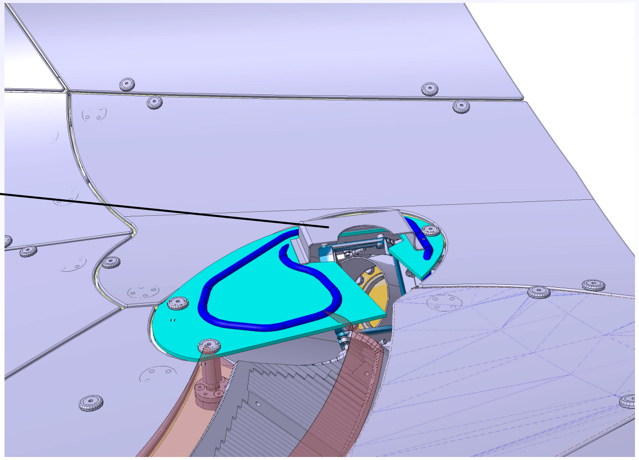


AEM21

First proper design with cooling:
- Installation similar to panels in PG.
- One special fitting to PG required.
  Possible under existing panels??
- Sufficient protection of port wall?

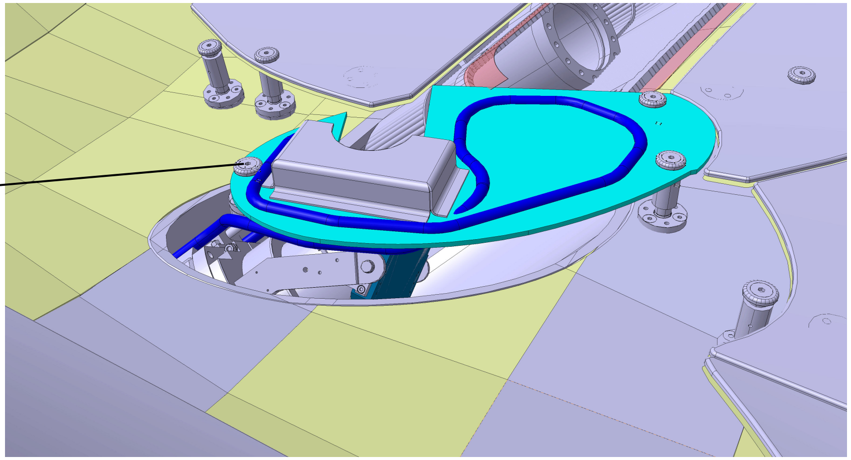


Slightly raised cap



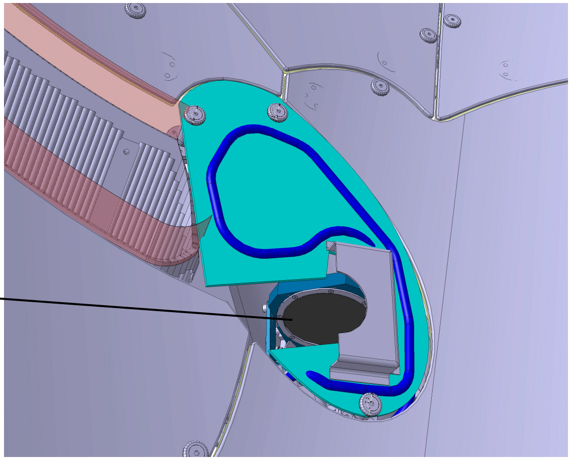
Cooling line welded in to steel plate

Modified PG mount for 3rd panel mounting.



Small modification to shutter drive to fit cooling pipes.

Relatively low exposure of shutter/mirror to plasma radiation



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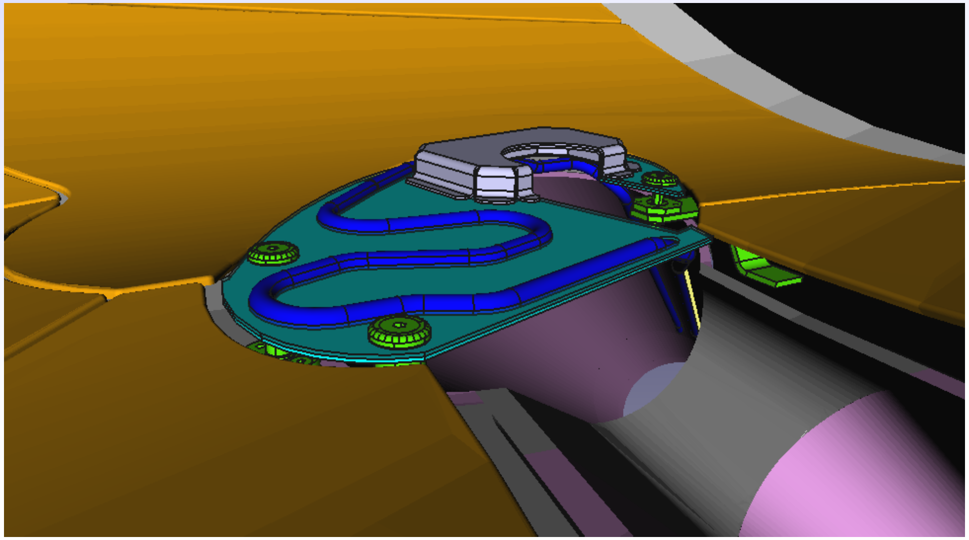
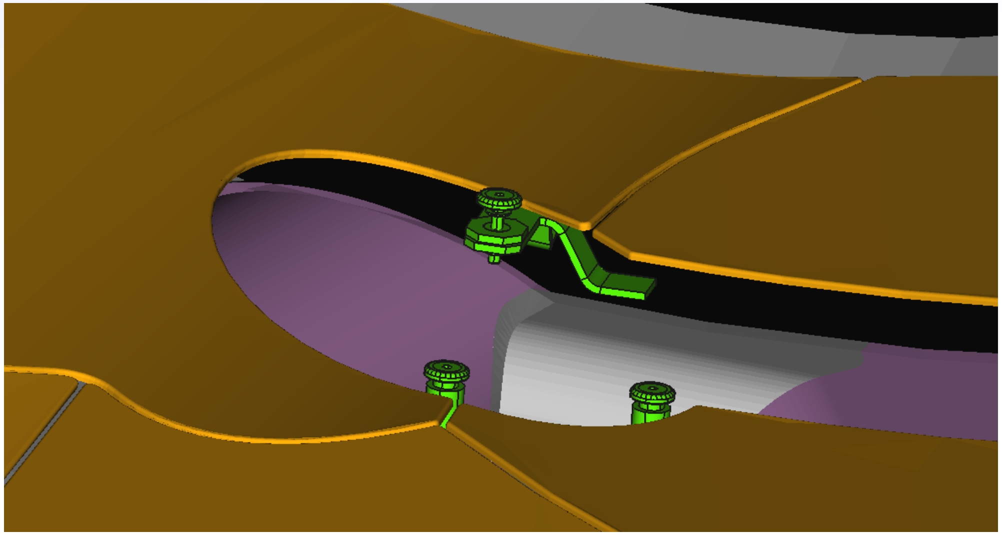
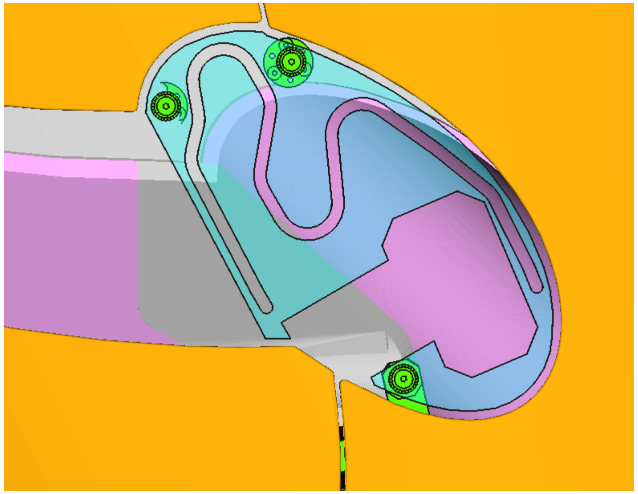
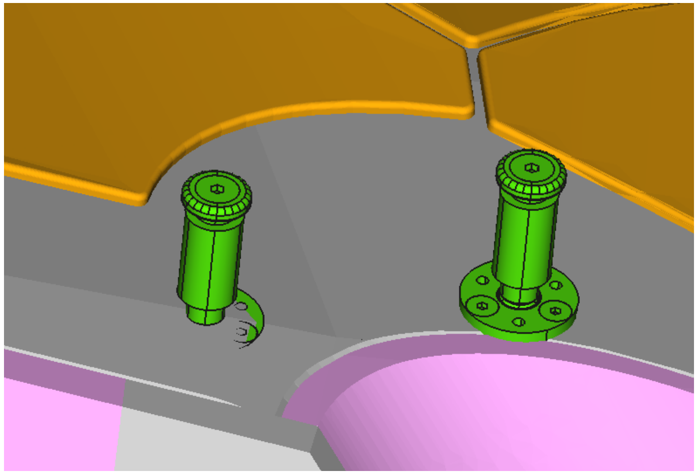
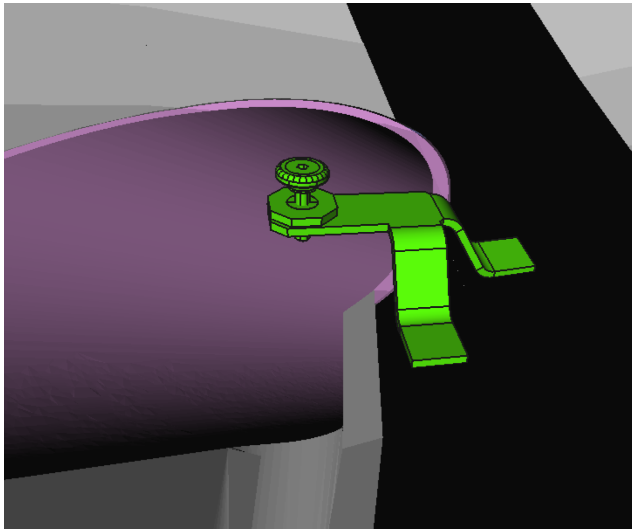
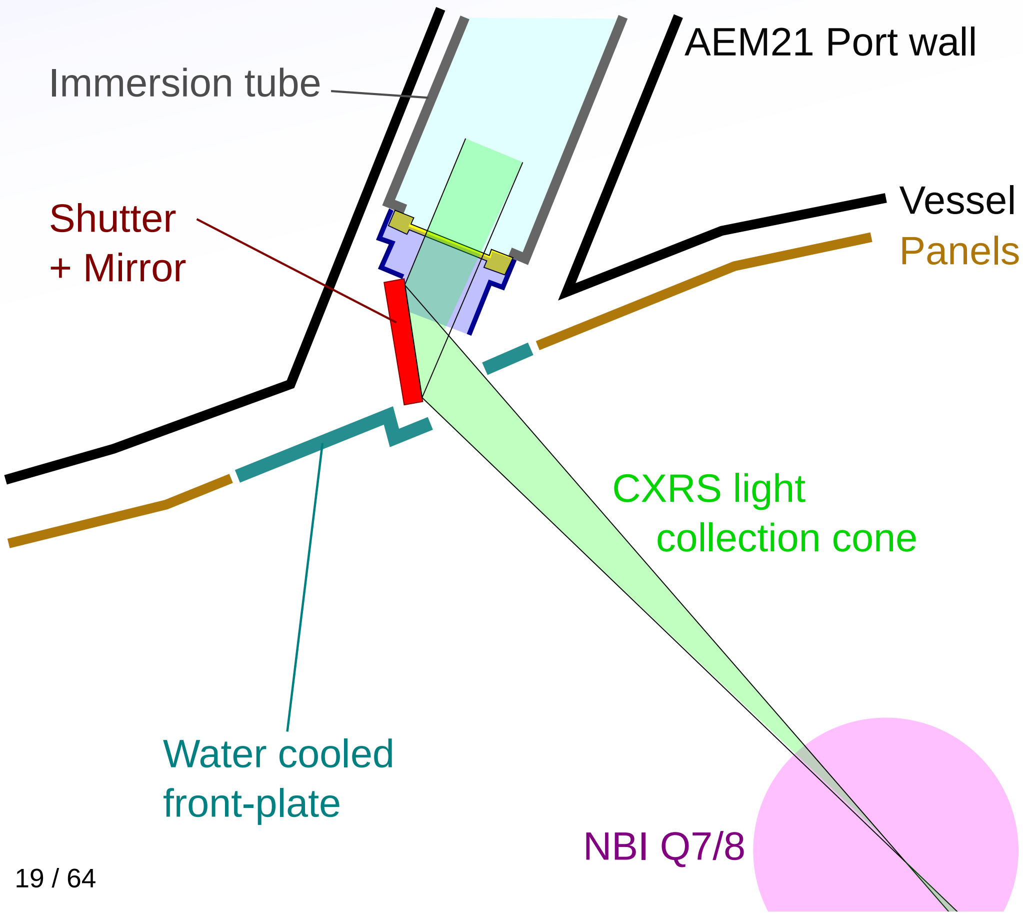
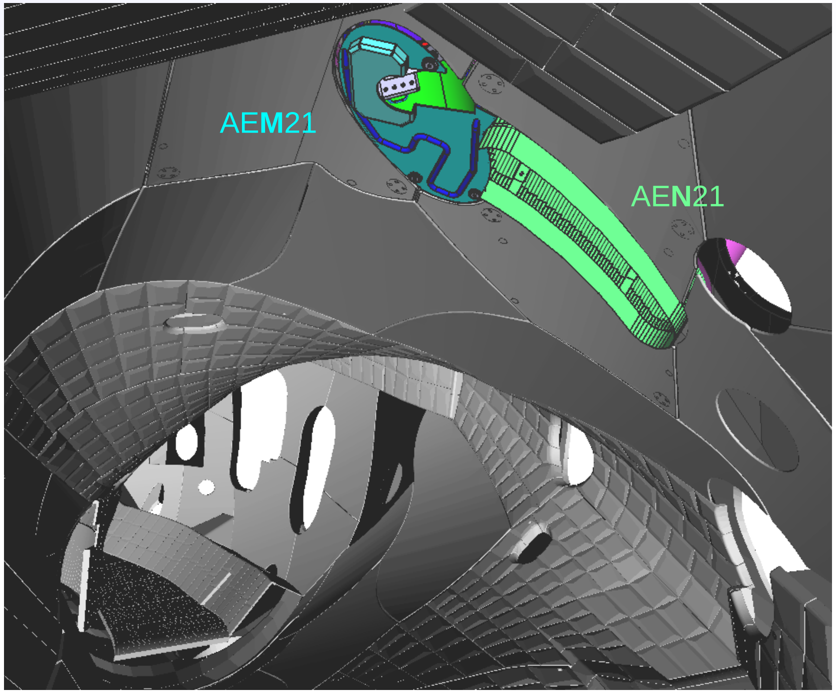






AEM21

Immersion tube in AEM21.
- Views NBI beam from above.
- No room for port-liner with existing immersion tube.
- Vessel/port wall otherwise exposed to heat load.

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

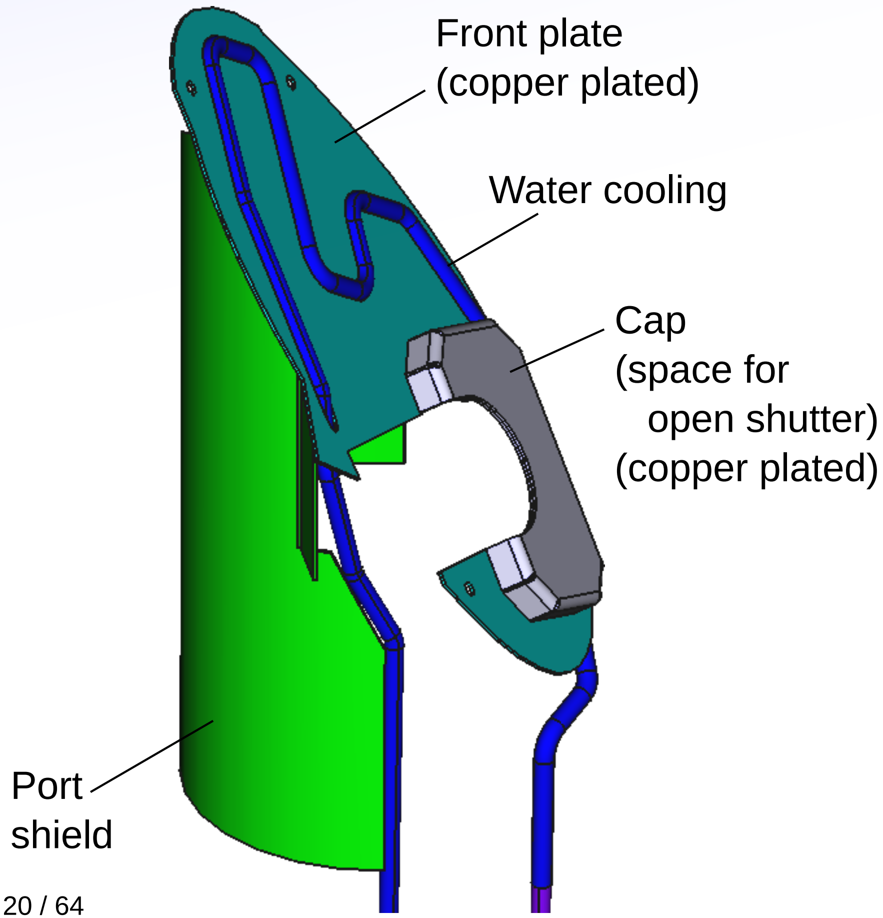




View including neighbouring AEN21 Portliner,

AEM21 - Front plate - Fertigung

Building of front plate will be done by TD (Talked to C. Hidde) as TD Auftrag.
- Plates laser cut by external firm.
- Pipes bent into shape by AS.
- Copper layer done by external firm (talk to T. Windisch), weird shapes possible as it's done not in a bath, not deposited.
- Round port shield possible, also with copper layer. Small bends every 10mm or so instead of actually round as rolling is difficult.



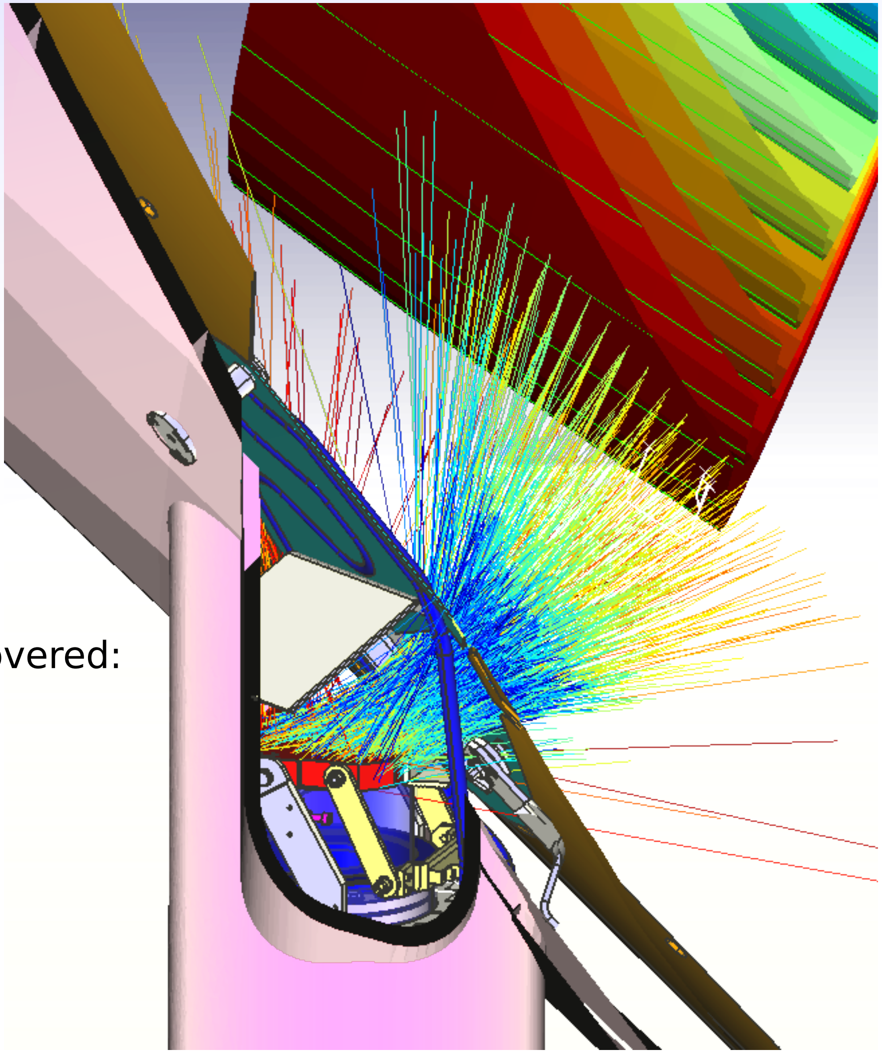
AEM21 heat load

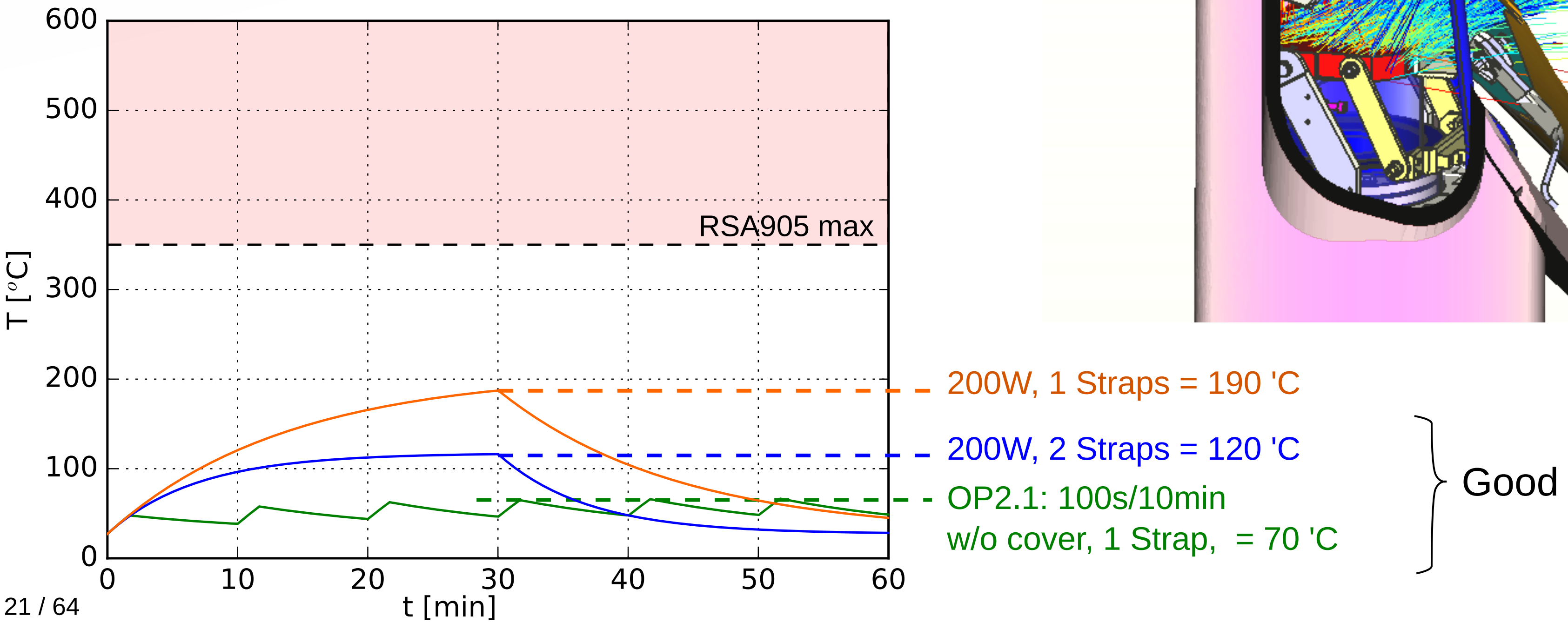
With proper design, heat loads (100kW m^{-2} at LCFS):

Panel:	5000 W	Matches 5.6kW total predited by A.Carls [1-ACH-S0009.5, 1-ACH-S0081.1]
Mirror block:	200 W	
Port wall:	180 W	
Zwickel:	~ 120 W	

Do we need some more covering around the side to reduce the load to port/vessel wall?
300W on port isn't much, but is on weld seams of Zwickle.

