QSK (CXRS) - Conceptual Design Review OP2

(Ladungsaustauschspektroskopie am Neutralheizstrahl)

CDR 06.02.2020

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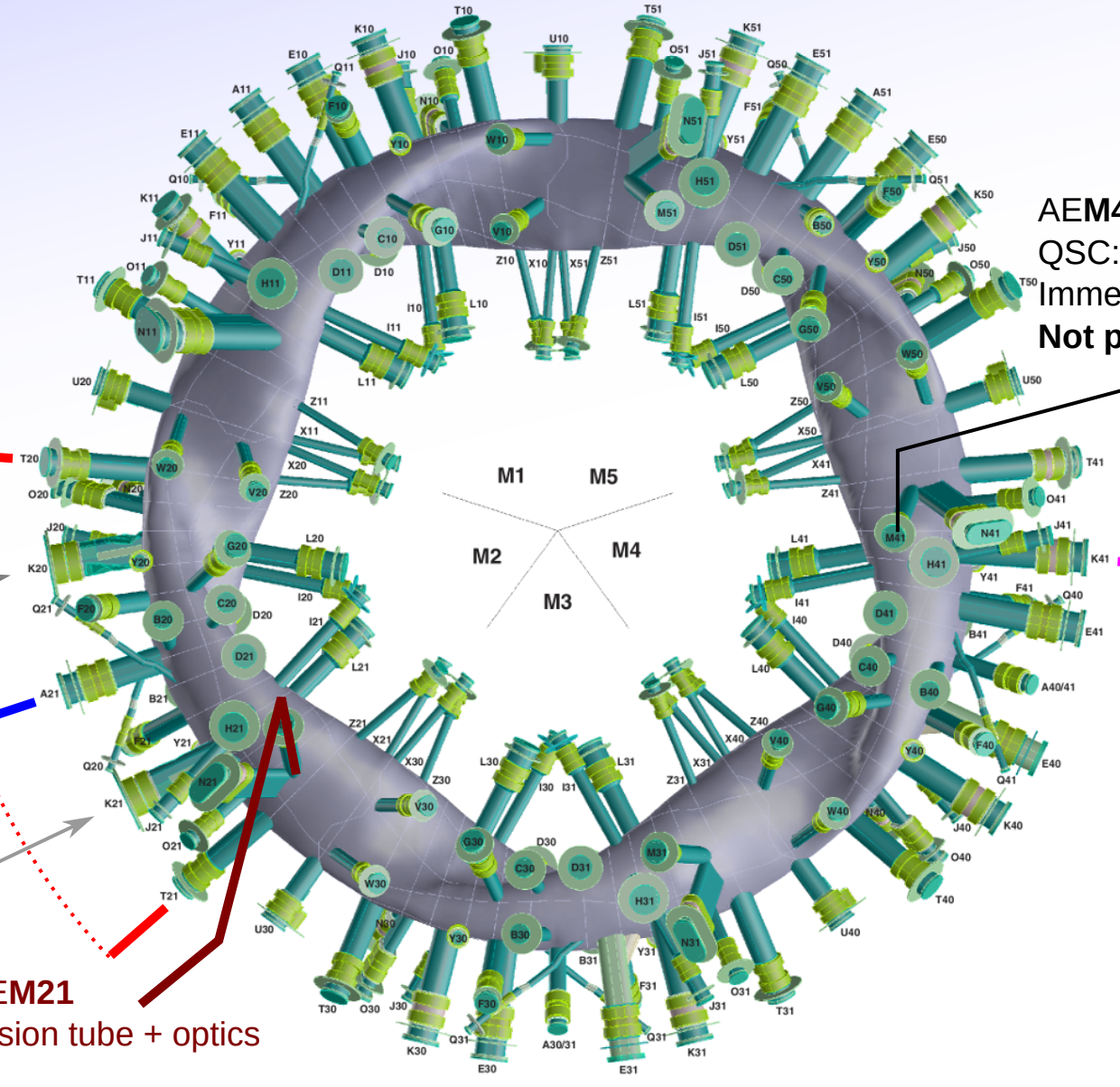
Component Overview



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

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

RuDIX

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!

Changes for OP2+

Upgrade for OP2 consists of 4 distinct changes:

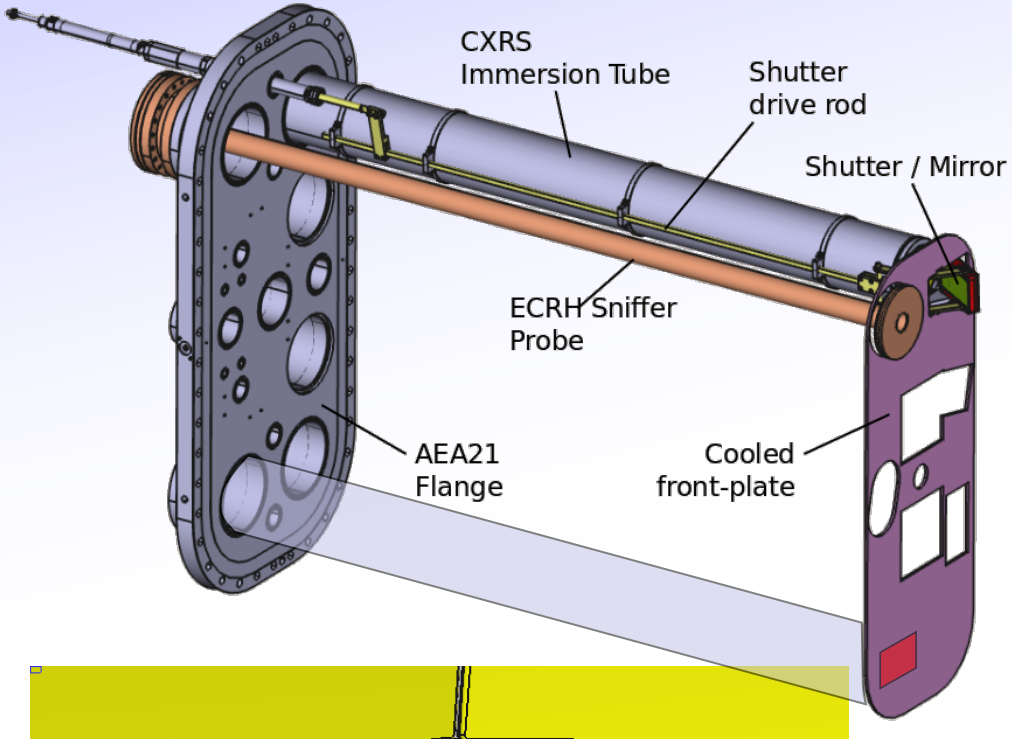
1) Add cooling to existing AEA21 components (K1):
- Thermal straps on shutter.

2) Add cooling to existing AEM21 components (K2):
- Water-cooled panel.
- Thermal straps on shutter + water citcuit.

3) Addition of 2nd immersion tube to AEA21 to view NI20.

4) Rebuild of AET20/21 tubes (K3) due to redesign of HST.

AEA21

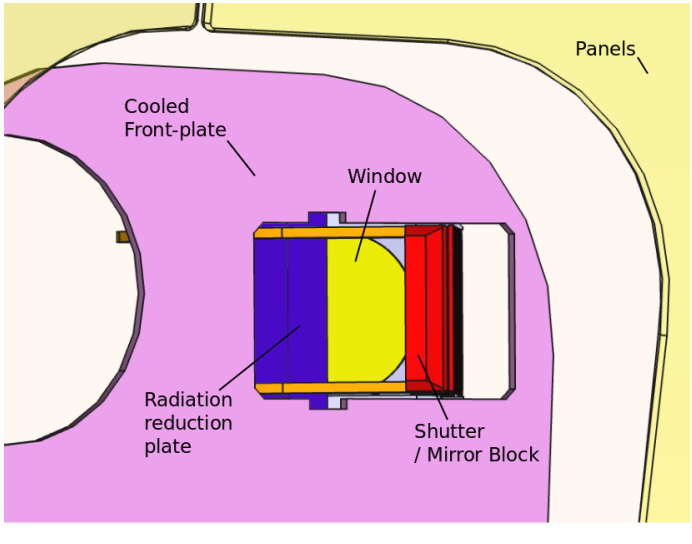


2 immersion tubes:
AEA21-O: Upper immersion tube from OP1.2b.
AEA21-U: Copy of AEA21-O - discussed later.

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

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

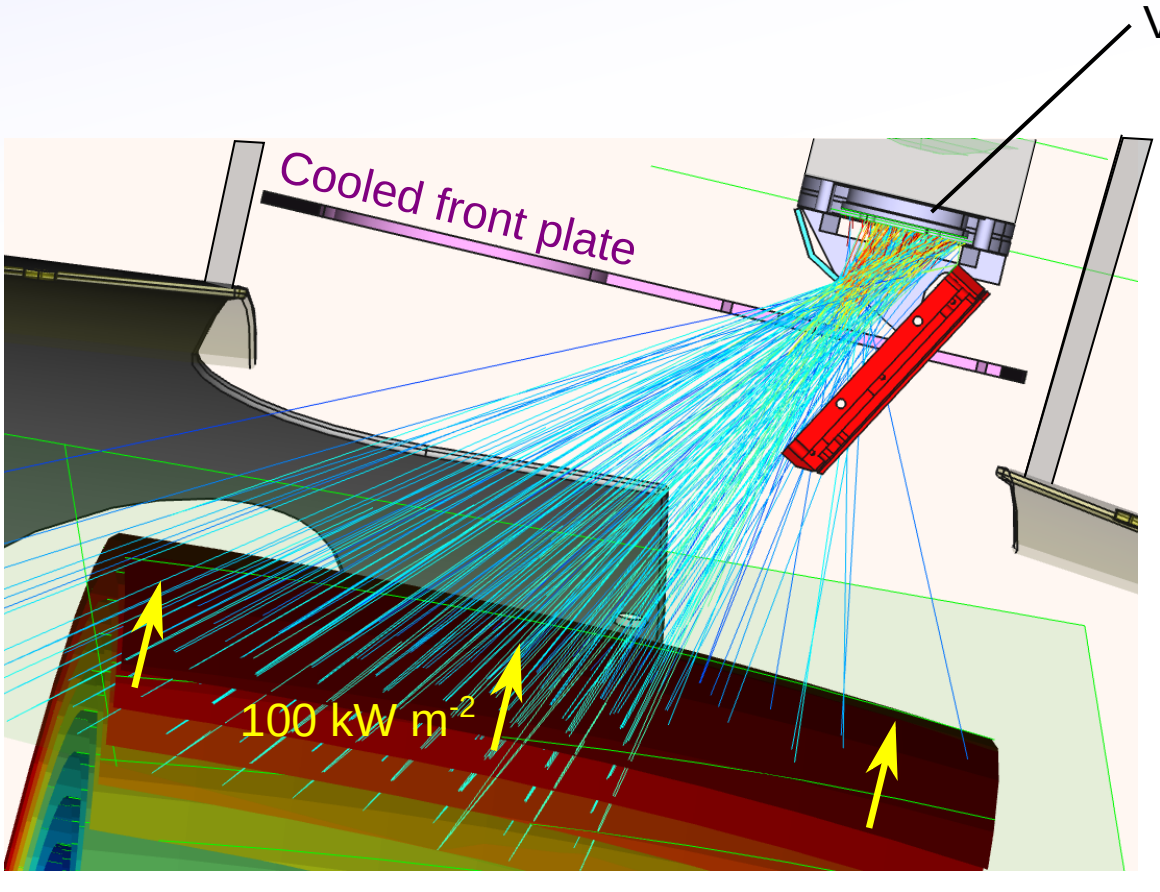
- Shutter contains aluminium (RSA905) mirror and should remain < 300°C.