Power to shutter block is slightly less than AEA21.
With 2 straps OP2.1 and full 30min conditions are easily covered:



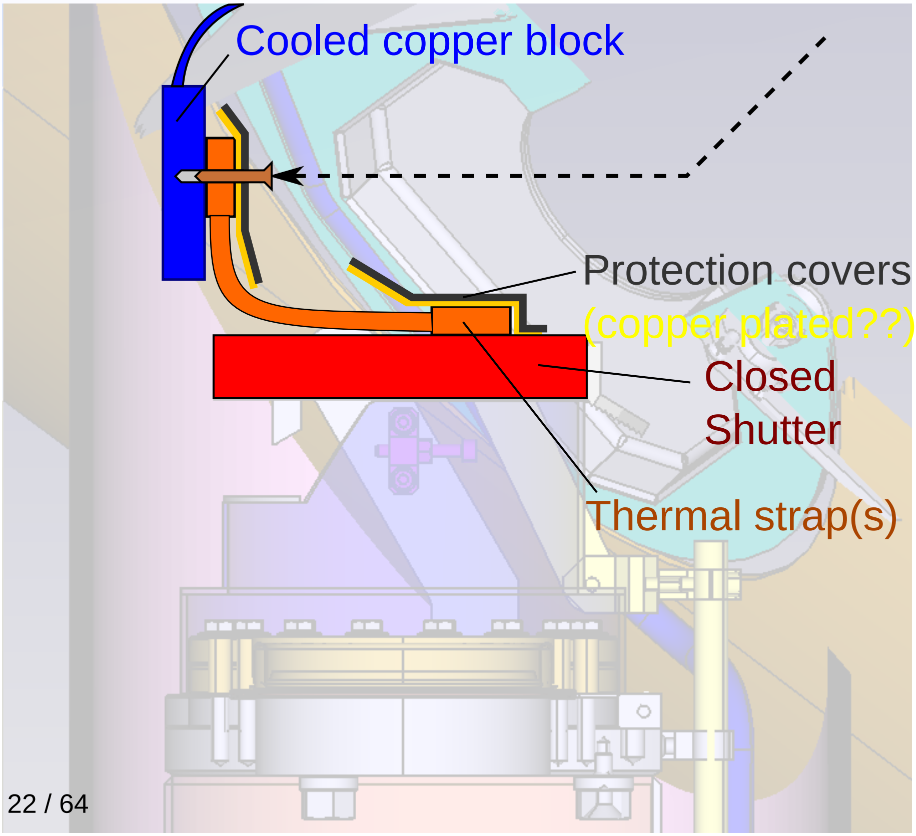


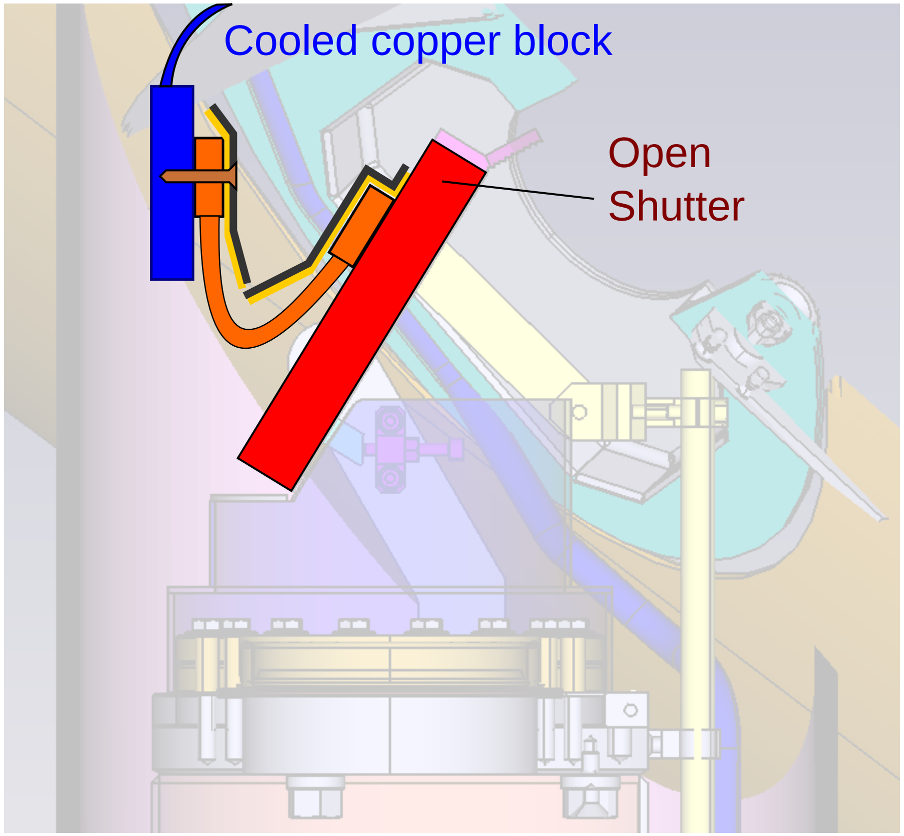
AEM21 heat load

Straps need to be connected to water cooled structure.

Options:

1) Connect strap to water cooled front plate.
   - Has to be attached from in-\vessel after installation of diagnostic tube.
   - diagnostics tube can not easily be removed.
   - Strap has to cope with movement of tube relative to vessel - stress on copper strap.



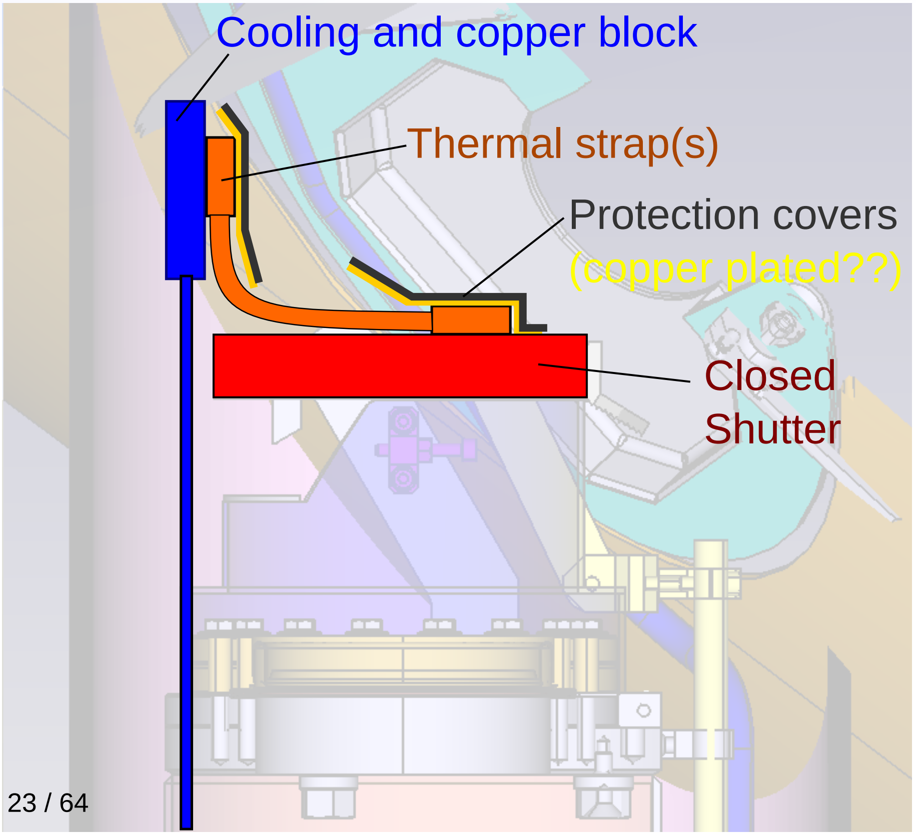


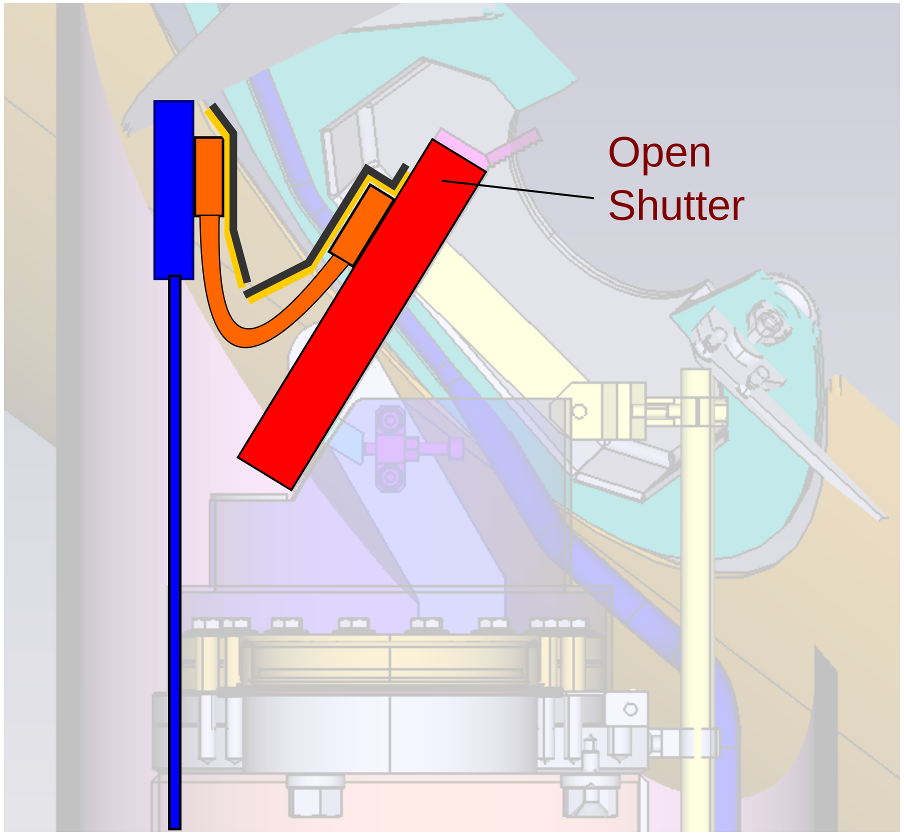
AEM21 heat load

Straps need to be connected to water cooled structure.
Options:
1) Connect strap to water cooled front plate.
  - Has to be done from inside vessel after installation of diagnostic tube - difficult and diagnostics can not be removed.

2) Connect to immersion tube and cool tube with air from inside.
  - May not be enough to conduct away 200W through SS tube wall.

3) Add thin cooling tubes to immersion tube and a block to cool from vacuum side.





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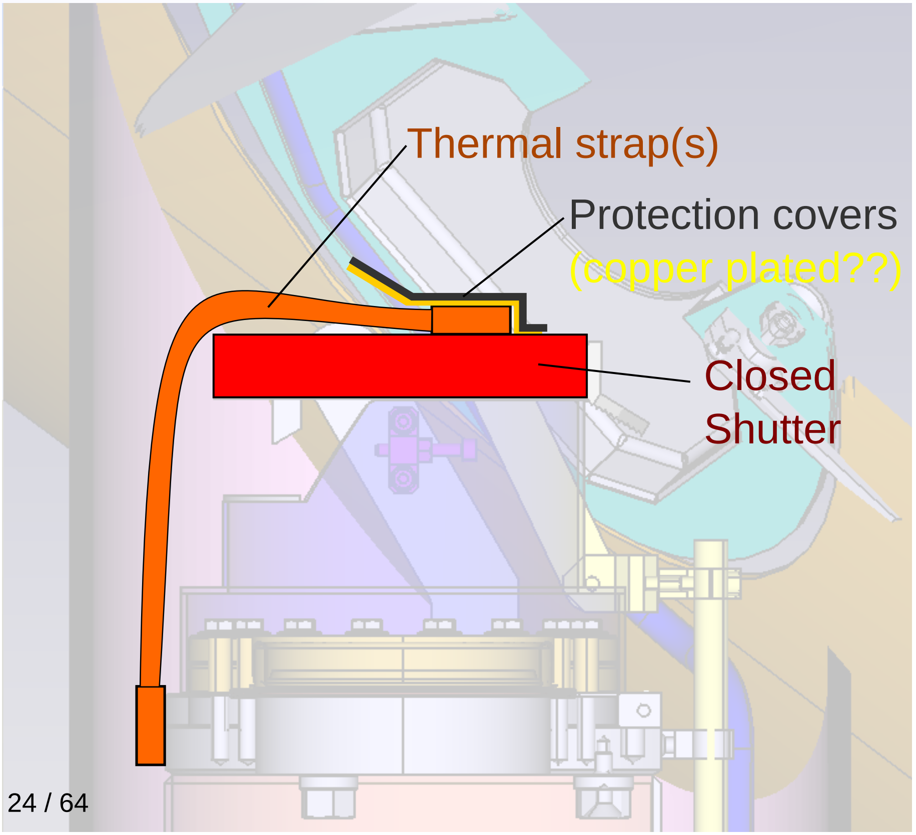

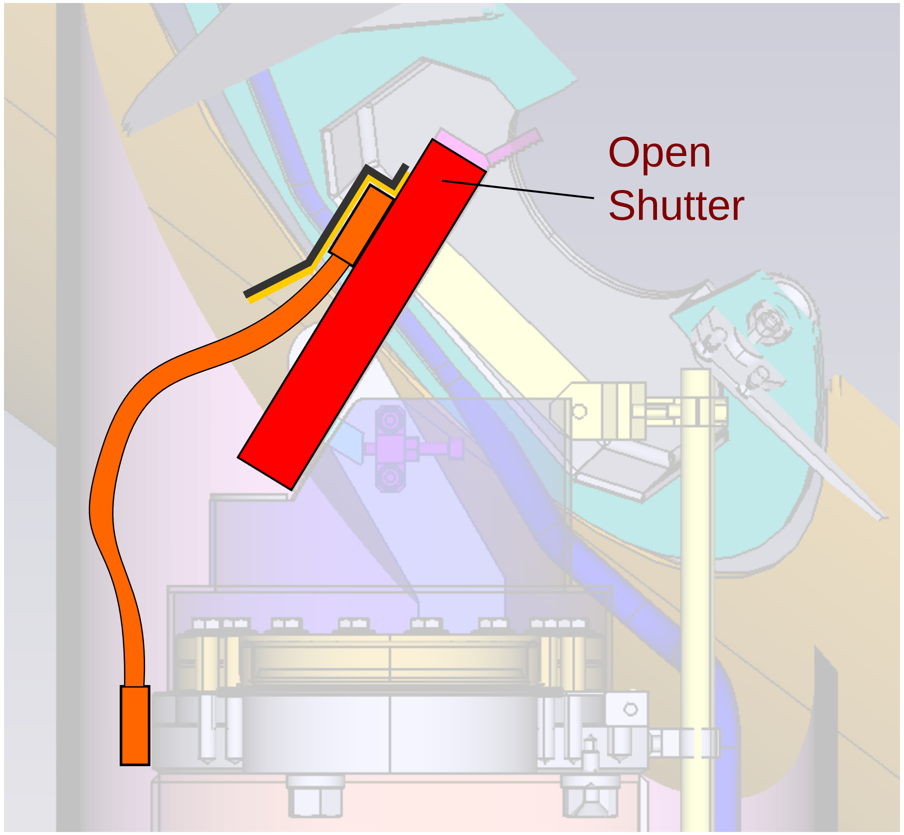

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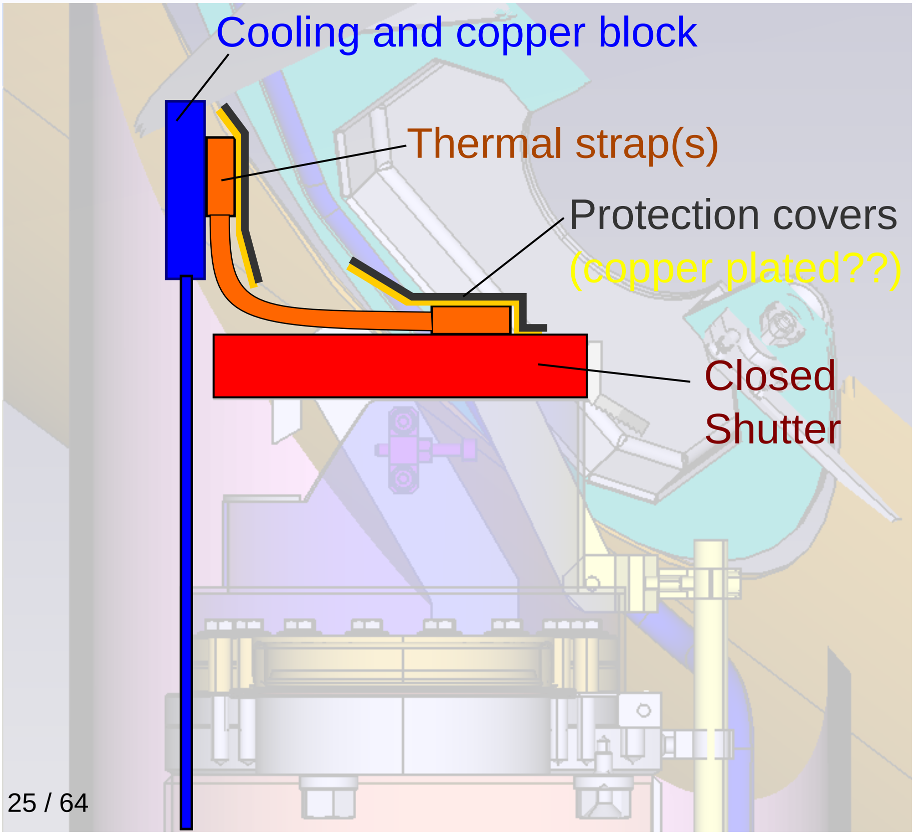
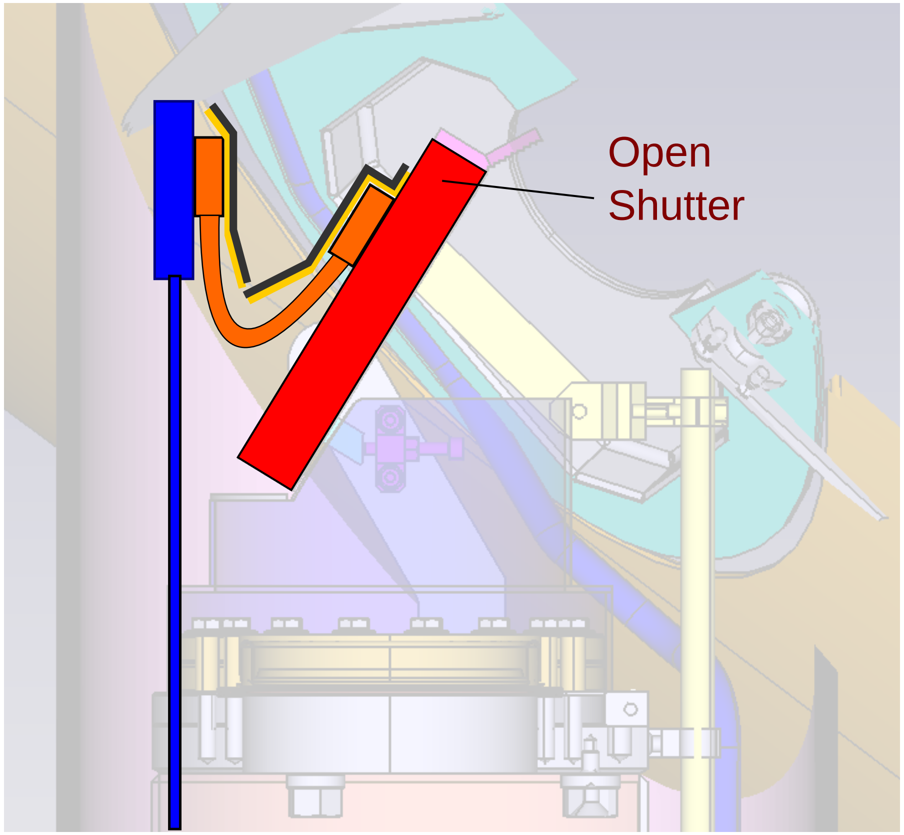




AEM21 portliner / passring

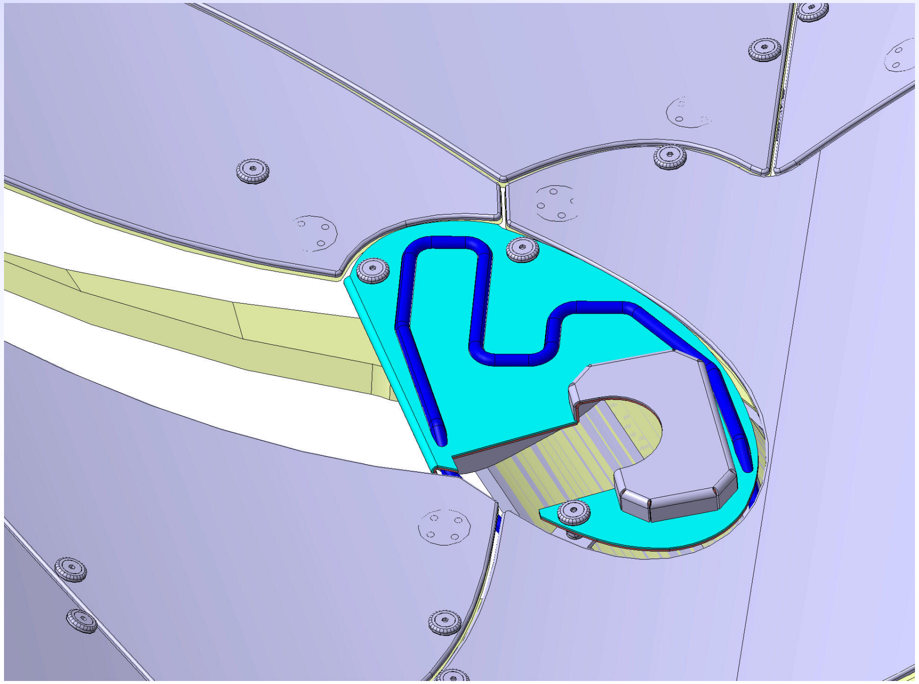
Port-liner/pot for AEM21 was already prepared, but can remain as standby if any AEMxx diagnostic must be removed.

Pass-ring design with water feed-throughs was prepared, but not yet manufactured (as of 09.19) now pushed to latest to be manufactured.
This one would not matched the plug-in geometry corrections, so cannot be used by QSK.

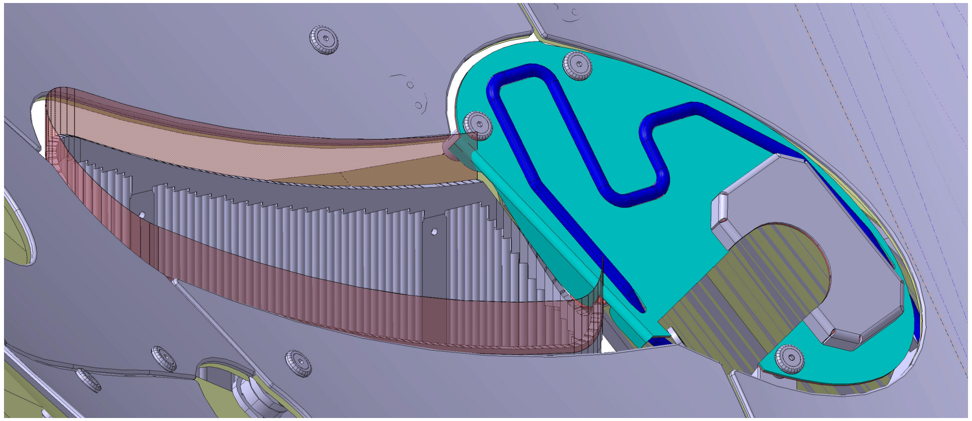
We need to modify the existing QSK AEM21 passring to fit the water feed throughs.

AEM21 panel/port-liner

More detailed design of panel:

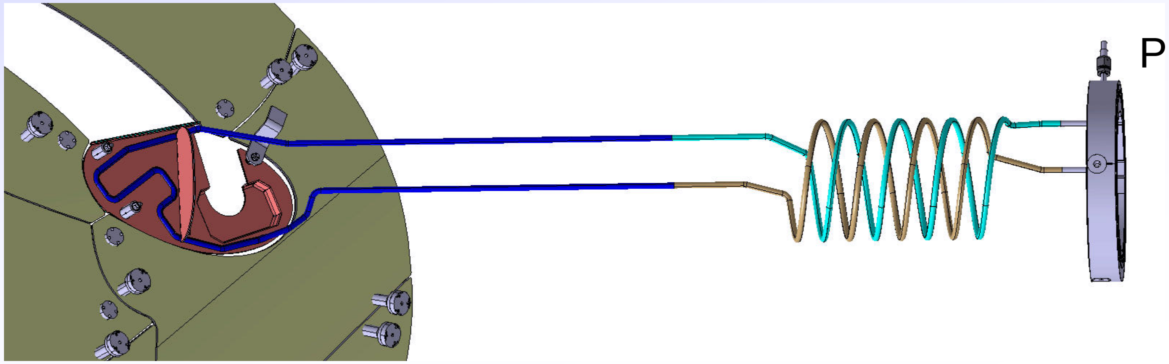


Interfacing with AEN21 portliner:

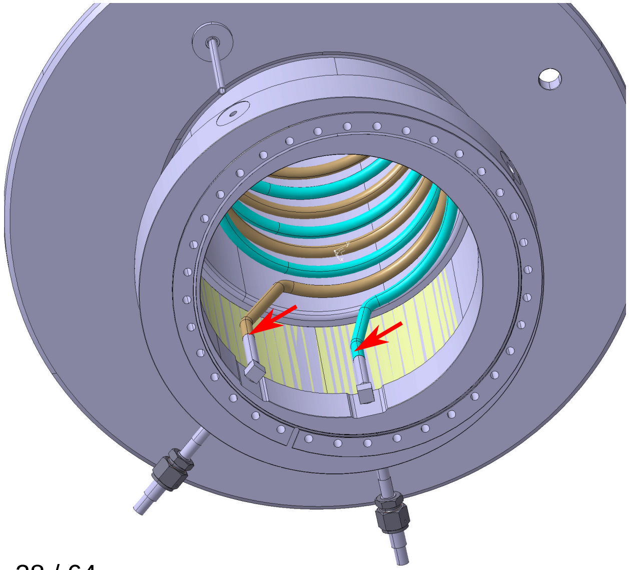


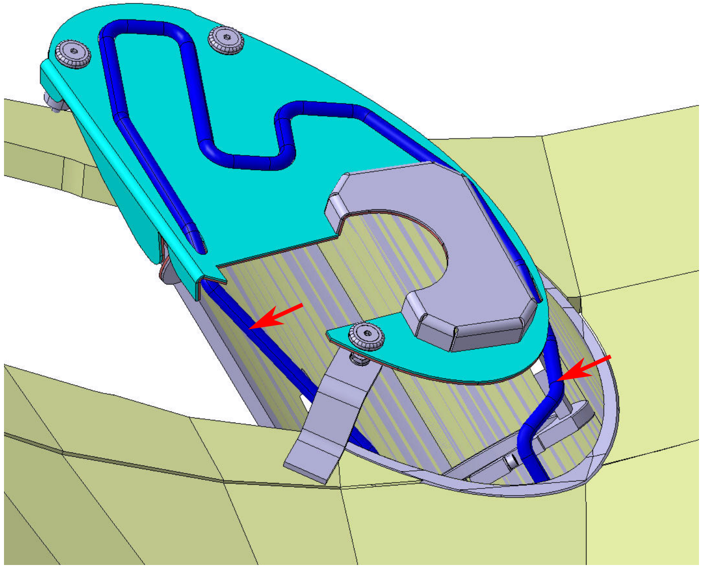
AEM21 panel/port-liner

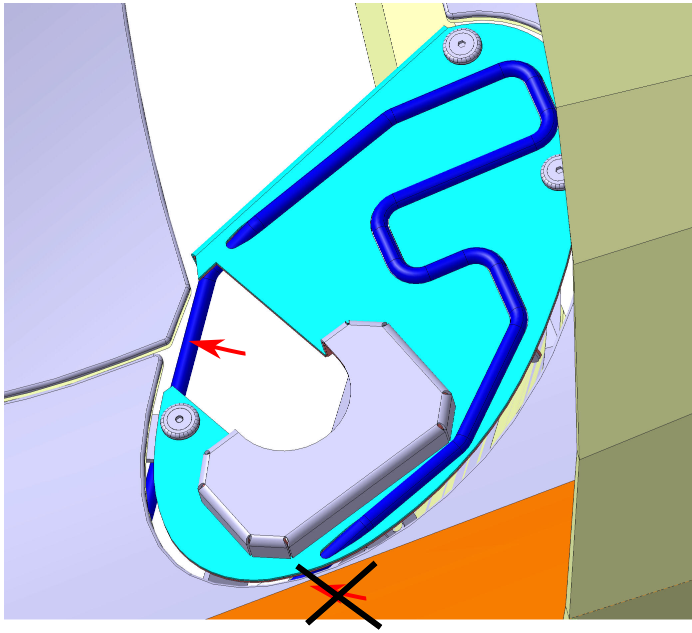
We need to find a way to install and connect water circuit.



We need to find a way to install and connect water circuit.
Preferred to weld at connection to passring, or at front.
Need to remove nearby panel for access??

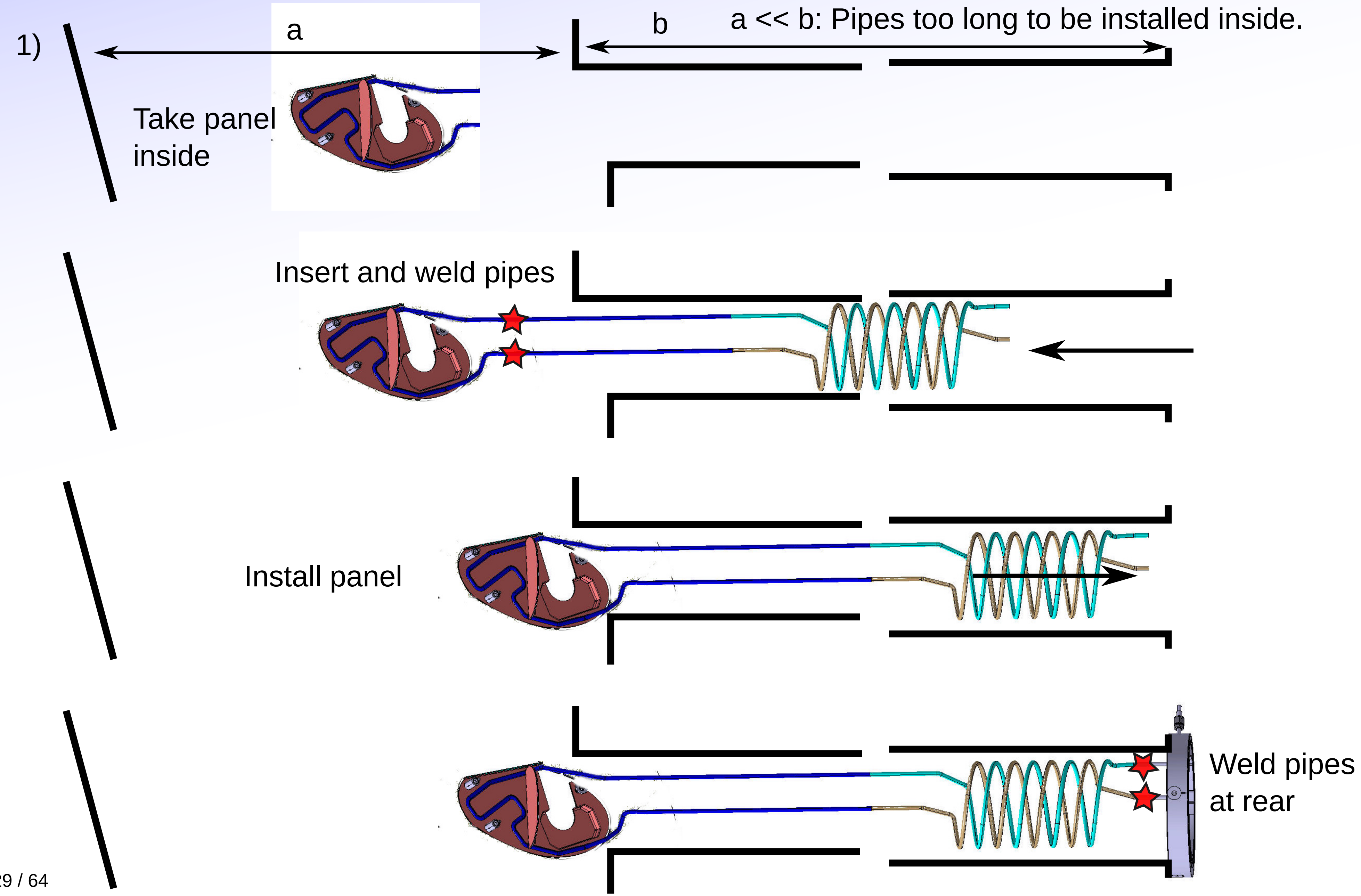






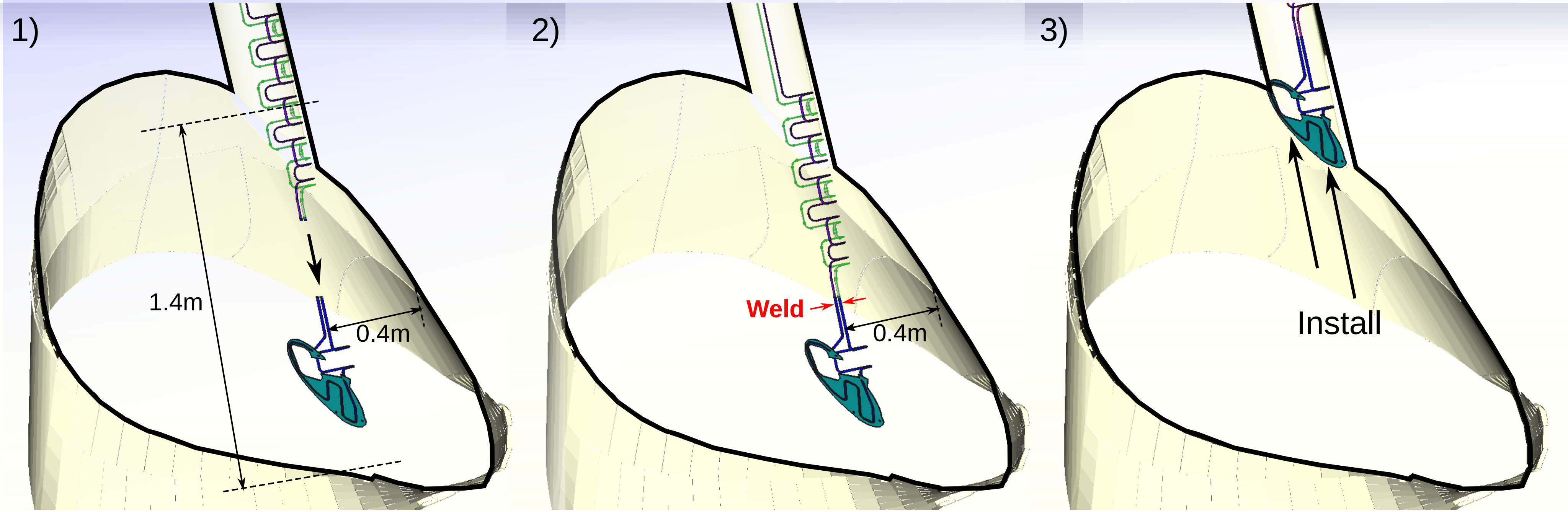
AEM21 panel/port-liner

Possible assembly proceedure:

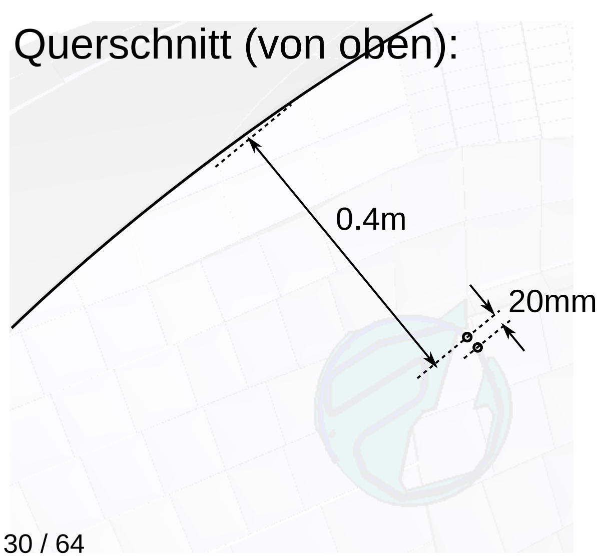


AEM21 in-vessel pipe welding

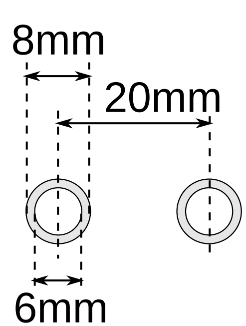
Querschnitt AEM21:

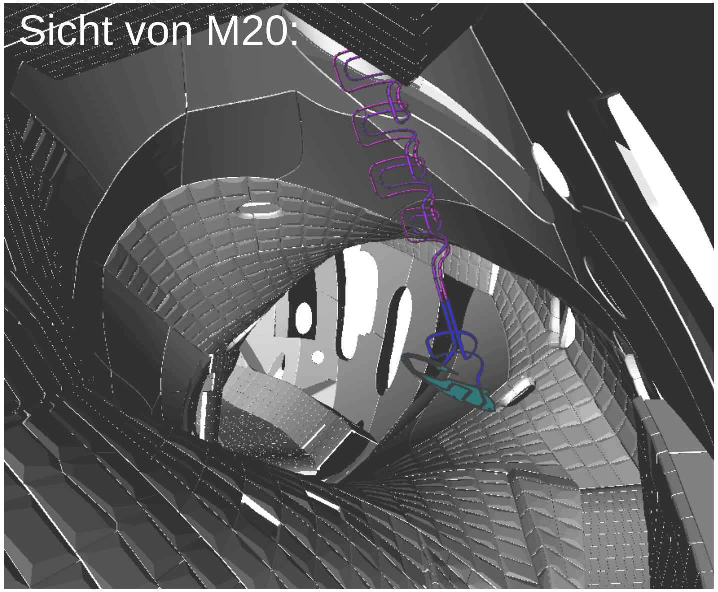


Querschnitt (von oben):



Querschnitt (von oben):

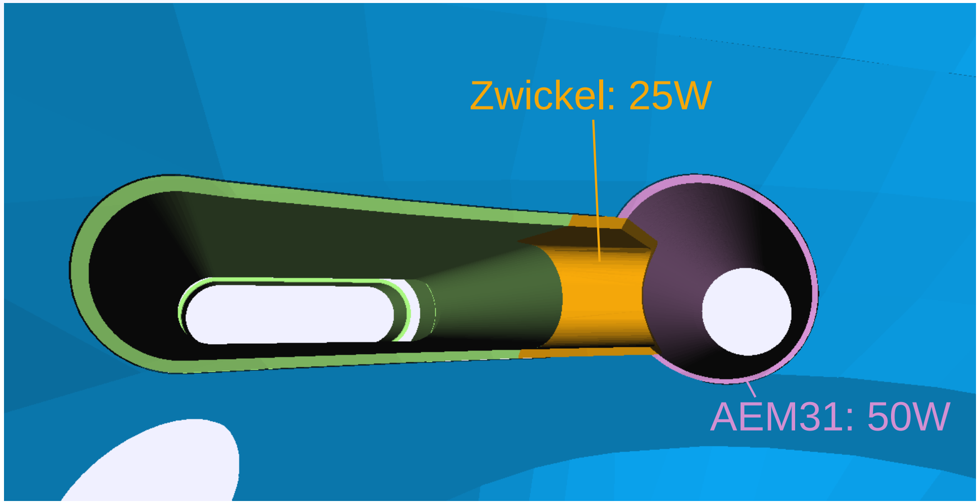




AEM21: Heat load - Vessel/Ports

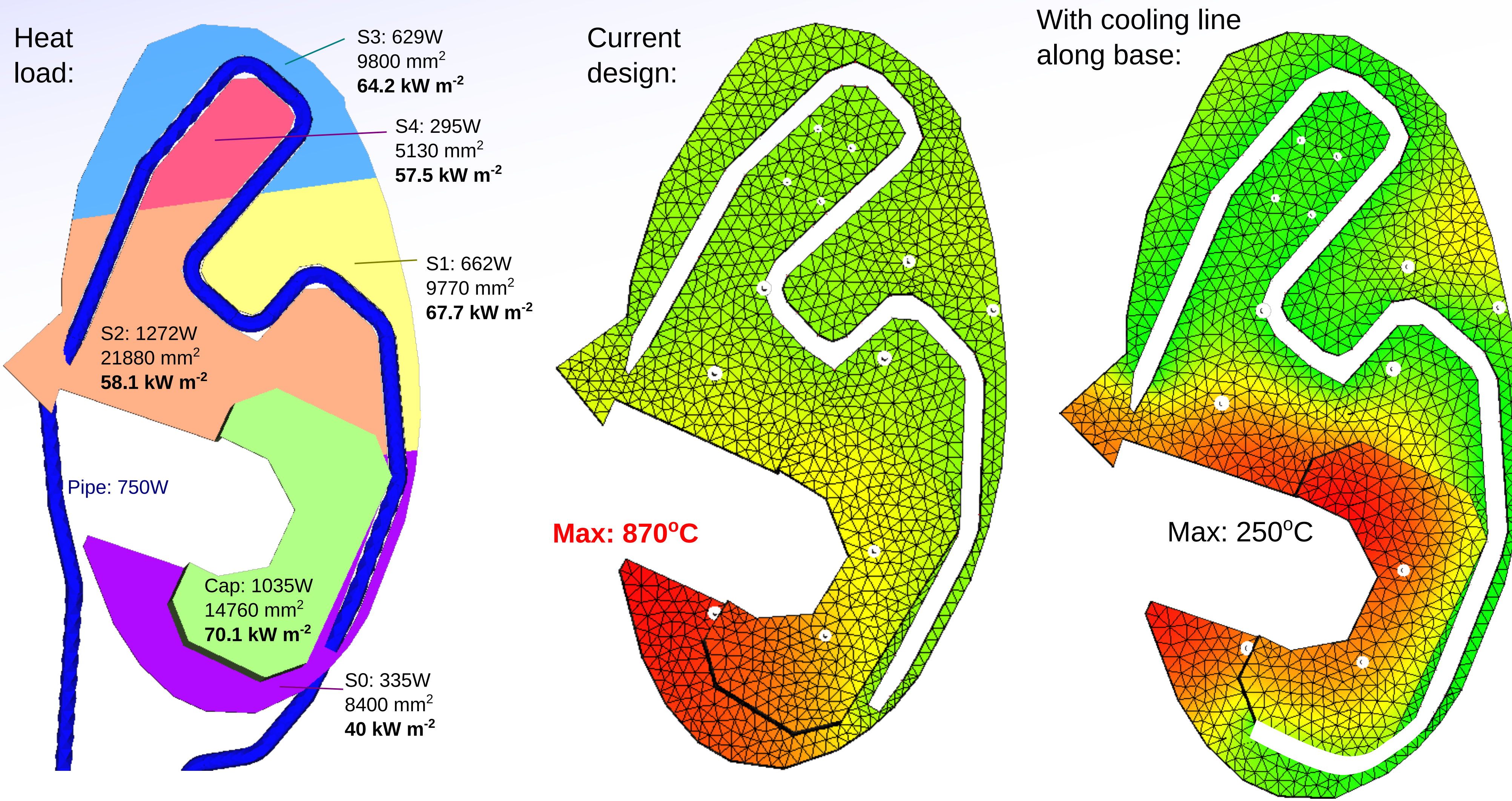
Preliminary thermal evaluation.
Ray tracing 100 kW m^{-2} from plasma surface to simplified model of all components: [radExposure-all30x30x30]

AEM21 port wall: 50 W [radExposure-portWalls (50x50x??)]
Zwickel: 25 W
= 75W to vessel walls



AEM21: Heat load - Front plate

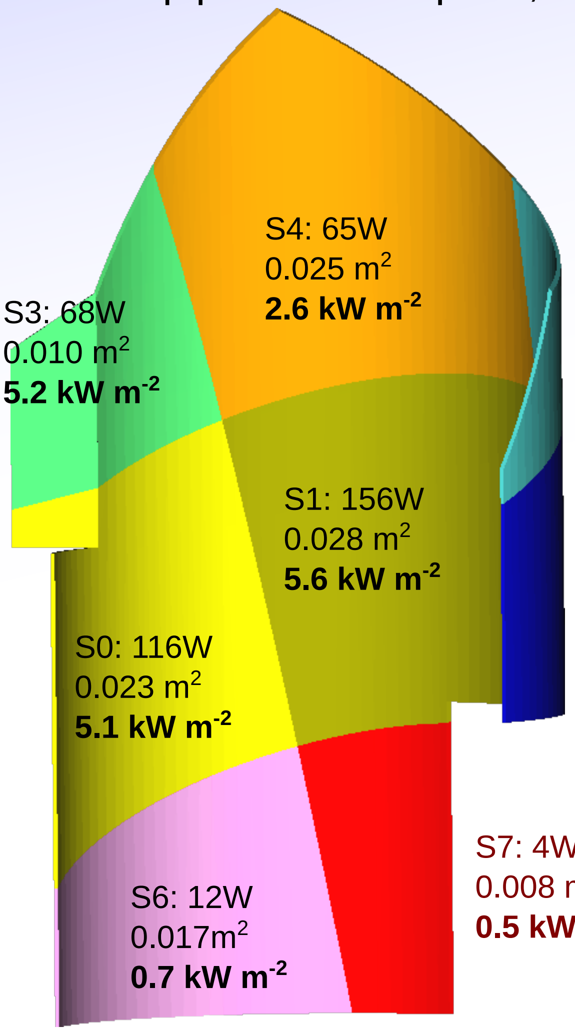
Ray tracing 100 kW m^{-2} from plasma surface to simplified model of all components: [radExposure-all30x30x30]
Total 5 kW heat load.
Calculation: 2mm copper, no radiation exchange.

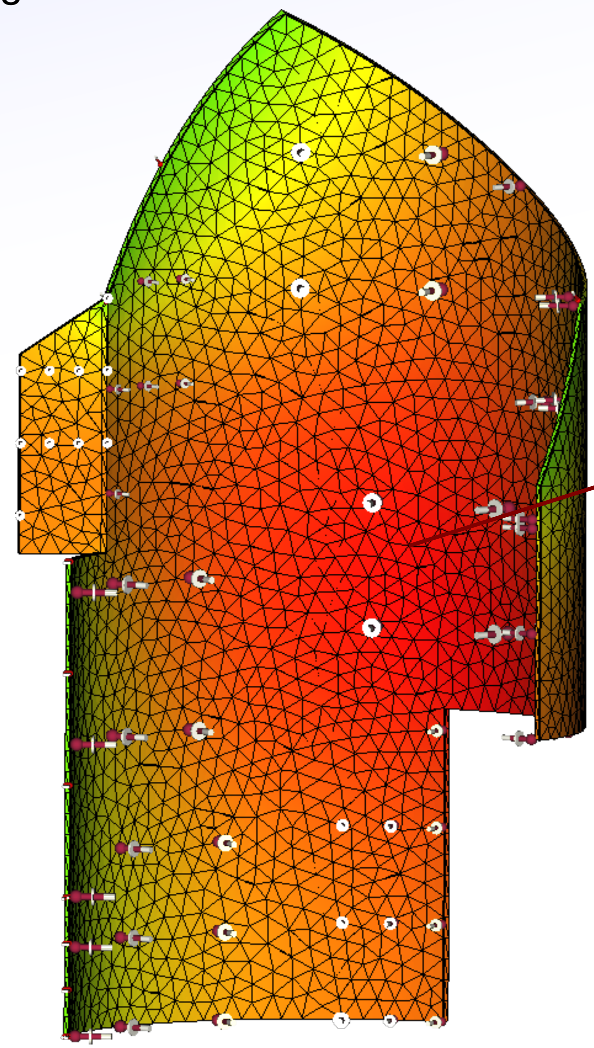


--> Use thicker copper layer and/or reroute pipe

AEM21: Heat load - Port shield

Port Shield. 470W, 2mm Steel, No Copper
Conduction to pipe and front plate, no radiation exchange.