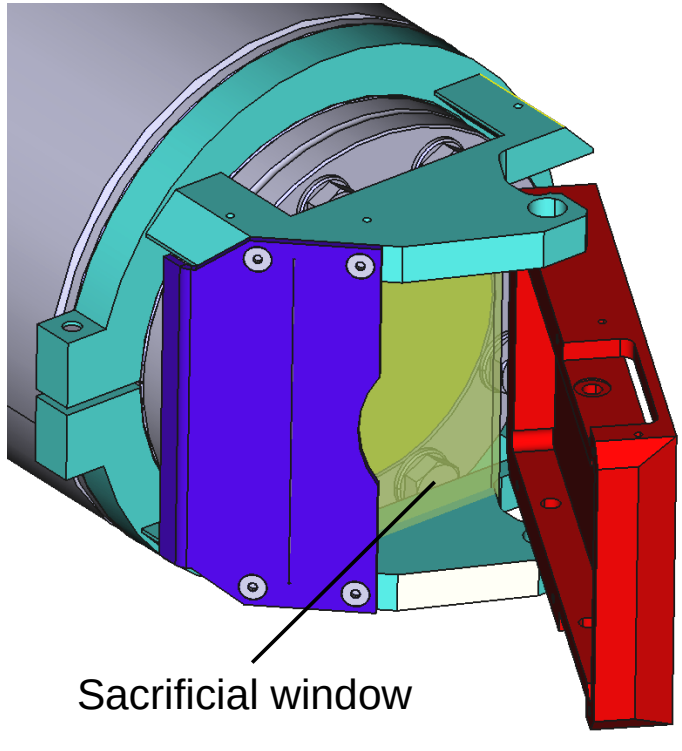


AEA21 - Vacuum window

- Vacuum window only exposed during **20s** open period.
- 100kW/m^2 at plasma boundary --> **20W** on window.
- **30ºC / min** heating rate = 5ºC in 10 seconds, but well above **2ºC / min** specification of window.

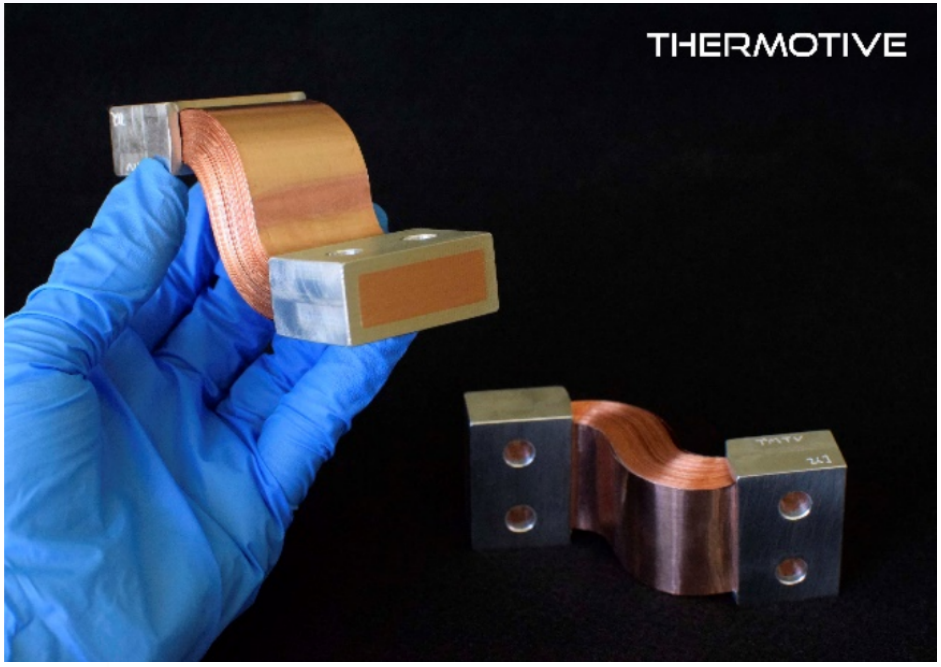
- Add 'sacrificial window' (glass plate) in front of vacuum window to absorb most of power (XUV-VUV)
- Cycle time of NBI ~10 min - enough time to cool by radiation or conduction to surrounding metal.