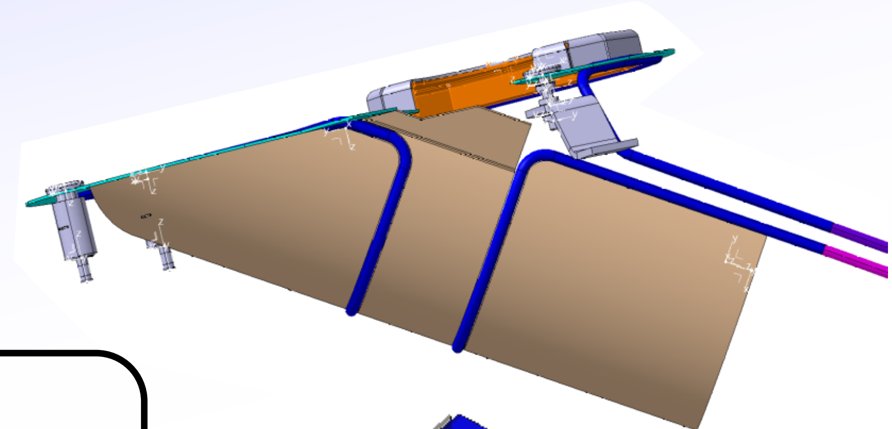




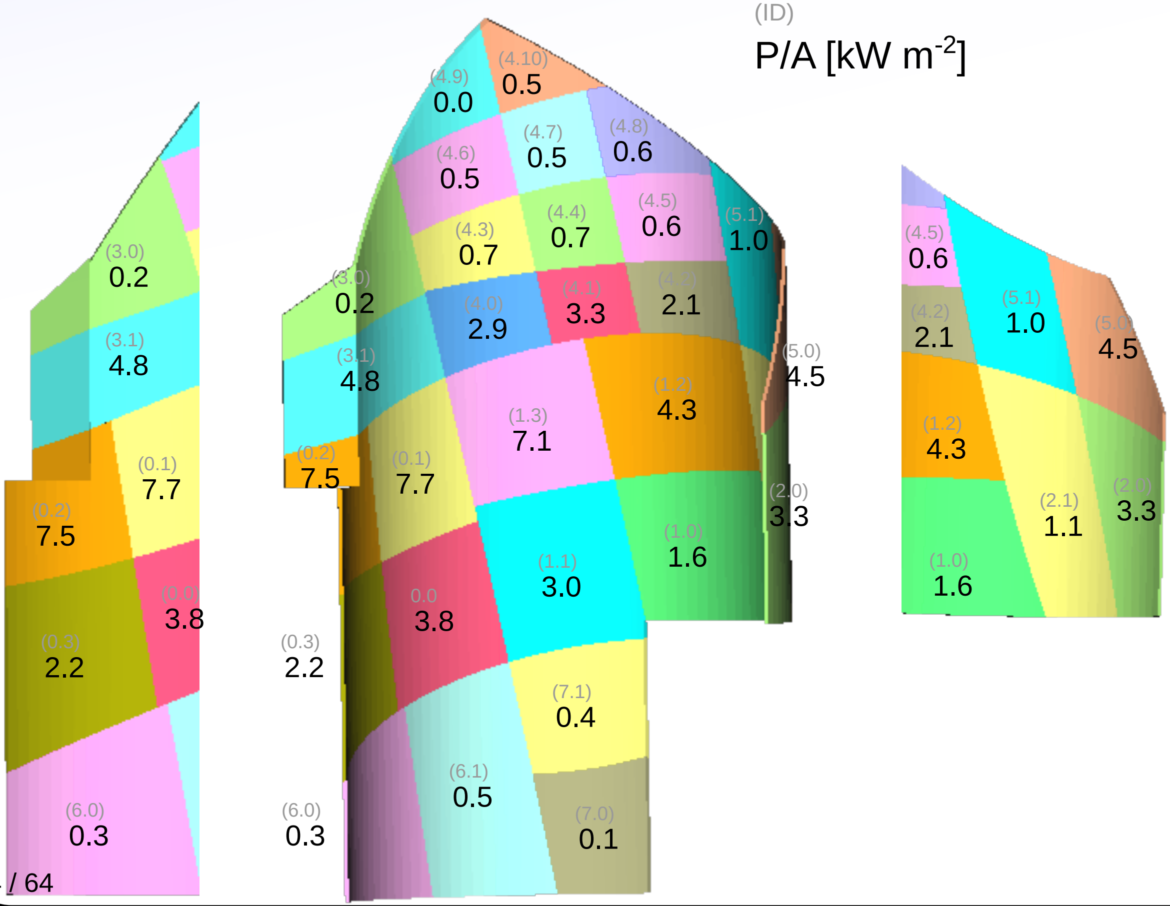
Too hot - would lead to radiation exchange to port wall.
1) Use much thicker steel (>= 5mm) or copper plating
2) Route water pipe through centre of shield area --> Stiffness vs flexibility during installation.

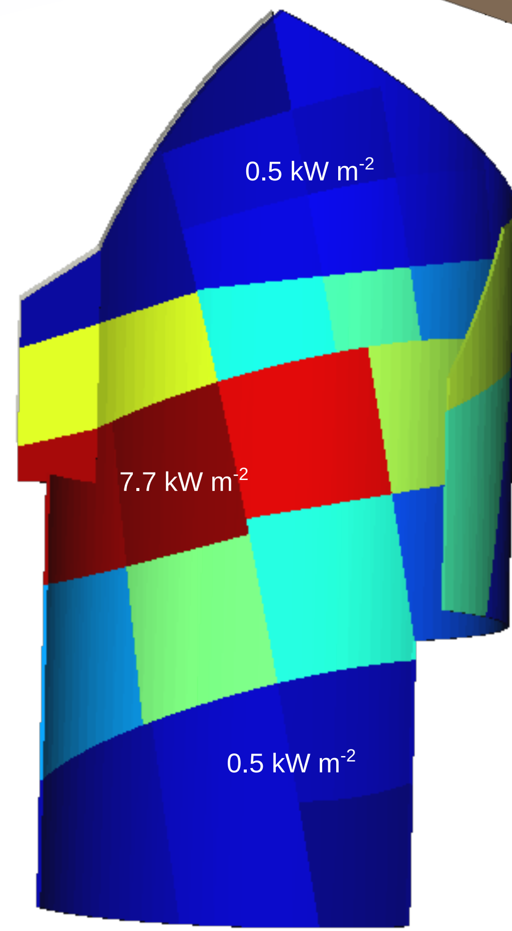
AEM21: Radiation load - Port shield - v3

Higher resolution splitting of port shield shows radiation concentrated where pipe addded:



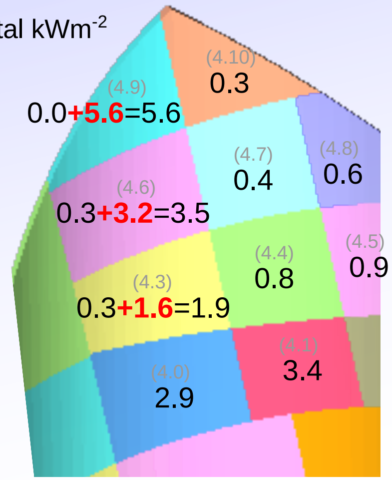
Load detail:



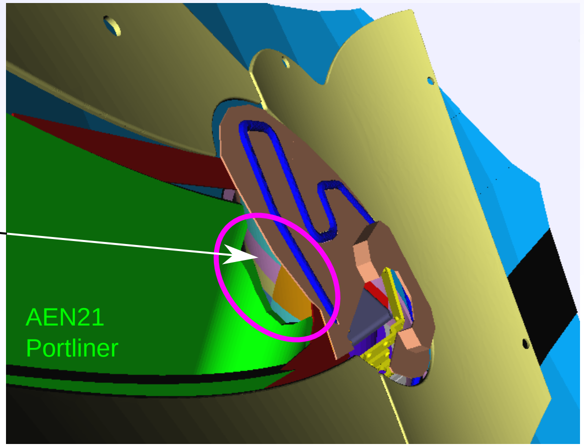


AEM21: Radiation load - Port shield - v4

front+**back** = total kWm^{-2}

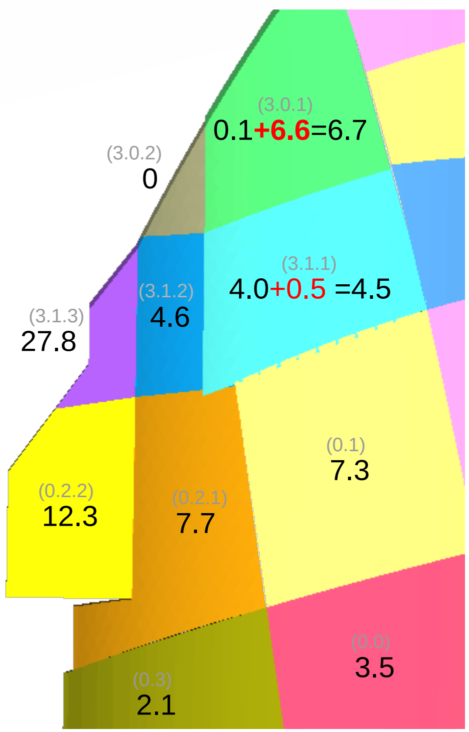


Correction needed to top because back-side is really exposed above AEN21 portliner:

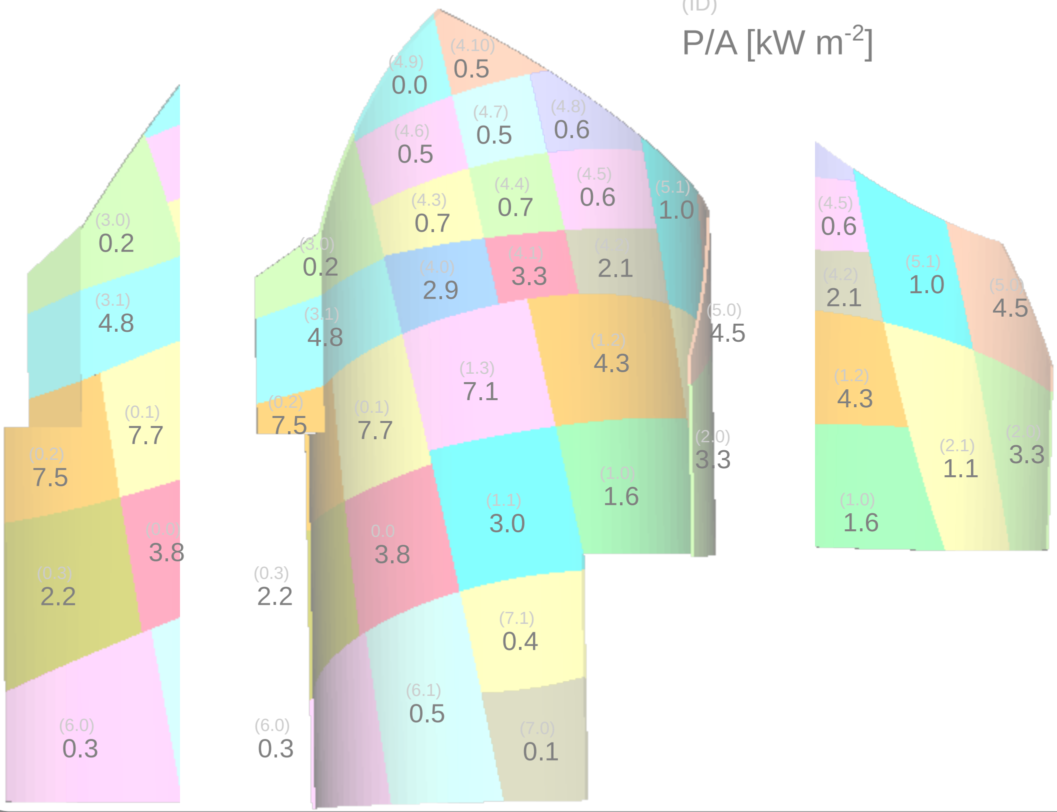


V4:

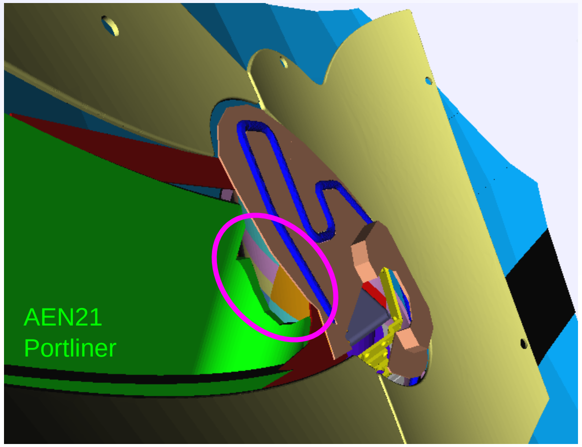
(modified left)

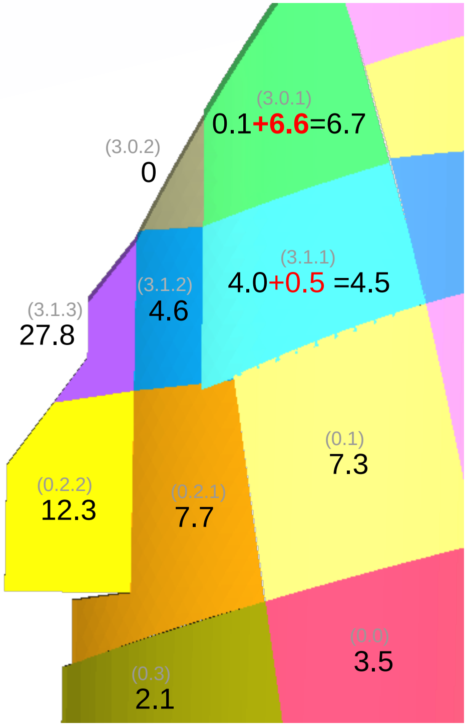


Loads from V3:

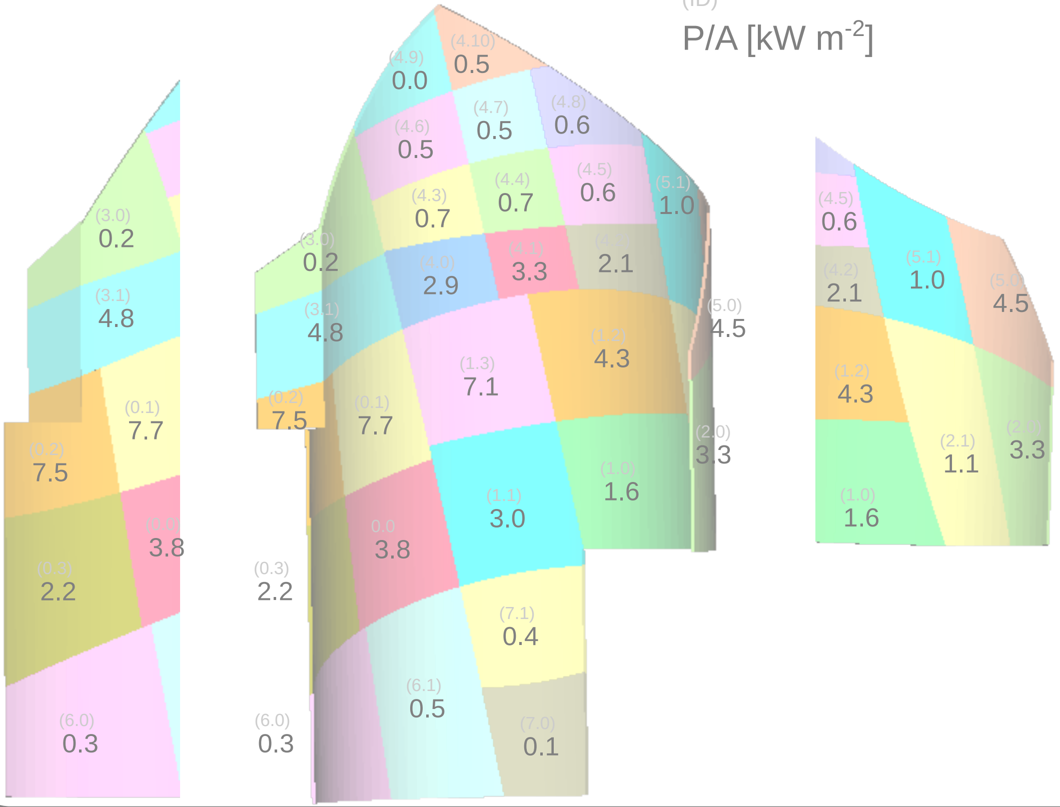


AEM21: Radiation load - Port shield - v4

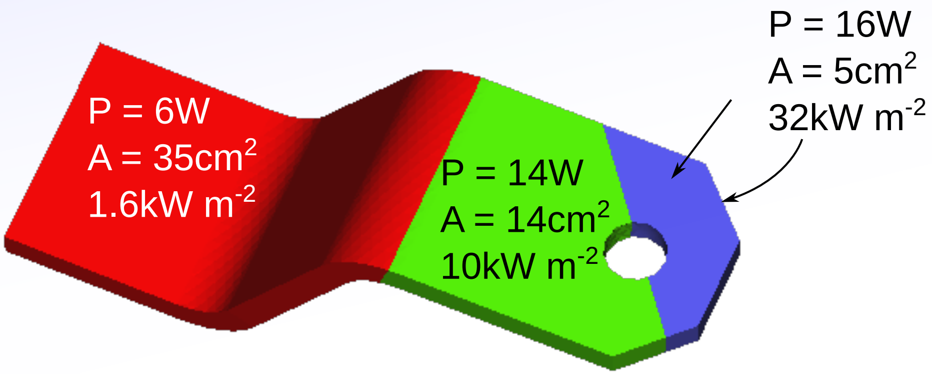




Loads from V3:

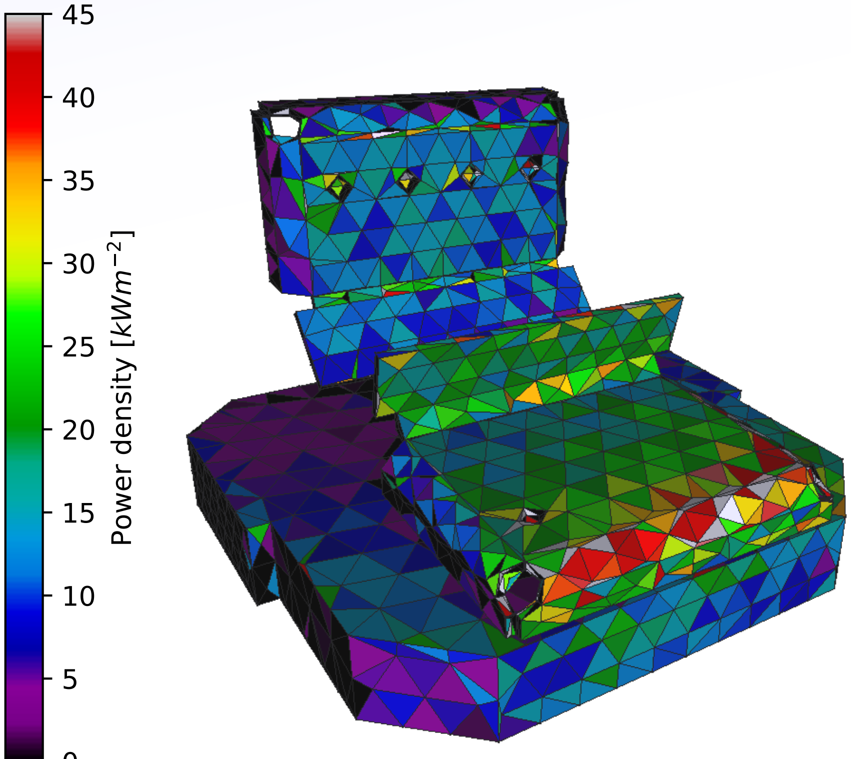


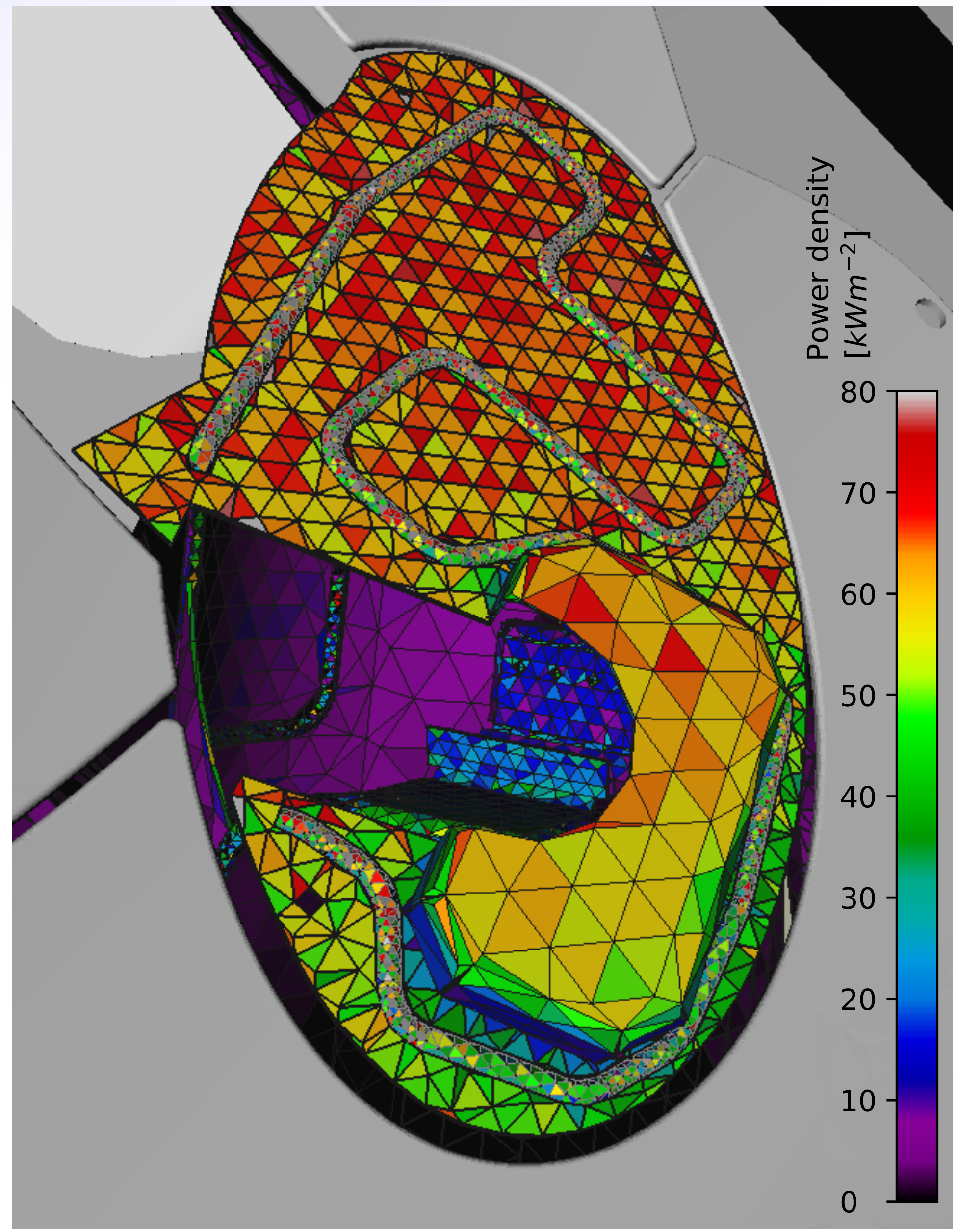
AEM21: Radiation load - Mounting bracket



AEM21: Frontplate May2020

Hopefully final iteration of front plate and port shield thermal calculation.
Radiation exposure now calculated per triangle.
Frontplate and shutter are the same as before:



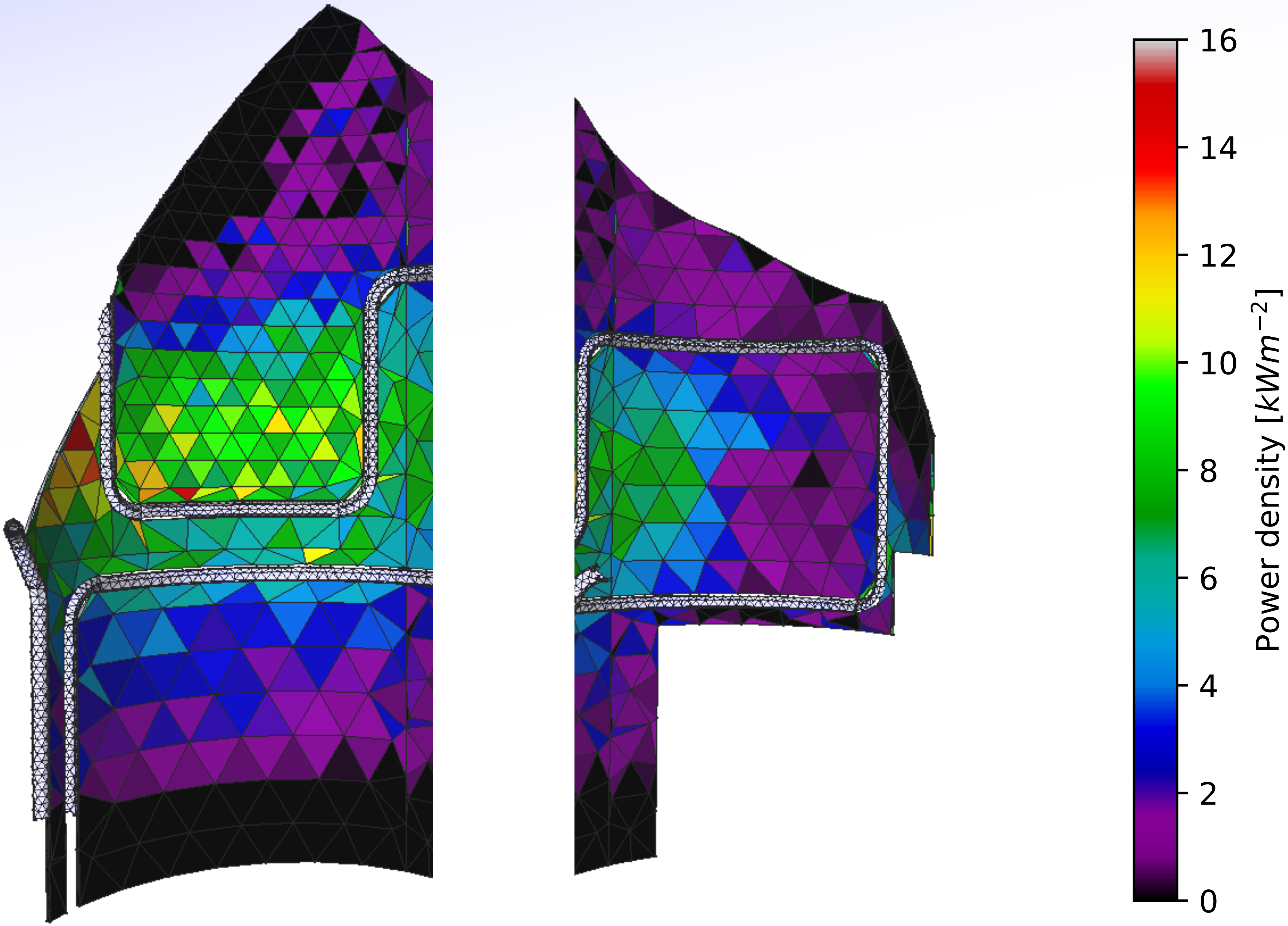


AEM21: Frontplate+Portshield May2020

Hopefully final iteration of front plate and port shield thermal calculation.
Radiation exposure now calculated per triangle:

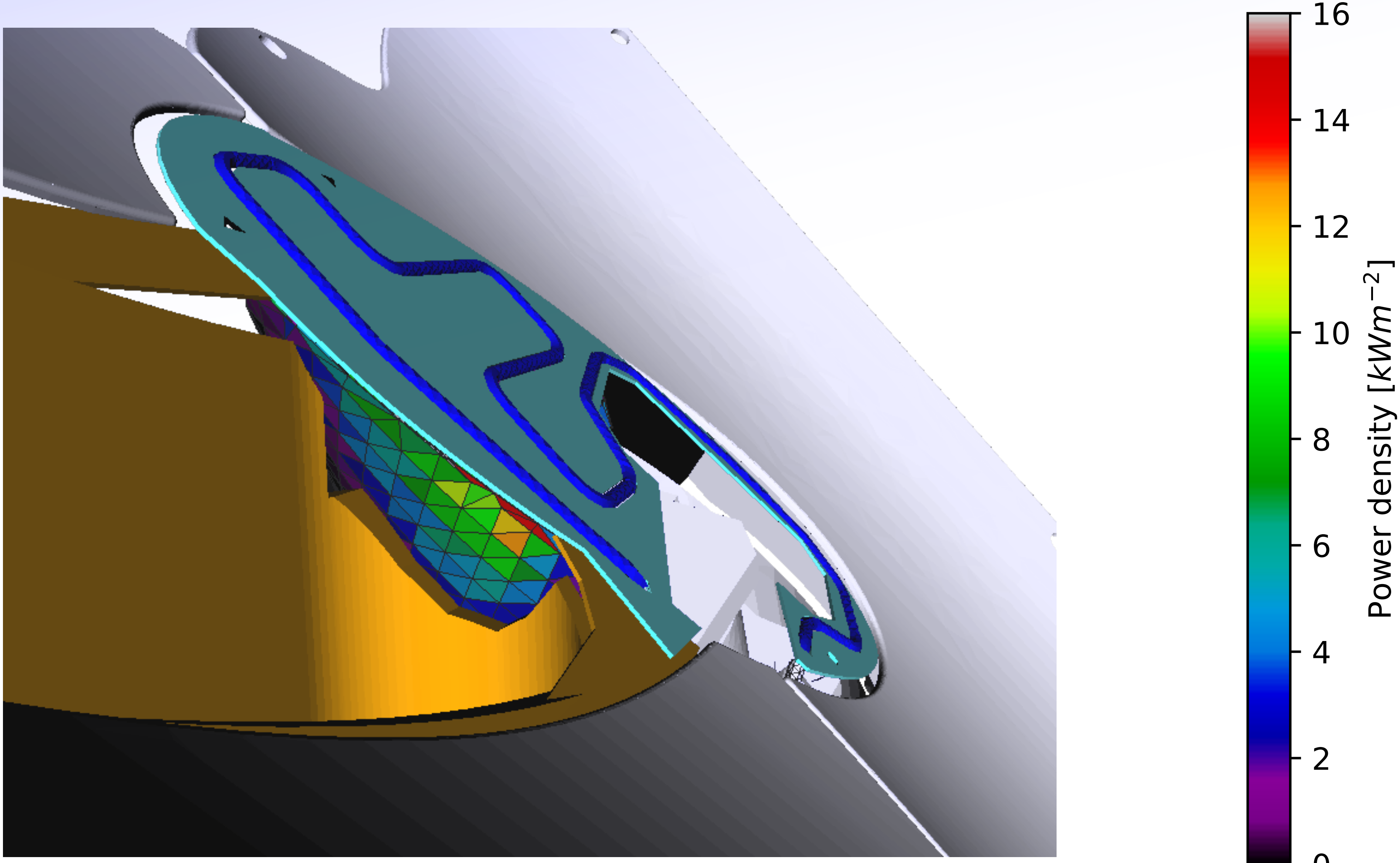
AEM21: Port Shield May2020

Port shield modified:



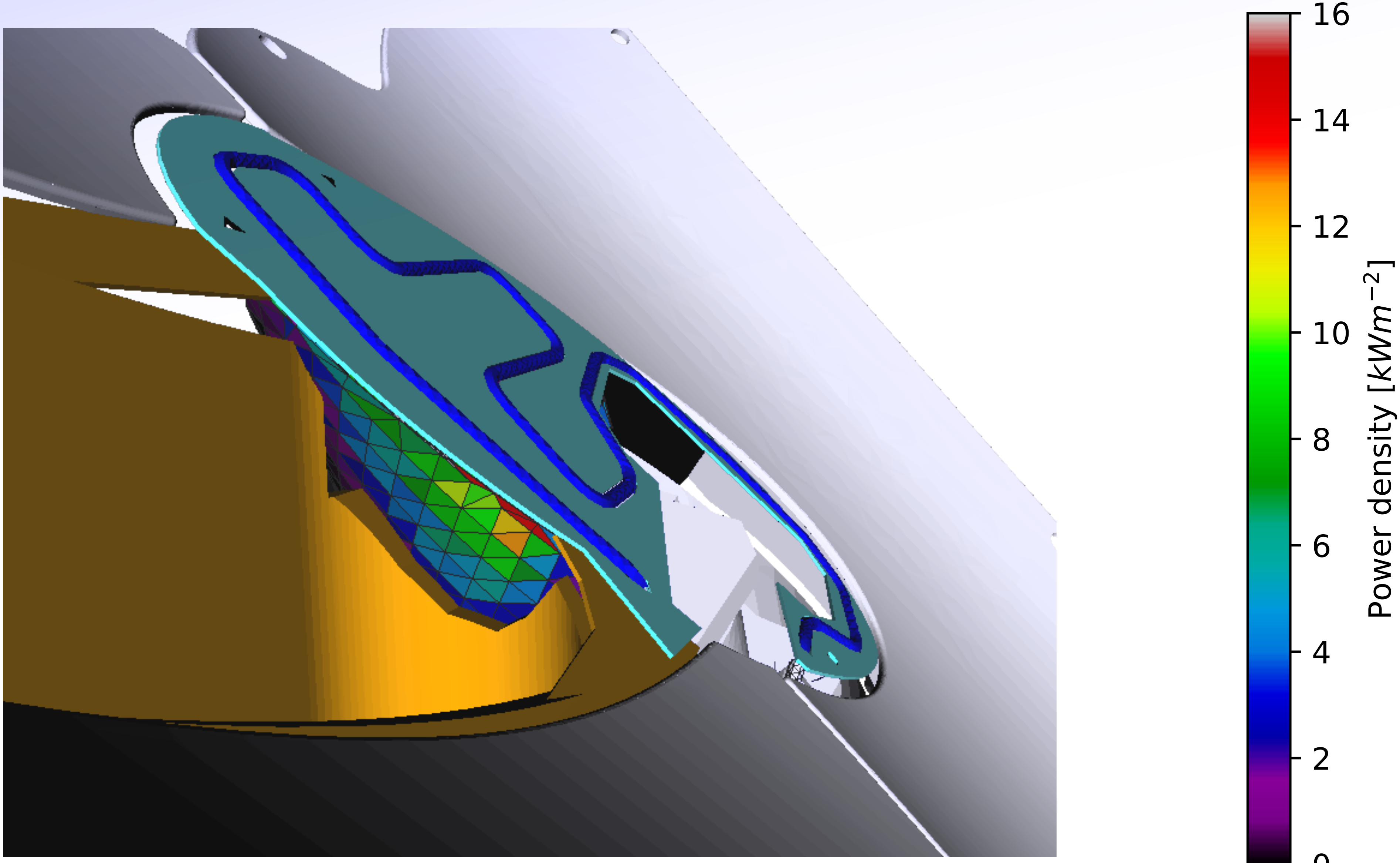
AEM21: Port Shield May2020

Same load to back side at intersection with AEN21 port liner:



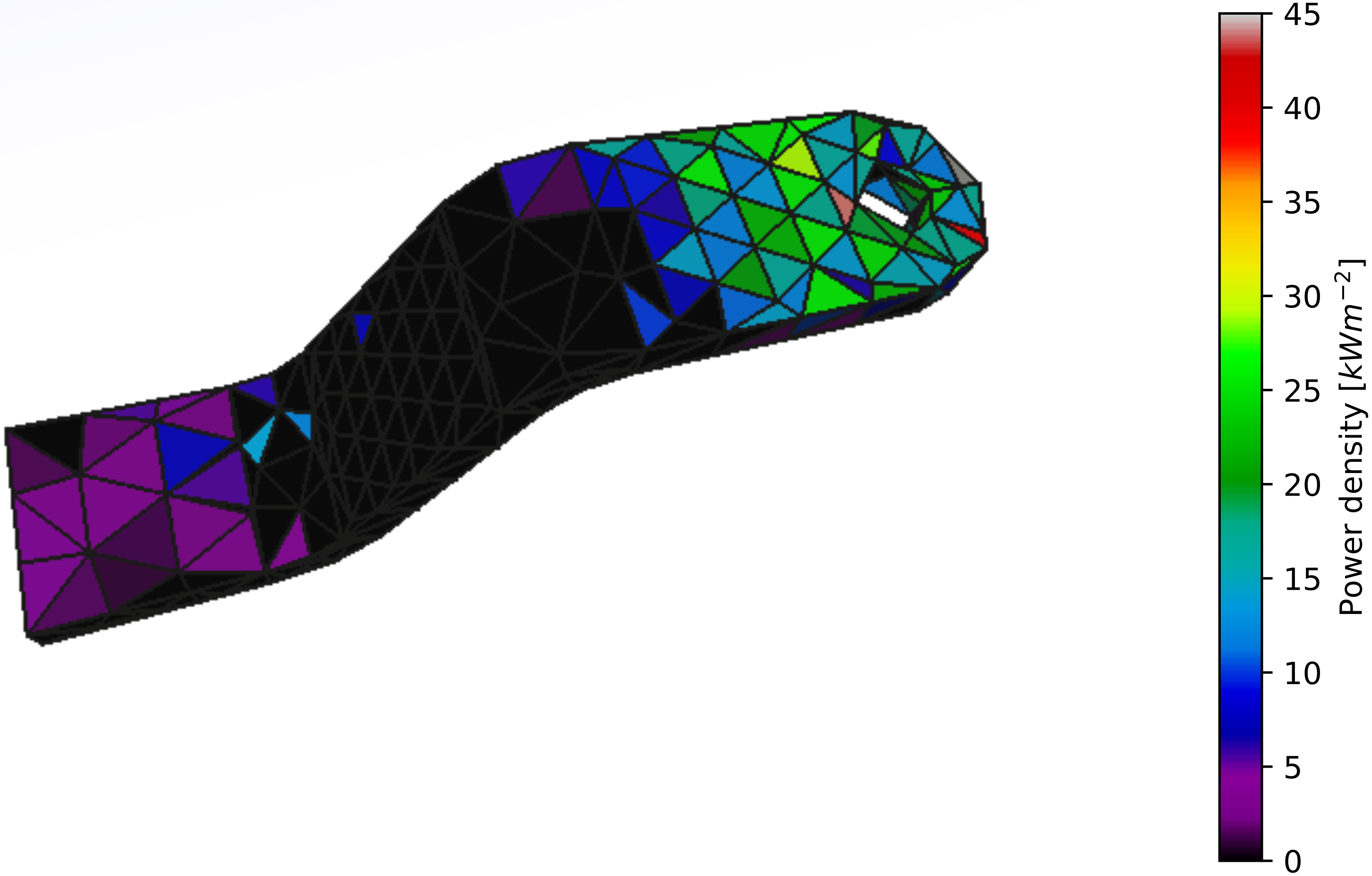
AEM21: Port Shield May2020

Same load to back side at intersection with AEN21 port liner:



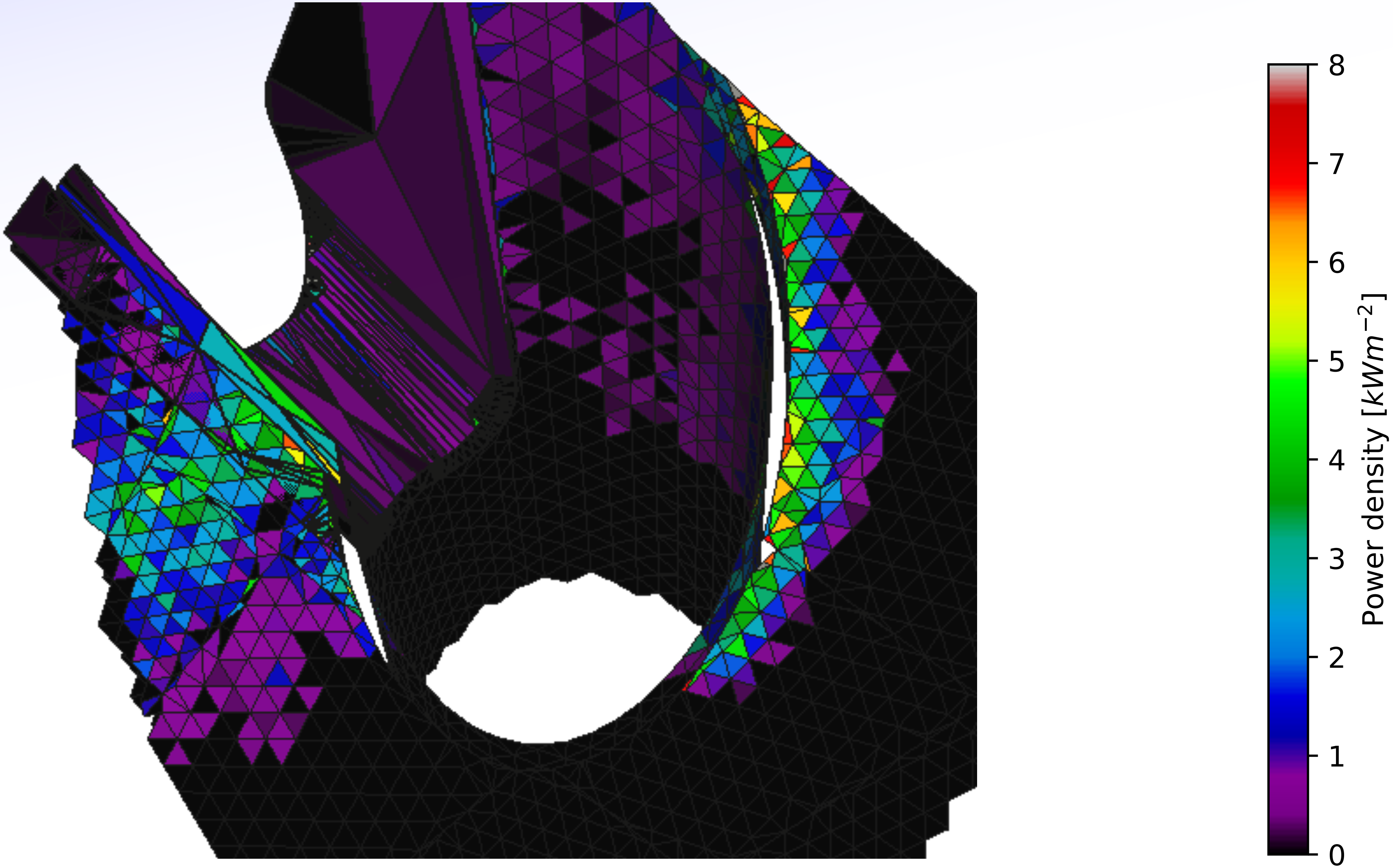
AEM21: Mount arm May2020

Mount arm sees minimal load:



AEM21: Vessel May2020

Vessel load remains negligible:



AEM21: Heat load - Shutter

Preliminary thermal evaluation.
Ray tracing 100 kW m^{-2} from plasma surface to simplified model of all components: [radExposure-all30x30x30]

AEM21 port wall: 50 W [radExposure-portWalls (50x50x??)]
Zwickel: 25 W
= 75W to vessel walls

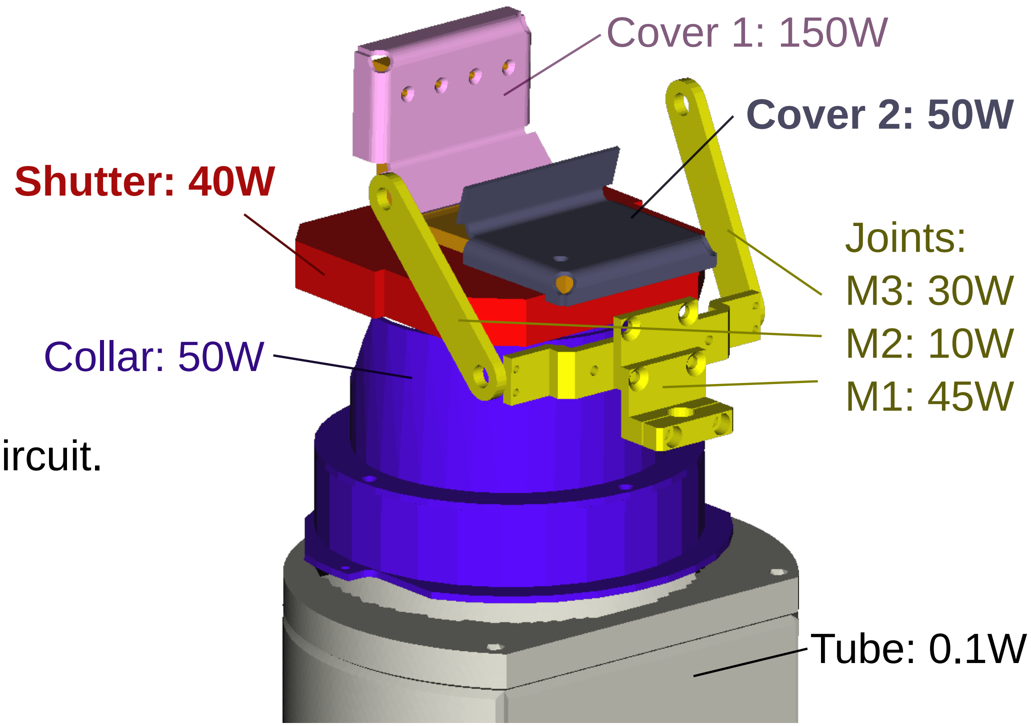
Front plate: 5000 W
Port Shield: 470W
= 5100W to ACK60-PL via front-plate water circuit.

Immersion tube: 0.1W
Protection collar: 50W

Shutter: 40W
Shutter strap cover : 150W
Straps direct: 2W
= 200W via straps

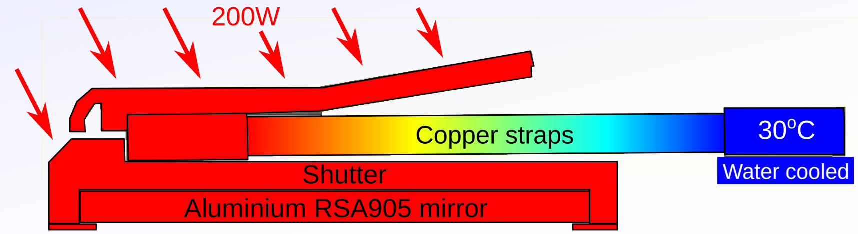
= 250W to ACK60-DIA via immersion tube water circuit.