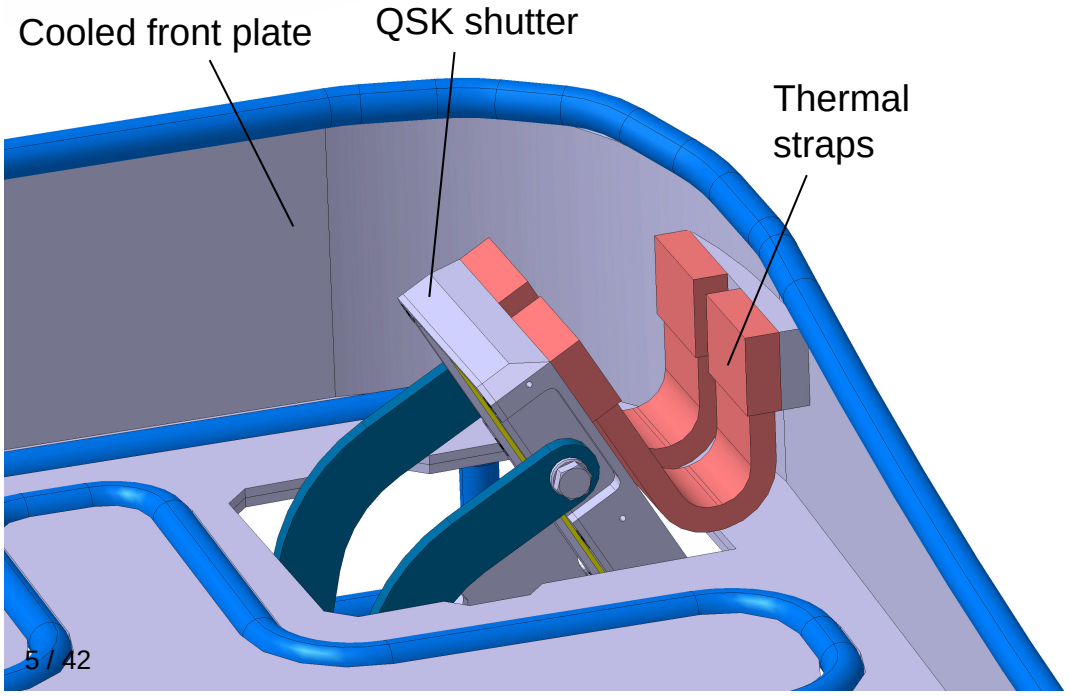




AEA21 - Shutter - Copper thermal straps

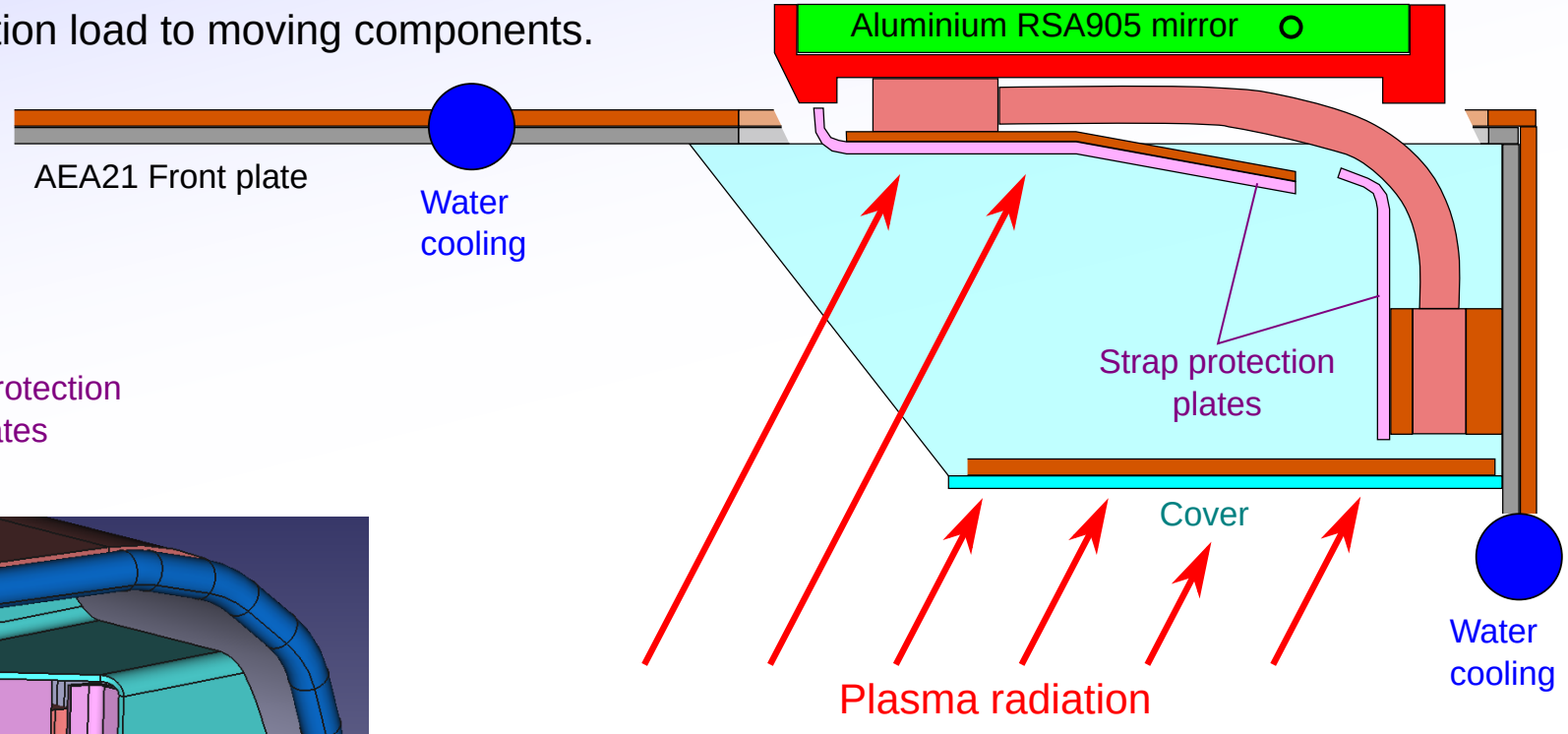
When closed, back side of shutter exposed to full 100kW m^{-2} x 30min.
Shutter holds RSA905 aluminium mirror --> requires cooling.