Non-cooled steel components: 80W
Worst case M3, radiation equilibrium = 400°C

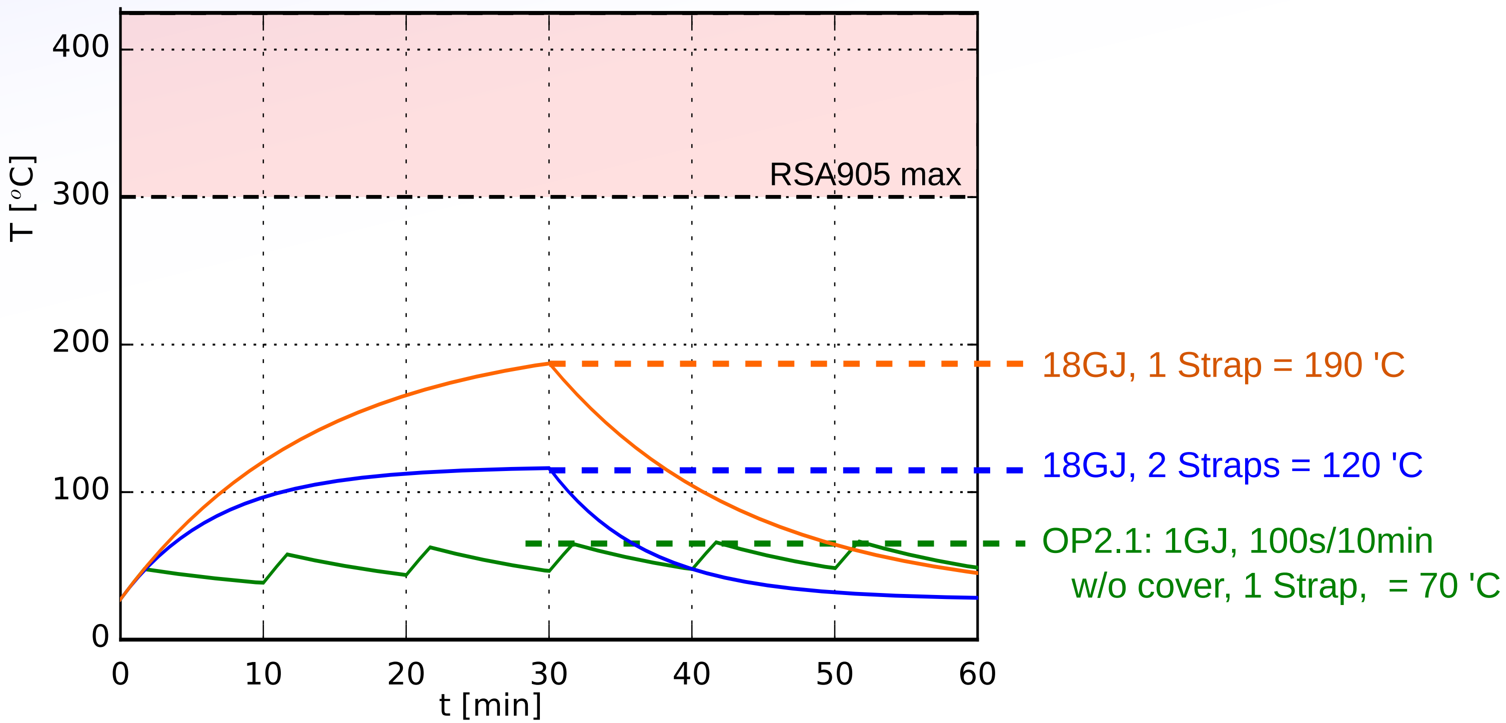


AEM21: Heat load - Shutter

Shutter: 40W
Shutter strap cover : 150W
Straps direct: 2W
= 200W via straps



- Head load, strap length and material are all the same as AEA21
--> Same temperature development of shutter and aluminium mirror.



1) With 2 straps and cover, 18GJ is OK by x2
2) 1GJ is OK even with no cover and only 1 strap

Thermocouple will be installed in shutter to monitor temperature rise in OP2.1 --> confirm safety.

AEM21 - Water flow

Due to limited space in port, we would like to use narrorer pipe:
- Outer diameter: 8mm
- Inner diameter: 6mm
- Length: 10mm (due to all the meandering, tube is ~2m long)

ACK60:
- max allowable flow rate = 0.2l/s
- max allowable pressure drop = 6bar.
- max allowable temperature rise = 50°C (In calc in 1-ACK60-S0000)
- Operation pressure is 25bar, so boiling point > 200°C. 35°C input temp --> 85°C max temp.

At 0.2l/s, pressure drop --> 9 bar
At 0.1l/s, pressure drop --> 3 bar (factor 2 under requirement)

Need to cool 6kW:
- 6kW / specific heat capacity / water density / 0.1 ls-1 = 15°C temperature rise (factor 3 under req.)

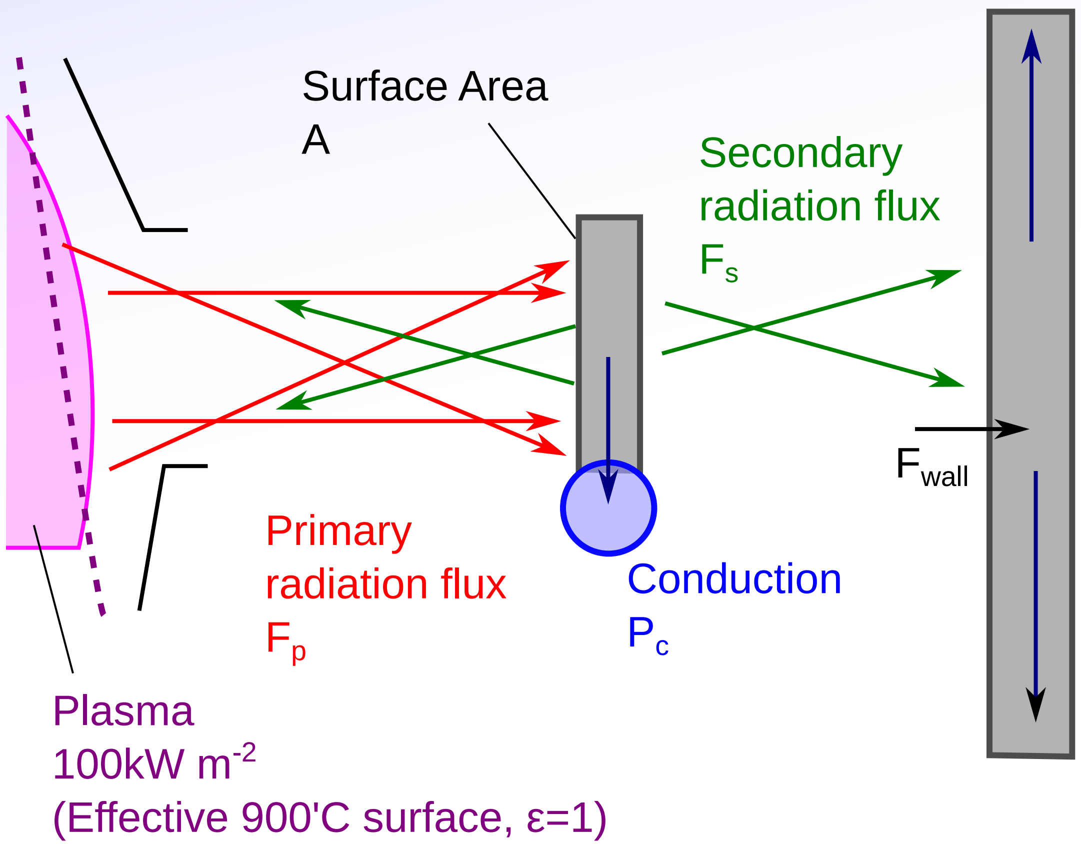
So 8mm pipe is OK.

Immersion tube pipe:
- 6mm outer, 4mm inner?, length ~ 5m
- 6 bar --> 0.077 l/s
- Need to cool ~ 300W --> 1°C temperature rise --> No concern.

http://www.pressure-drop.com/Online-Calculator/
Wolfram alpha: 300W / ((4 J K^-1 g^-1) * (997 kg m^-3) * (0.077l s^-1))

Thermal balance

The steady-state temperature of a structure in vacuum can be found from the balance of heat flux to/from the surface:



Absorbed primary power:

$P_p = \varepsilon_a F_p A$

$\varepsilon_{a,e}$ = emissivity (absorbed, emitted)

Radiated secondary power:

$P_s = F_s \, 2 A$

$F_s = \sigma \varepsilon_e T^4$

σ = Stephan Boltzmann's constant

Steady state power balance (no cooling)

$P_p = P_s$

$\varepsilon_a F_p A = 2A \sigma \varepsilon_e T^4$

$T = (½ F_p (\varepsilon_a/\varepsilon_e) / \sigma)^{1/4}$

Emissivity

Strong dependence on relative emissivity of absorbtion and re-radiation.

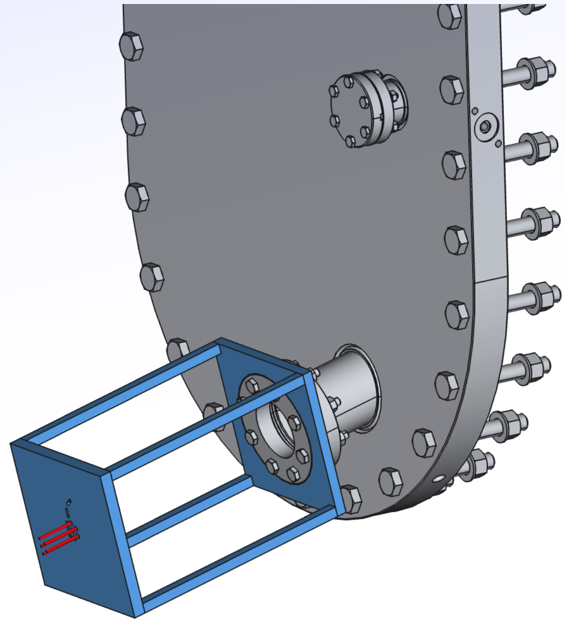
Best case: Plasma radiation as black-body: $\varepsilon_a/\varepsilon_e = 1$ (Independant of emissivity)
Worst case:
Plasma radiation in X-Ray / VUV: $\varepsilon_a \sim 1$
Radiation from stainless steel (unpolished): $e_e \sim 0.4$ (Ranges 0.4 - 0.6)
---> $\varepsilon_a/\varepsilon_e < 3$

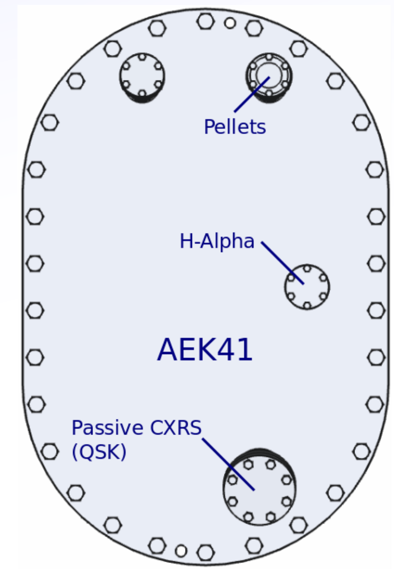
$$T = (\tfrac{1}{2} F_p (\varepsilon_a/\varepsilon_e) / \sigma)^{1/4}$$

	$\varepsilon_a/\varepsilon_e = 1$		$\varepsilon_a/\varepsilon_e = 3$	
F_p [W m^{-2}]	T [°C]	F_{wall} [W m^{-2}]	T [°C]	F_{wall} [W m^{-2}]
100	700	50	1000	300
50	550	25	800	150
20	400	10	600	60
10	300	5	450	30
5	200	2.5	350	15
1	50	0.5	150	3

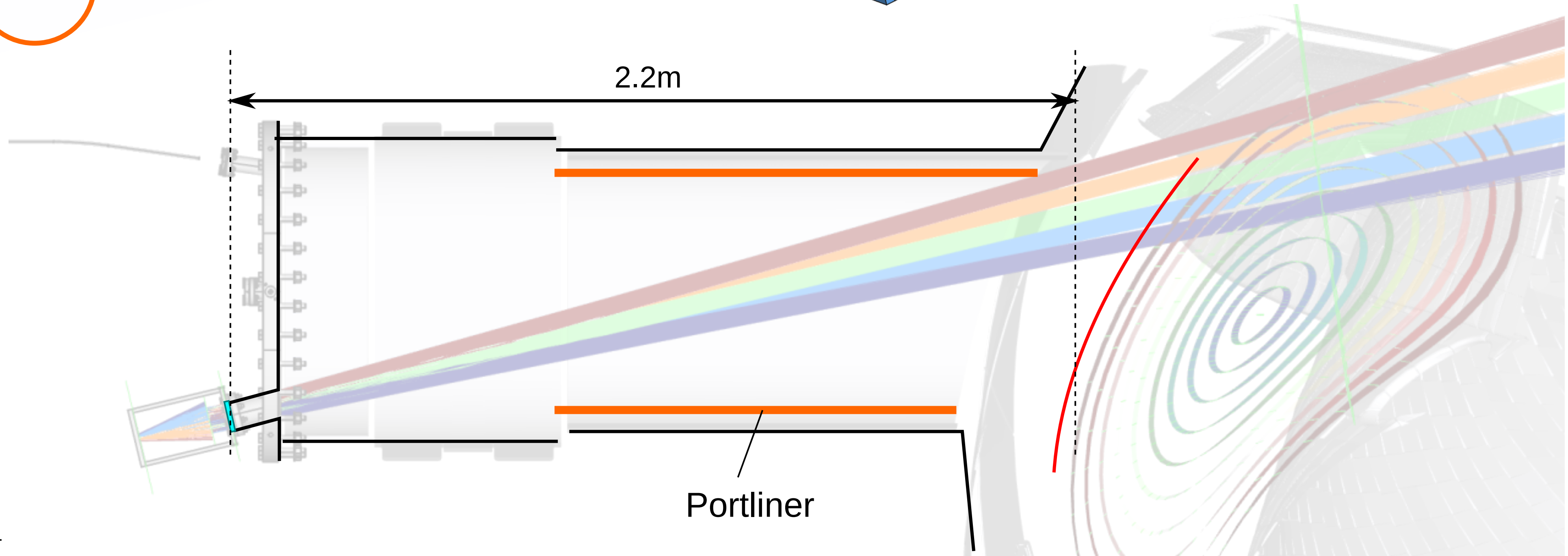
Passive CXRS - AEK41

'Passive CXRS' system on AEK41 will remain as in OP1.2:
650x350mm * 100kW m-2 = 22kW into port.
22kW on 6cm window at 2m distance = **4W**
On port area (720x400mm) = 660W

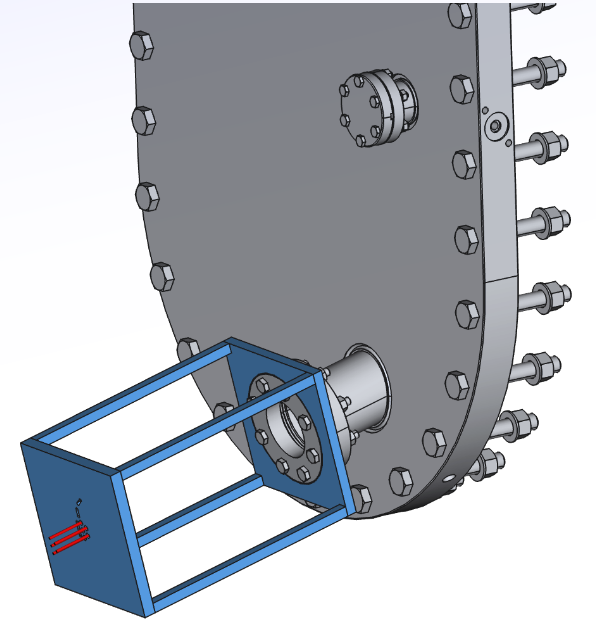




AEK41 Portliner =
650x350mm (inside)



Passive CXRS - AEK41 - Window heating



22kW on 6cm window at 2m distance = **4W**

Power = 4W
Diameter = 60mm
Thickness ~ 5mm
Material = Fused Silica
Density = 2.2 g cm^{-3}
Mass = 31g
Specific heat capacity = 740 J kg^{-1} K^{-1}
Heating rate = 10 K / min
Max heating rate = 2 - 25 K / min (exact specification not known).

--> Heating of glass is a concern to breaking window. Calcuation is very sensitive to glass thickness and ge
sacrificial window on vacuum side.

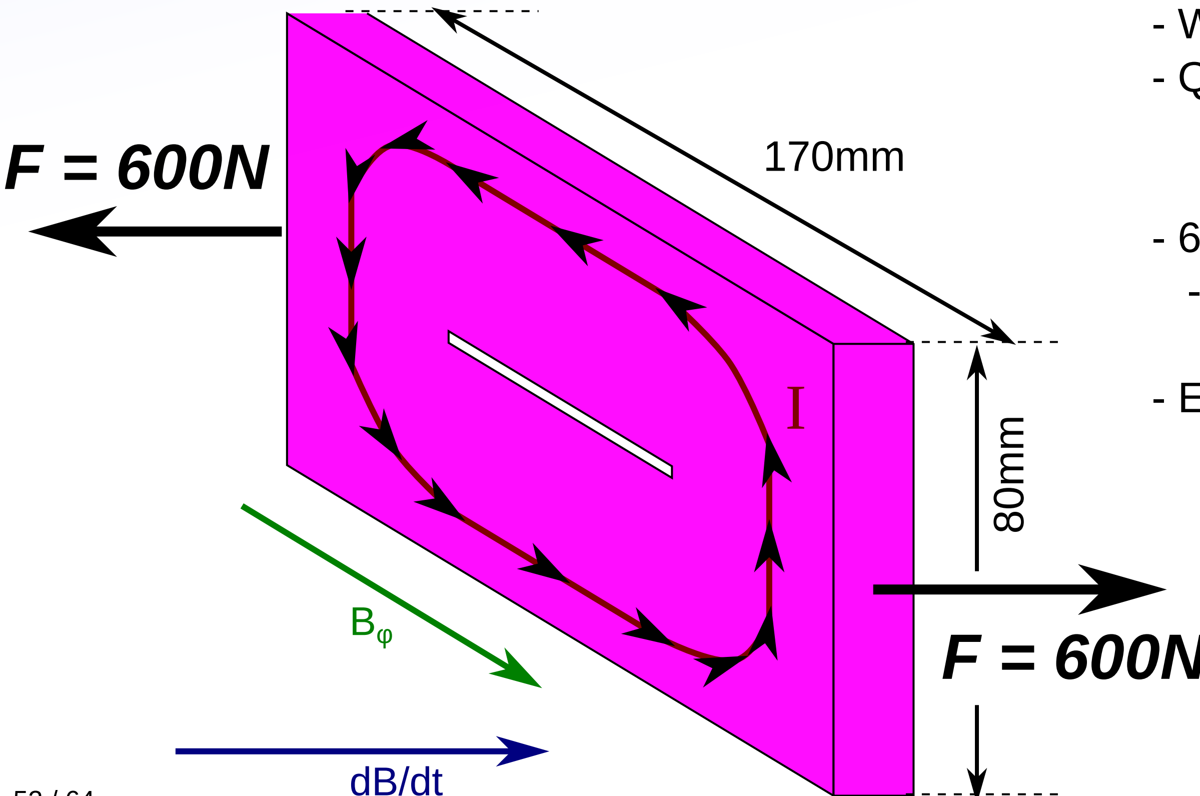
Power to flange = 660W.
Material = Steel
Flange size = 740 x 560 x 38mm
Density = 8g cm^{-3}
Mass = 120kg
Specific heat capacity = 420 J kg^{-1} K^{-1}
Heating rate = **0.7 K / min**

--> Heating of window CF flange not a concern to breaking the window.

Forces due to fast current shutdown

4 components of interest with lower resistivity:
1) AEA21 Mirror (RSA-905 Aluminium)
2) AEA21 Copper-plated front-plate - Not handled here --> QMR
3) AEM21 Mirror (RSA-905 Aluminium)
4) AEM21 Copper-plated front plate.
5) Copper thermal straps

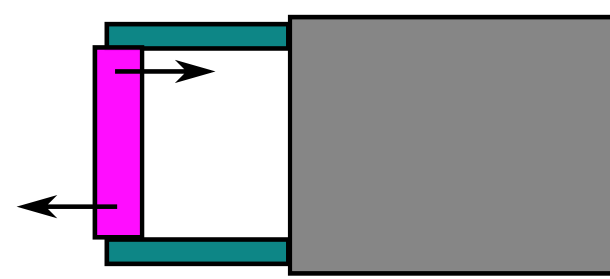
Calculation for long-pulse video endoscopes (QRT) RSA905 mirrors performed by J. Fellinger:
[1-QRT02-T0017.0, J. Fellinger, "Impact of fast plasma decay on front mirrors of AEA endoscopes"]



- Worst case scenario of vectors --> 600N
- QSK mirrors are smaller, and F ~ r^2 (or r^3)
  (120 x 60mm or ⌀=120mm)

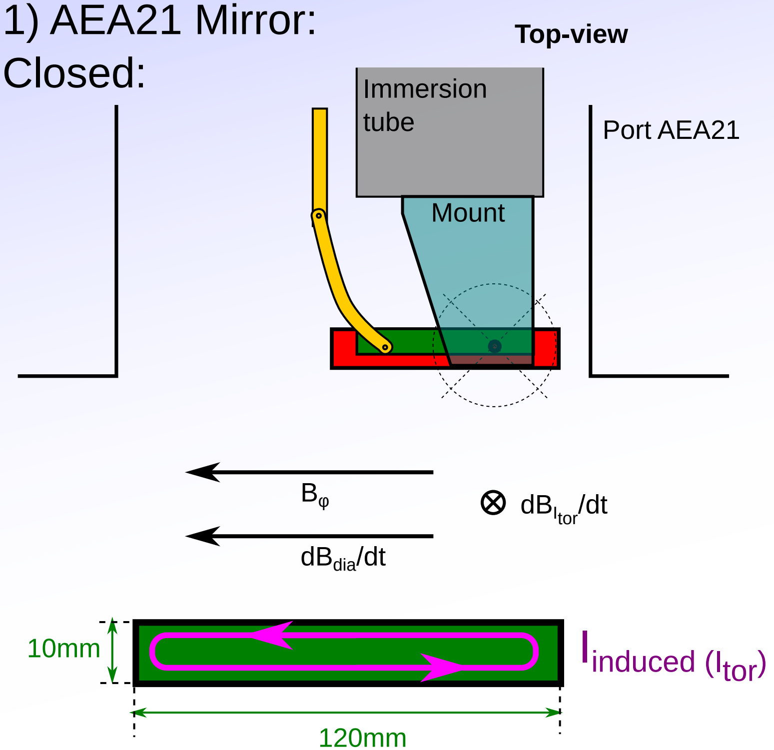
- 600N force acceptable on each mount.
  --> Should be OK regardless of QSK details.

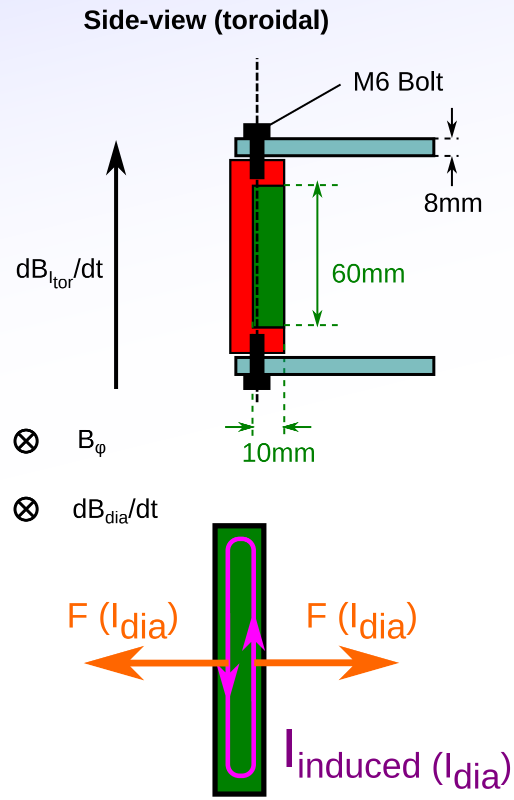
- Effect is always a twisting moment or
  stretch/compression of material.
  --> No net force on immersion tube.

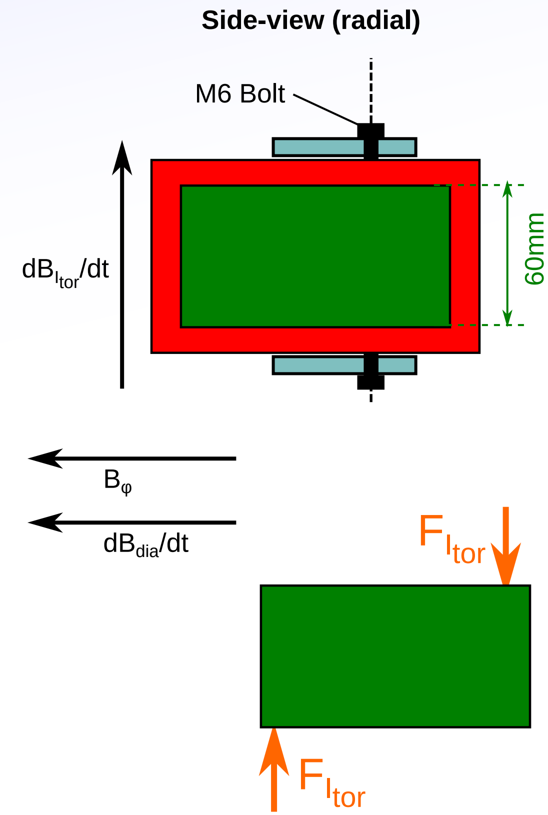


Forces due to fast current shutdown

1) AEA21 Mirror:
Closed:







Itor changes:

Negligible induction area: 120mm x 10mm

j x B force rotates mirror in plane against two M6 bolts in 8mm thick steel mounts.