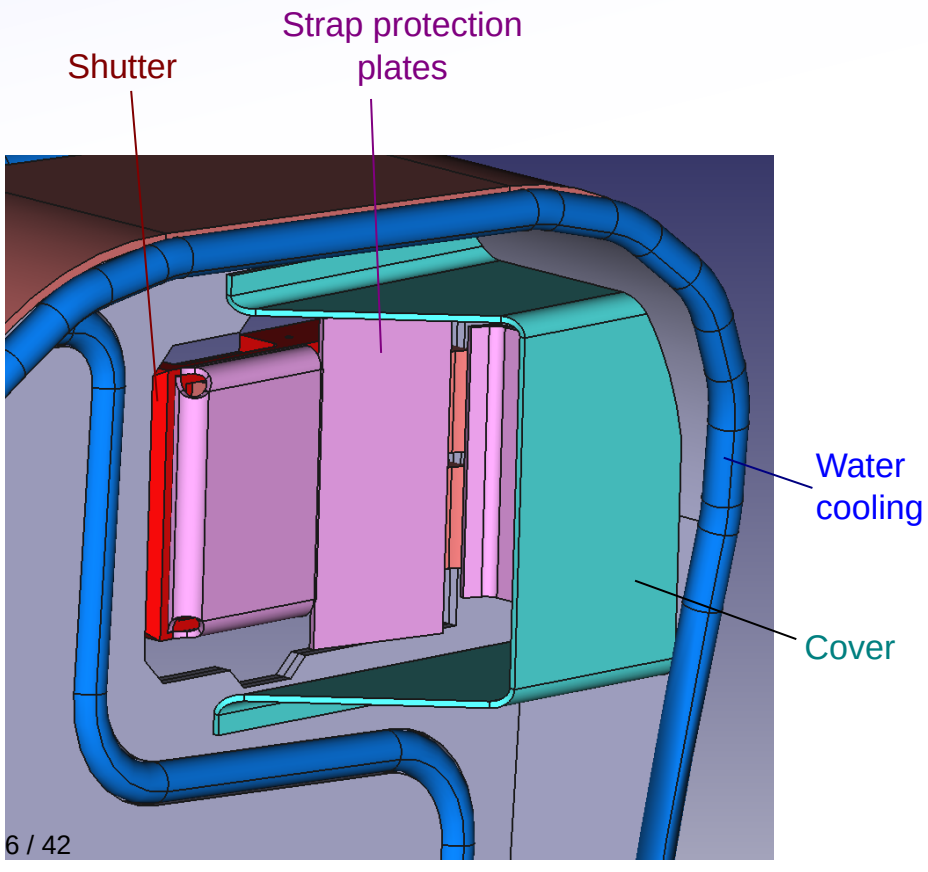




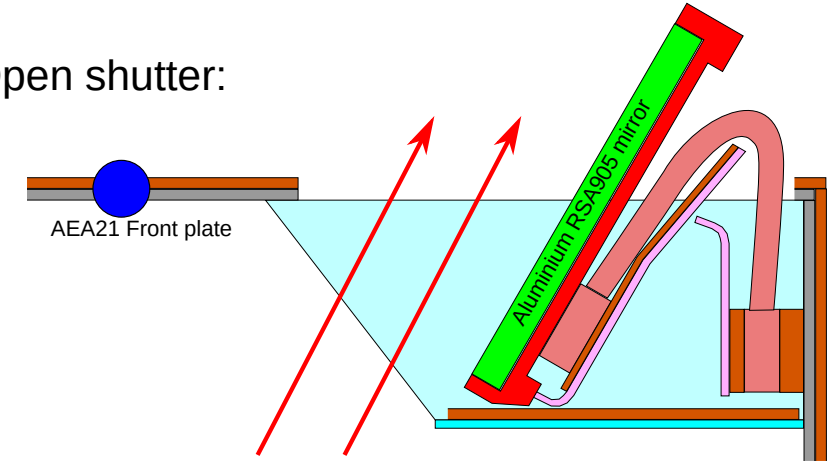
AEA21 - Concept

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





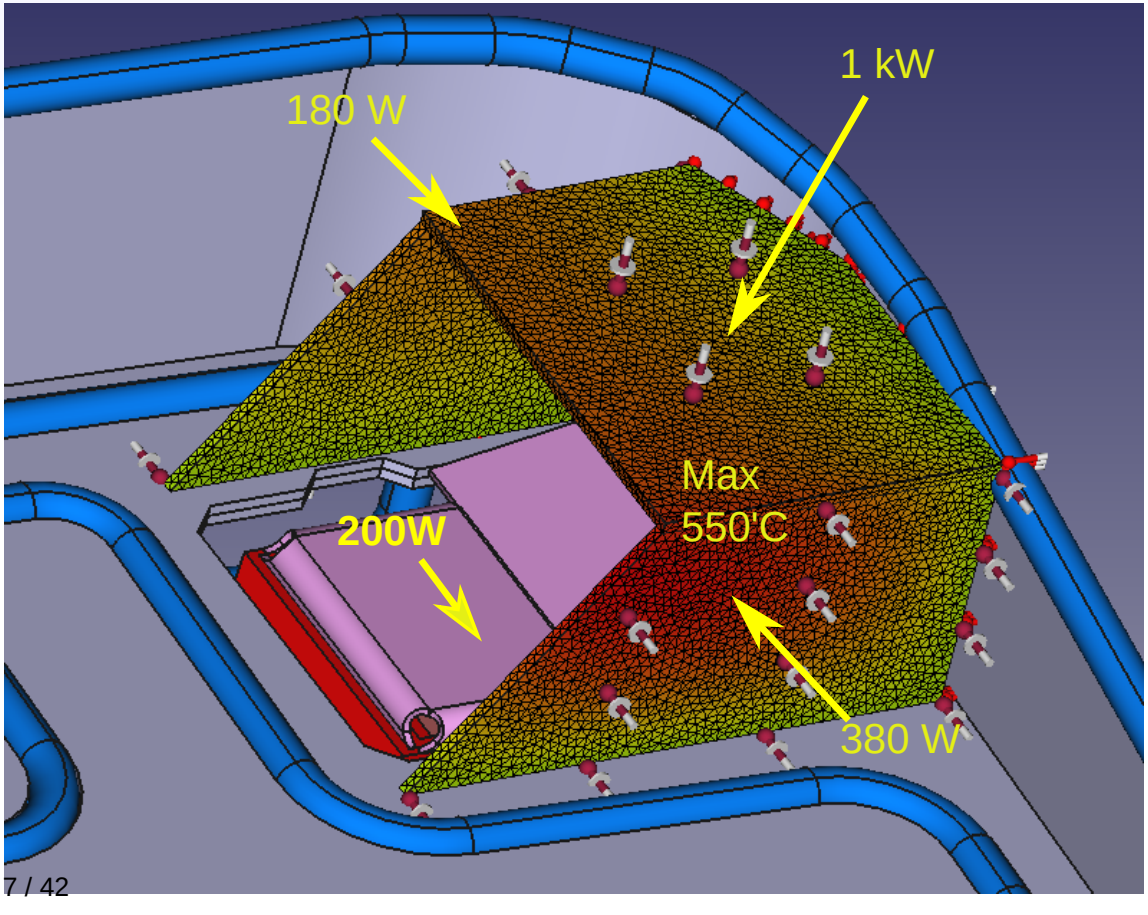
Open shutter:

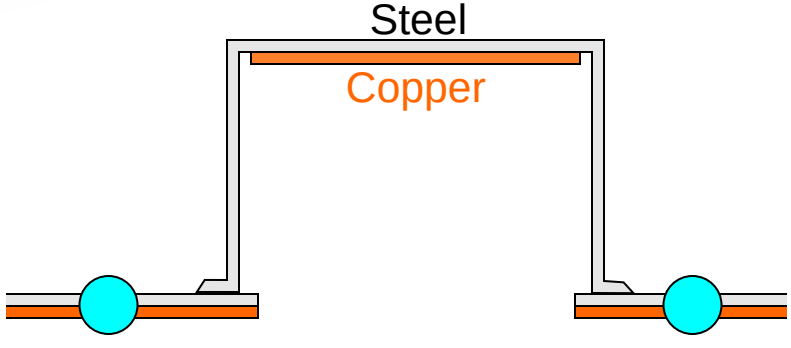


AEA21 - Cover

Ray traced 100kW m^{-2} at plasma boundary to cover:
Cover: 1.6 kW
Shutter etc. : 200W (all parts cooled by straps)

FEM thermal calculation of cover gives max 550'C, if copper plated under top of cover.