Idia changes:

Negligible induction area: 60mm x 10mm

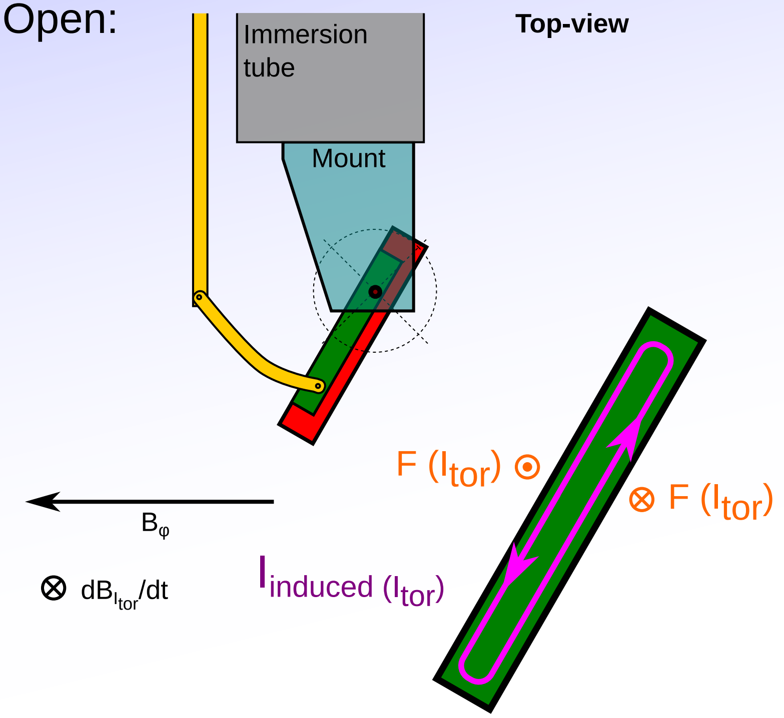
j x B force act outwards on mirror --> no rotation

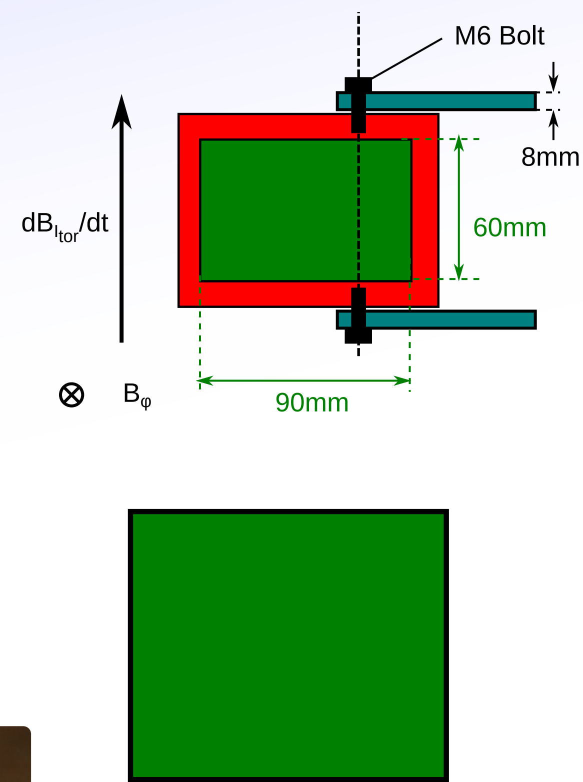
--> No conceivable mechanical failure

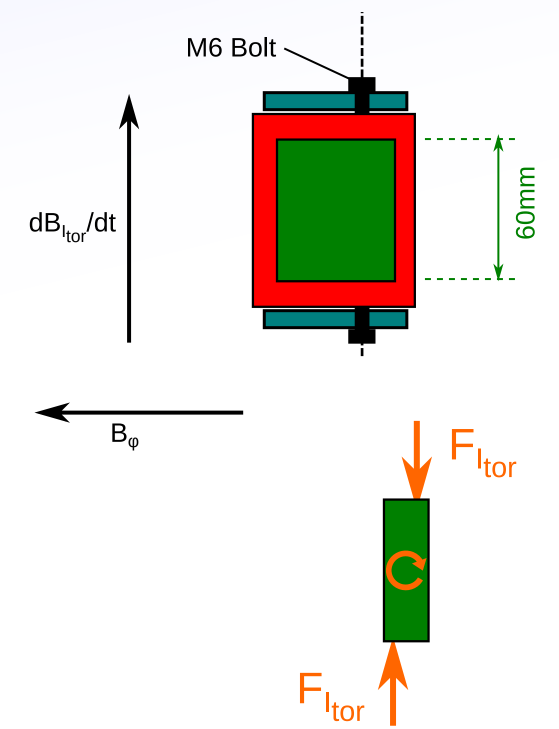
Forces due to fast current shutdown

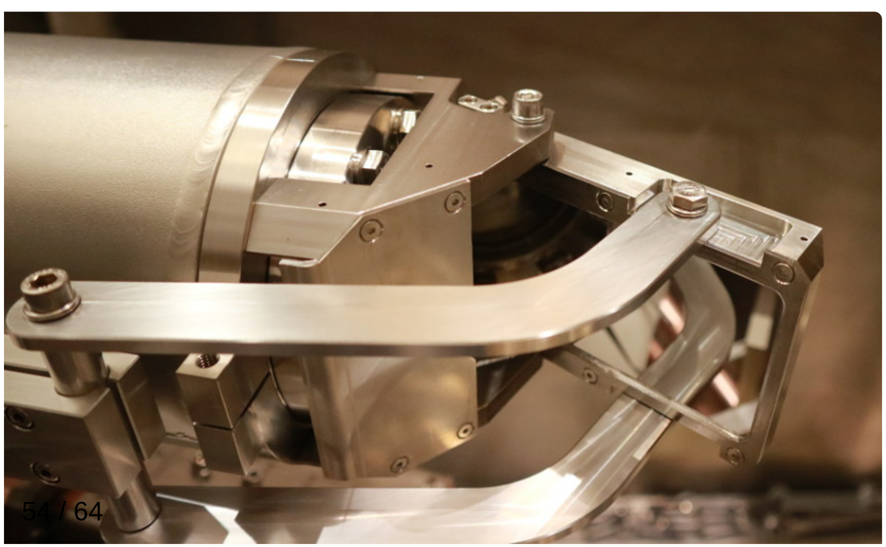
1) AEA21 Mirror:

Open:







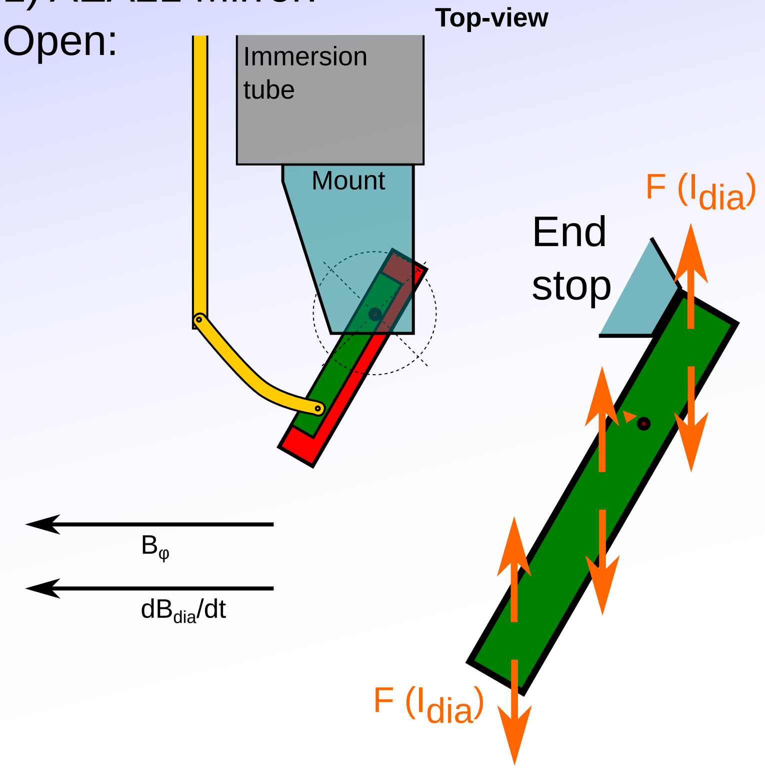


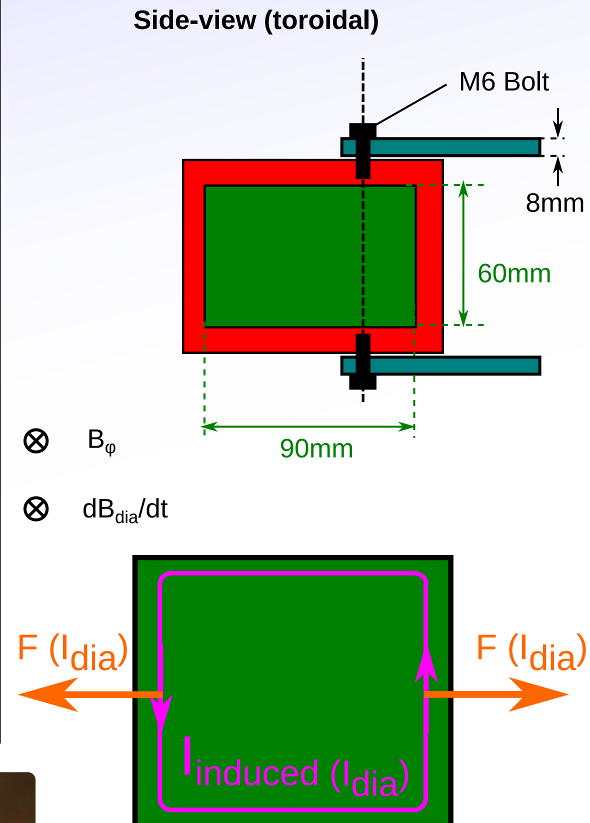
Itor changes:

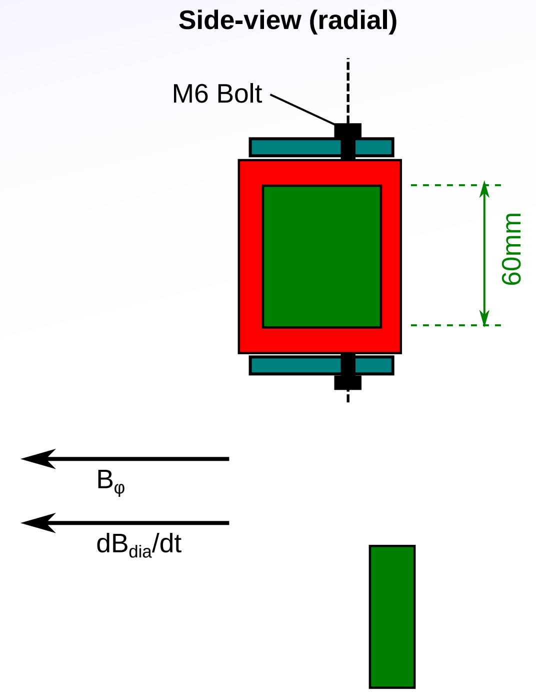
- Negligible induction area: 120mm x 10mm
- j x B force rotates mirror around horizontal axis against two M6 bolts in 8mm thick steel mounts.

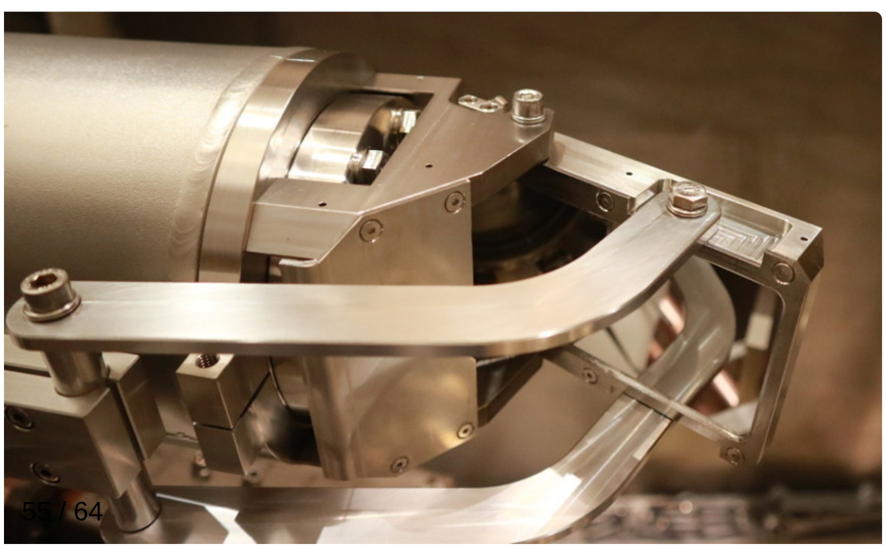
Forces due to fast current shutdown

1) AEA21 Mirror:
Open:









Itor changes:

- Negligible induction area: 120mm x 10mm
- j x B force rotates mirror around horizontal axis against two M6 bolts in 8mm thick steel mounts.

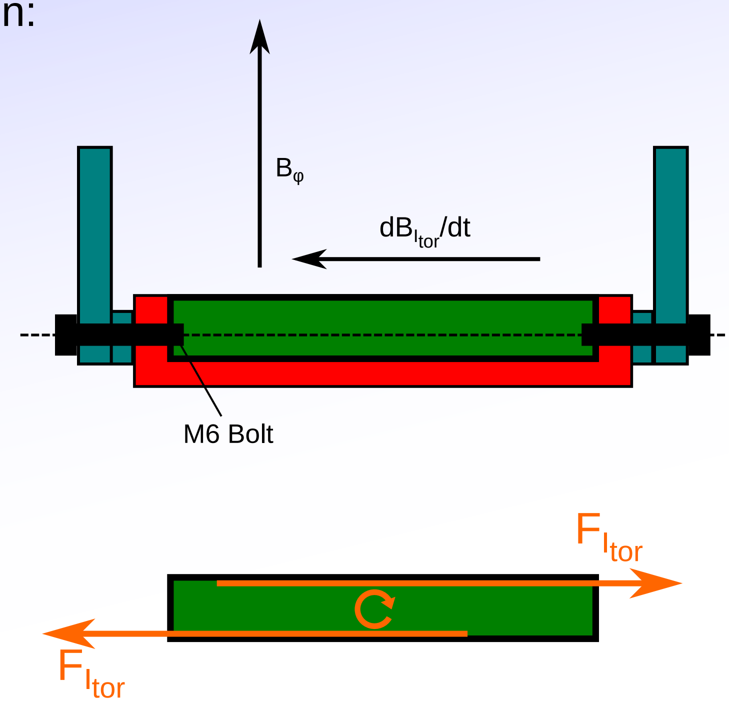
Idia changes:

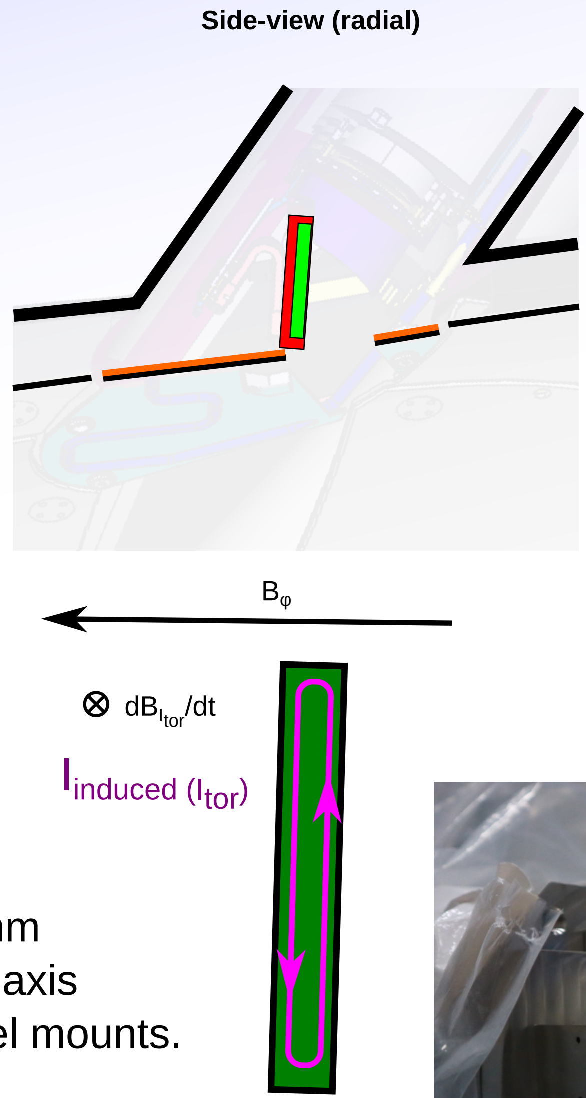
- Induction area: ~90mm x 60mm
- j x B force act outwards on mirror --> no rotation

--> No conceivable mechanical failure

Forces due to fast current shutdown

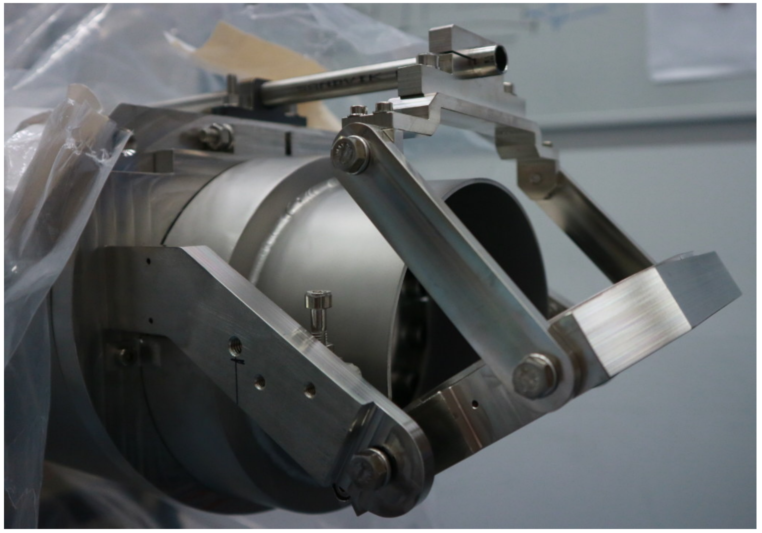
3) AEM21 Mirror:
Open:





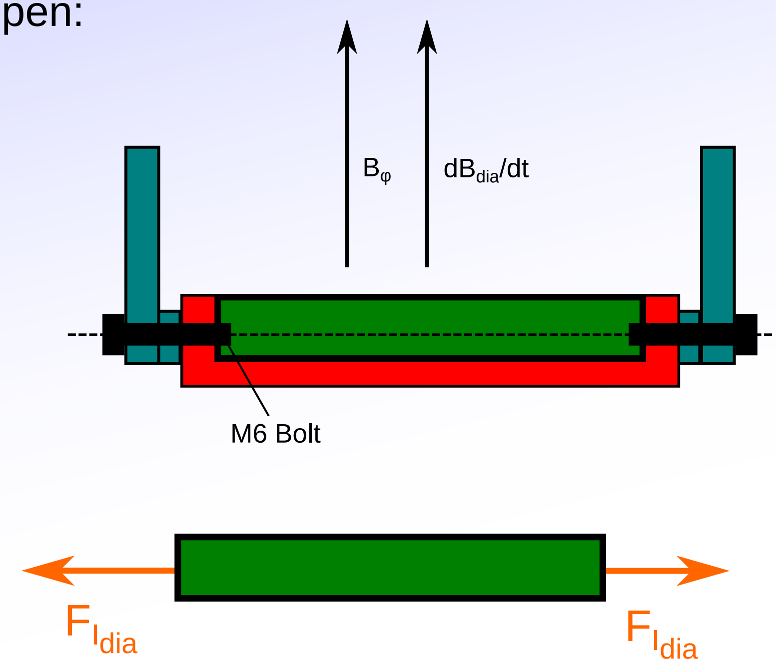
Itor changes:

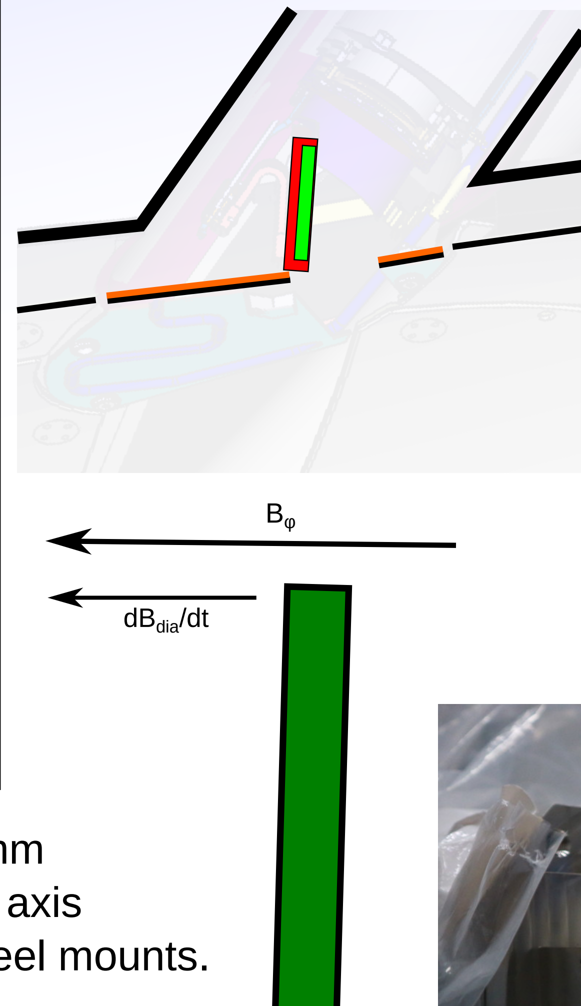
- Negligible induction area: 120mm x 10mm
- j x B force rotates mirror around vertical axis against two M6 bolts in 5mm thick steel mounts.

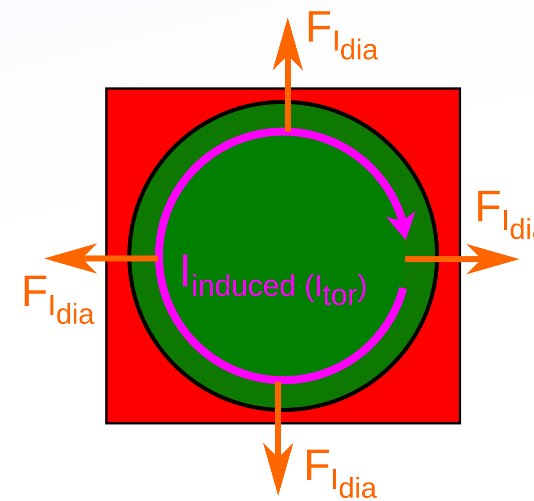


Forces due to fast current shutdown

3) AEM21 Mirror:
Open:



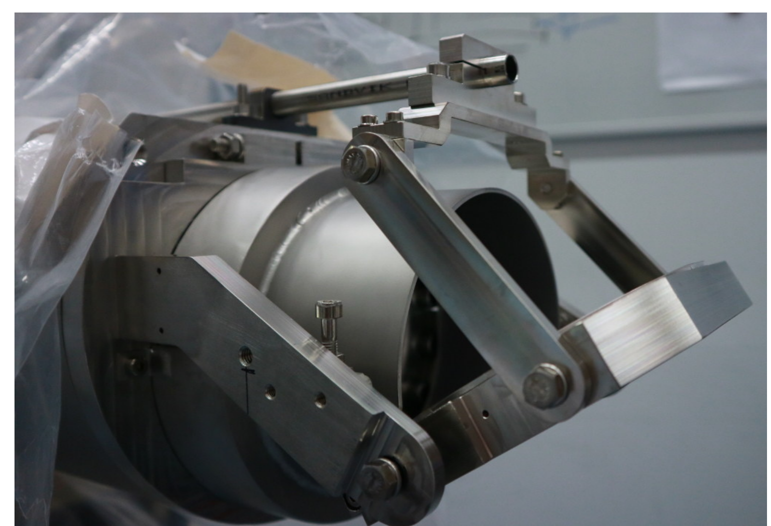




Itor changes:
- Negligible induction area: 120mm x 10mm
- j x B force rotates mirror around vertical axis against two M6 bolts in 10mm thick steel mounts.