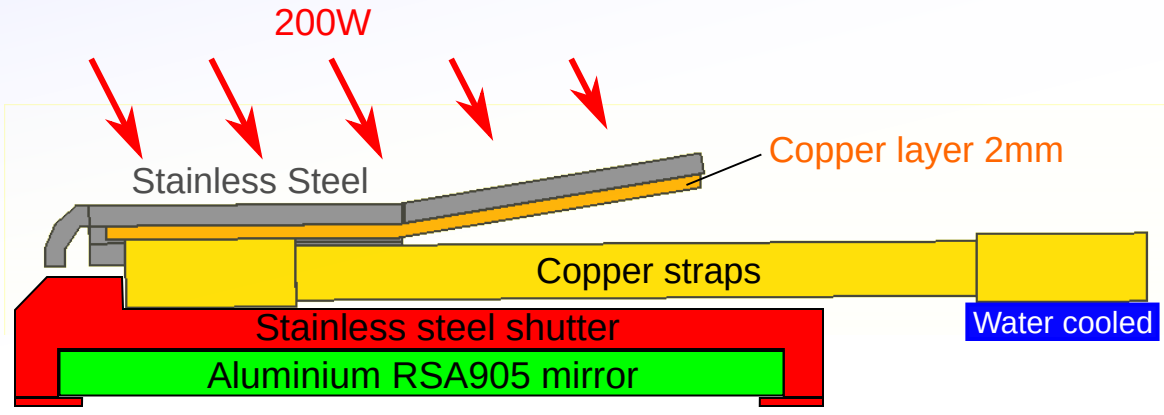


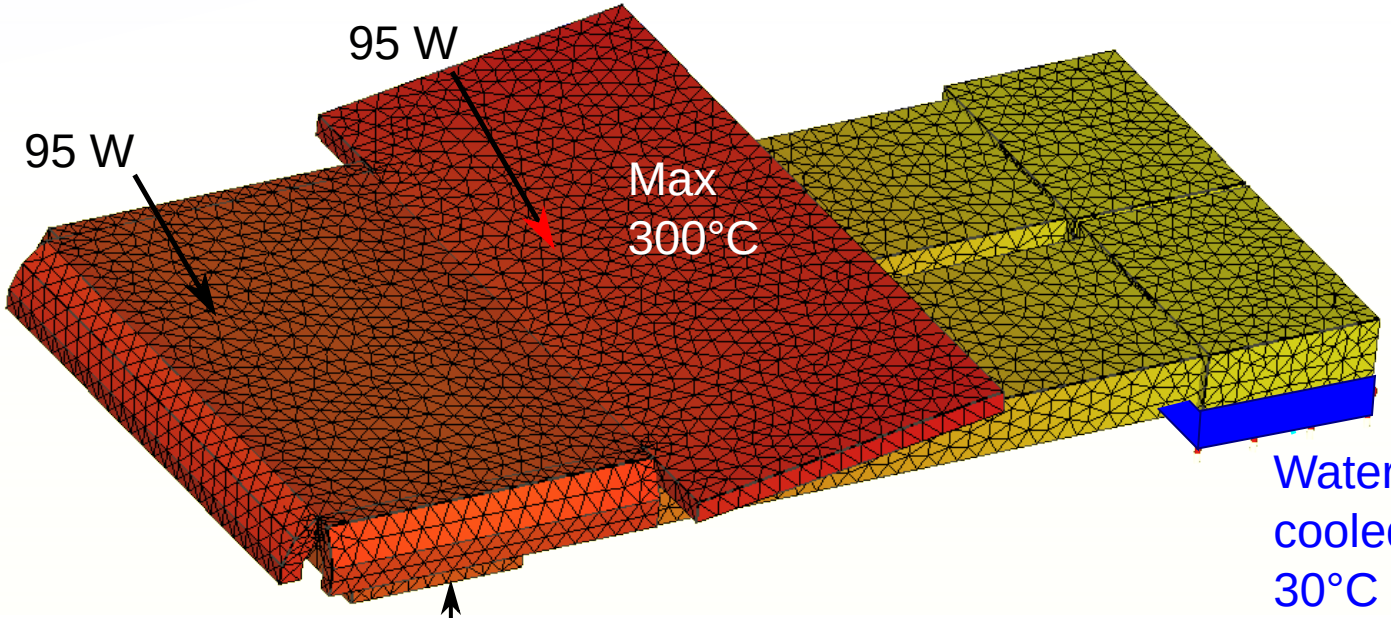
Only 3mm Stainless steel --> 1200°C

With 3mm copper layer on
inside of top cover --> 550°C

AEA21 - Strap protection plates

Heat loads to protection plate ~200W
Thermal calculation for steady state gives ~300'C max