Idia changes:
Negligible induction area: 60mm x 10mm
j x B force act outwards on mirror --> no rotation

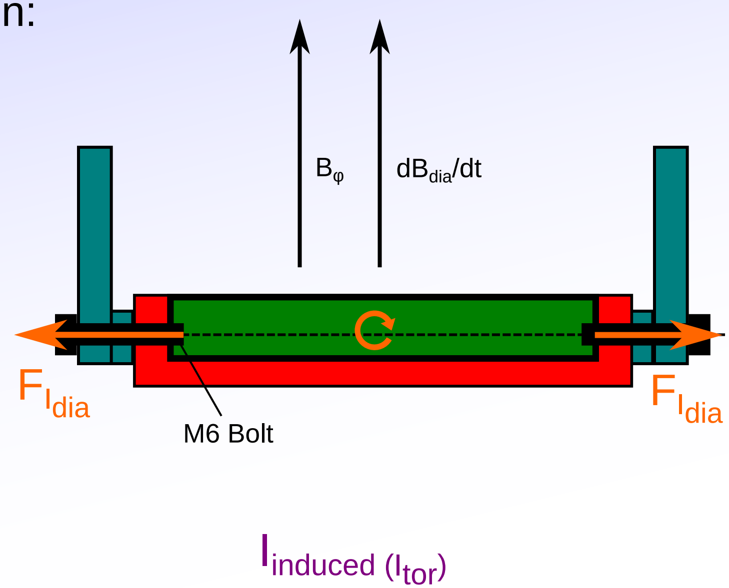
--> ***No conceivable mechanical failure***



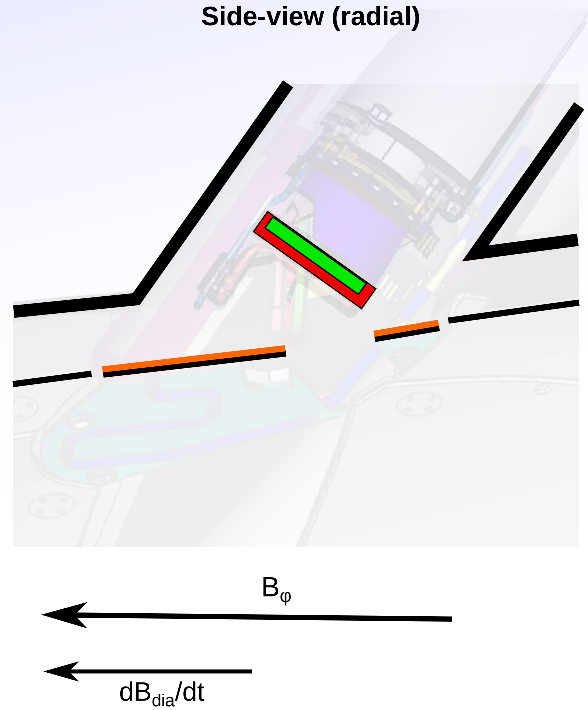
Forces due to fast current shutdown

3) AEM21 Mirror:
Open:

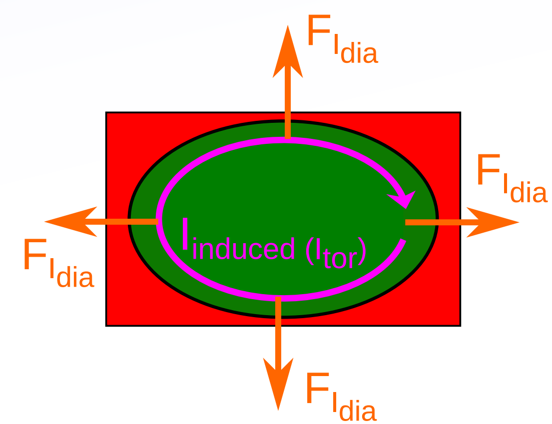
Top-view

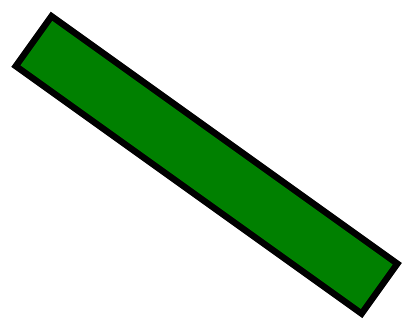


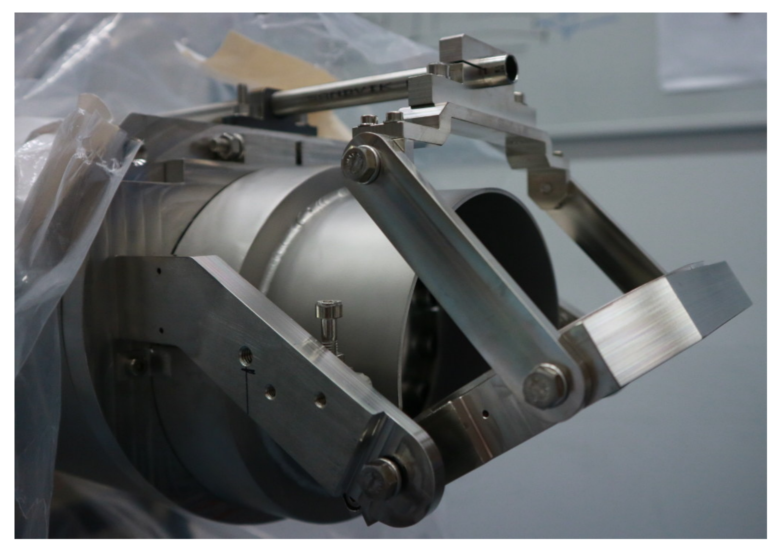
Side-view (radial)



Side-view (toroidal)







Itor changes:
- As open

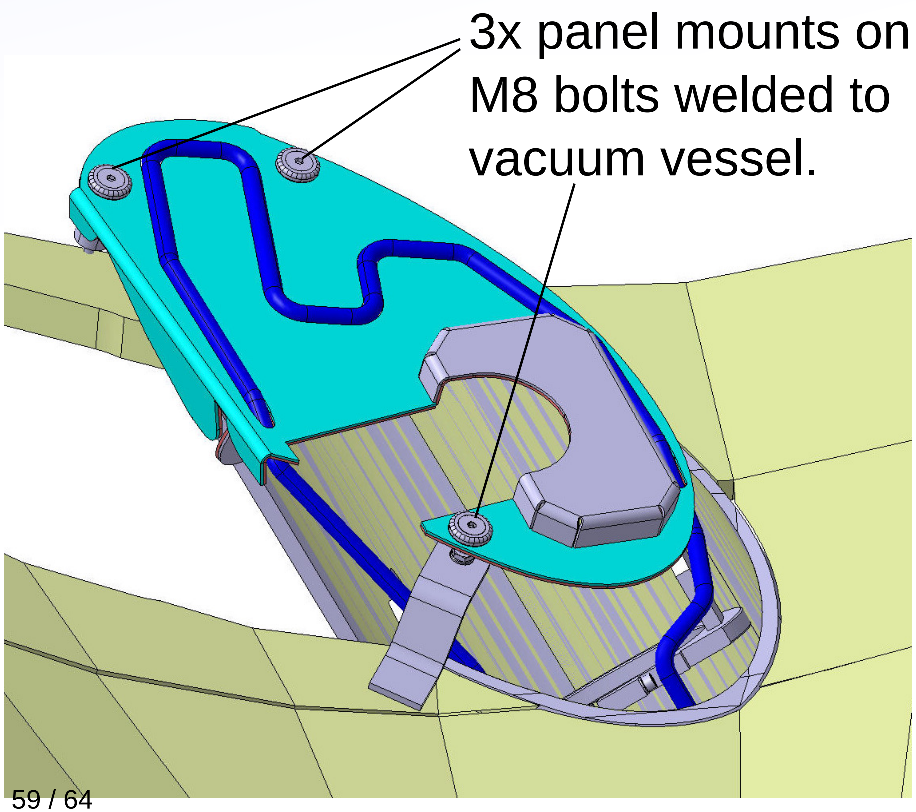
Idia changes:
As open, but:
1) less induction area --> less force.
2) Force acts slightly to open mirror.

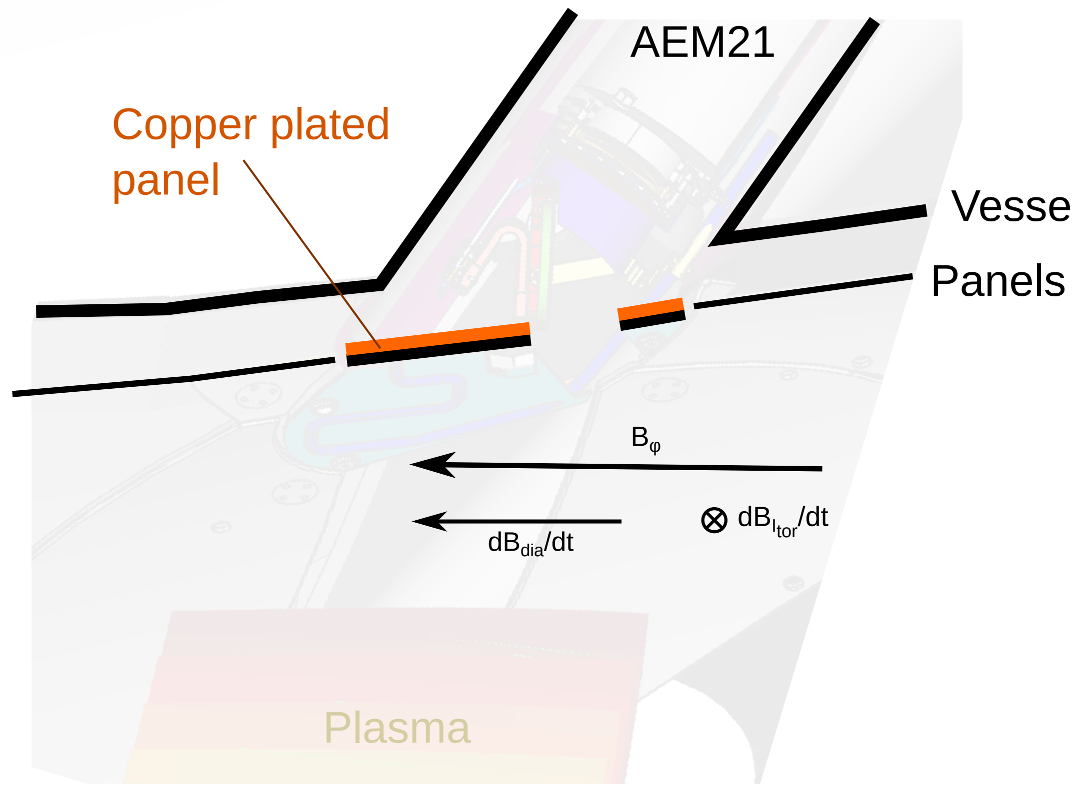
--> No conceivable mechanical failure

Worst case: Shutter opens briefly against pneumatic drive.

Forces due to fast current shutdown

4) AEM21 Panel:
- Copper plated stainless steel panel.
- Follows contour of panels --> dB_{Itor}/dt and dB_{Idia}/dt are both ~parallel to surface.
- Mounted by 3 panel mounts welded to PG.





Forces due to fast current shutdown

5) Copper thermal straps:

Two small copper blocks screwed firmly (2x M4+) to shutter or to immersion tube structure:

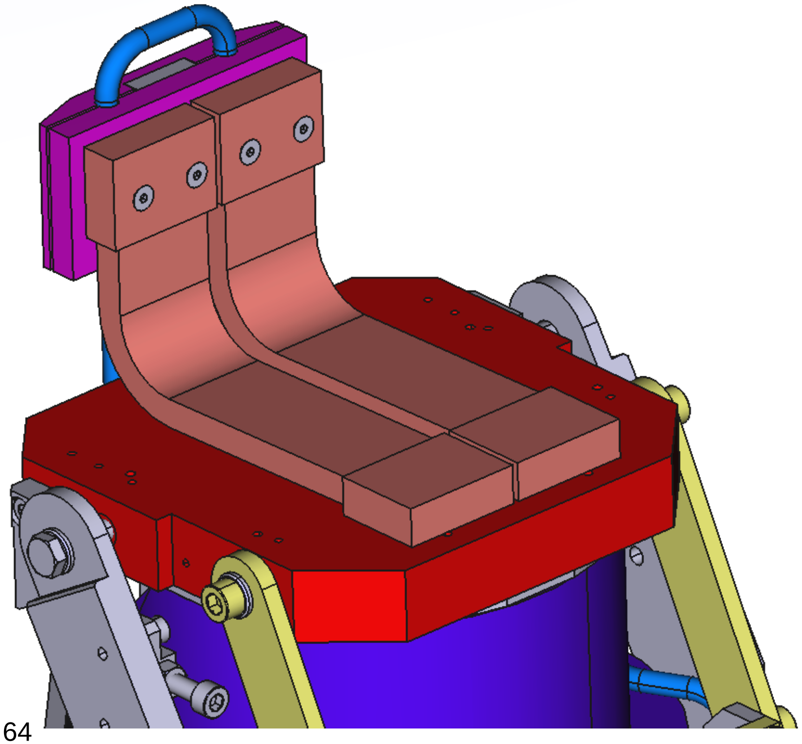
- Much smaller than previous calculations --> No significant moment transferred to structure.

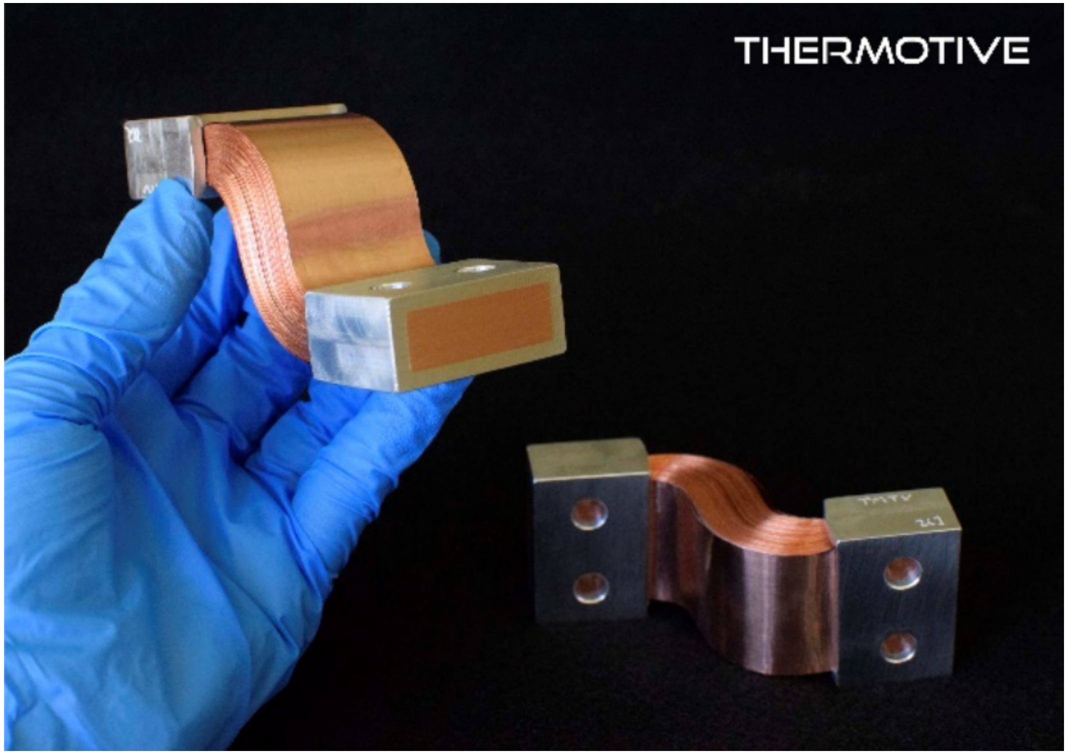
Many thin (0.2mm) foils of strap:

- Possible movement of flexible foils, but unlikely to result in significant force.

Absolute worst case: Broken foils, reduced cooling that will be detected by thermocouple on shutter.

--> No significant risk





Notes

KKL notes:
Medienabsprerrung Handvetil seitens TD, nicht im letzten 1m.
Letzen 1m muss bei DE angemeldet.
12 l /min max flow rate
40bar prüfdruck
20bar Betriebsdruck
Alles im Hausmittelung

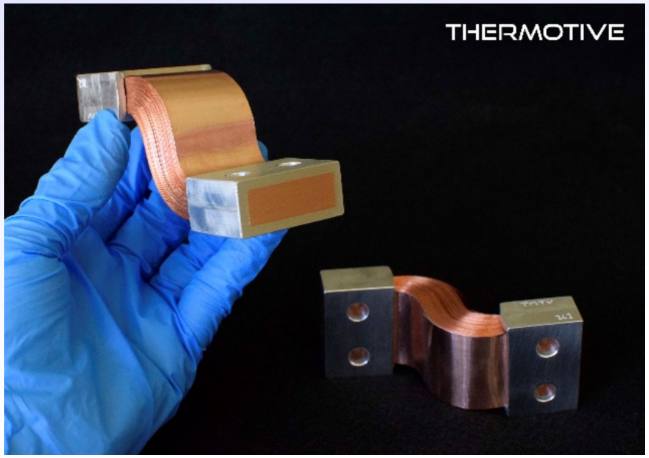
Connections: (from 1-ACK60-S1000)
QSK AEA21 - No KKL needed - 1-ACK62KA005KR09 [x4]
QMR AEA21 - Frontplate - 1-ACK62KA005KR09 [x4]
QSK AEM21 - Frontplate - 1-ACK62KA005KR27 [Only]
QSK AEM21 - Tauchrohr - **?? - None assigned!**!
QSC AEM41 - 1-ACK64KA005KR67 [Only]

QYB - AET20 - 1-ACK62KA009KR23 [Only]
QYB - AET21 - 1-ACK62KA005KR23 [Only]
QHF - AEN21 - 1-ACK62KA005KR15 [Only] - (Currently as 'Visible Spec Bulk')

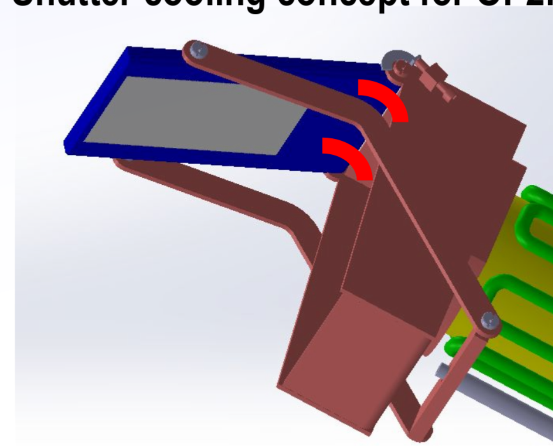
Thermal Straps

Some calculations done for similar solution on Gas Puff Imaging [Stechow, CDR]

Copper thermal straps: 111/L W/K conductance



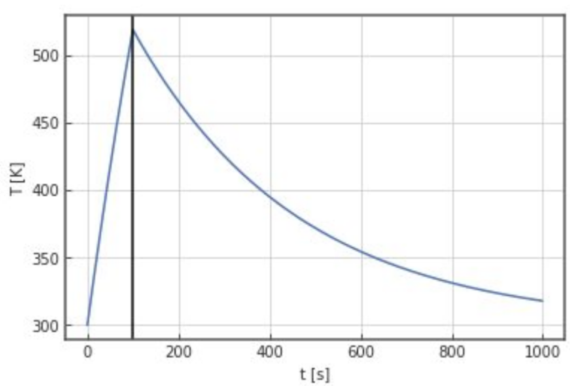
Shutter cooling concept for OP2.0/2.1



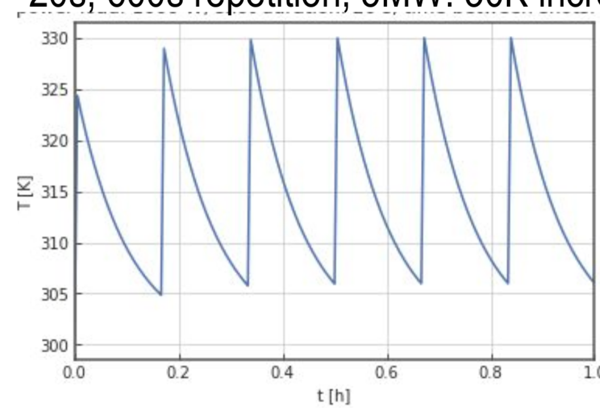
Model calculation for OP2.1 heat loads

plasma → radiation: 100 kW/m^2 → mirror + shutter (+ thermocouple) → conduction (thermal strap) → cooled component (300 K)

2kW total power
100s, 10MW: 220K increase, cooldown 10 min.

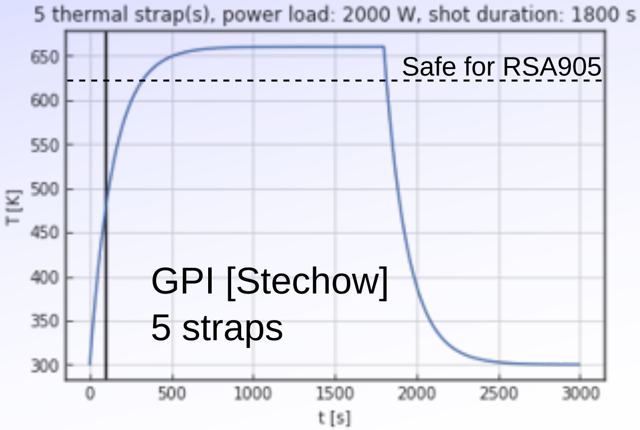


2 x 11 W/K conductance
20s, 600s repetition, 5MW: 30K increase

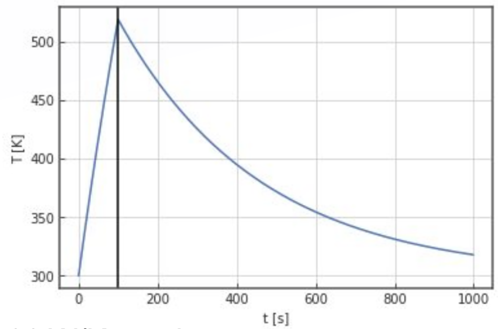


Thermal Straps

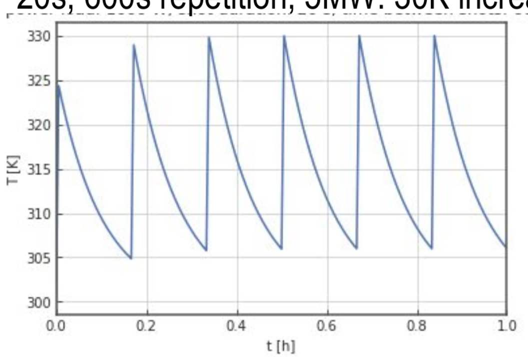
Some calculations done for similar solution on Gas Puff Imaging [Stechow, CDR]



2kW total power
100s, 10MW: 220K increase, cooldown 10 min.



2 x 11 W/K conductance
20s, 600s repetition, 5MW: 30K increase



- 2 straps not sufficient to balance steady-state heat load.
  --> Equilibrium ~600'C.

- 5 straps would be needed to stay below 350'C (OK for RSA905) in equilibrium.

- 2 straps for 100s: ~250'C but requires ~10min cooldown between shots.