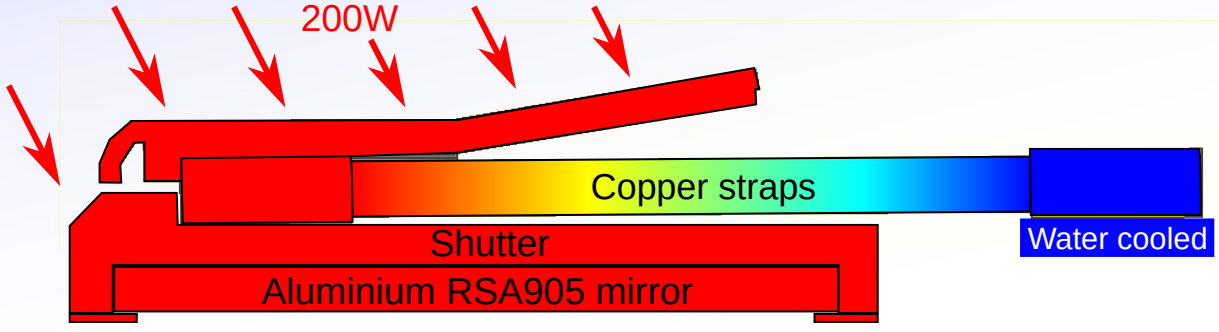


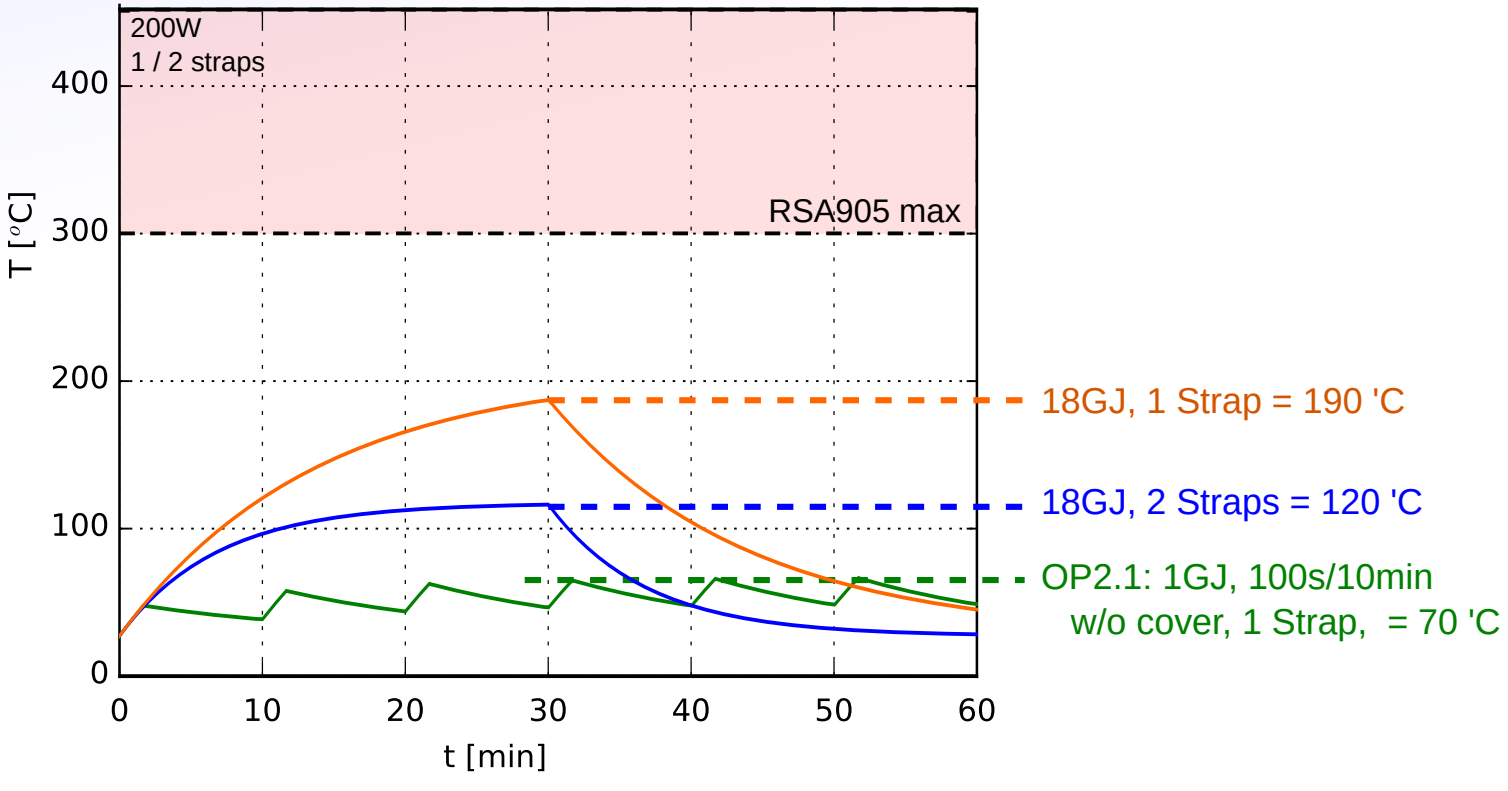
Mirror block connected to straps at ~ 200°C.
Direct radiation < 50W

AEA21 - Thermal strap

Worst case temperature of mirror calculated assuming all 200W heating of shutter/mirror block.

Conductance of strap ~111/L W/K.
Mirror max T = 300°C





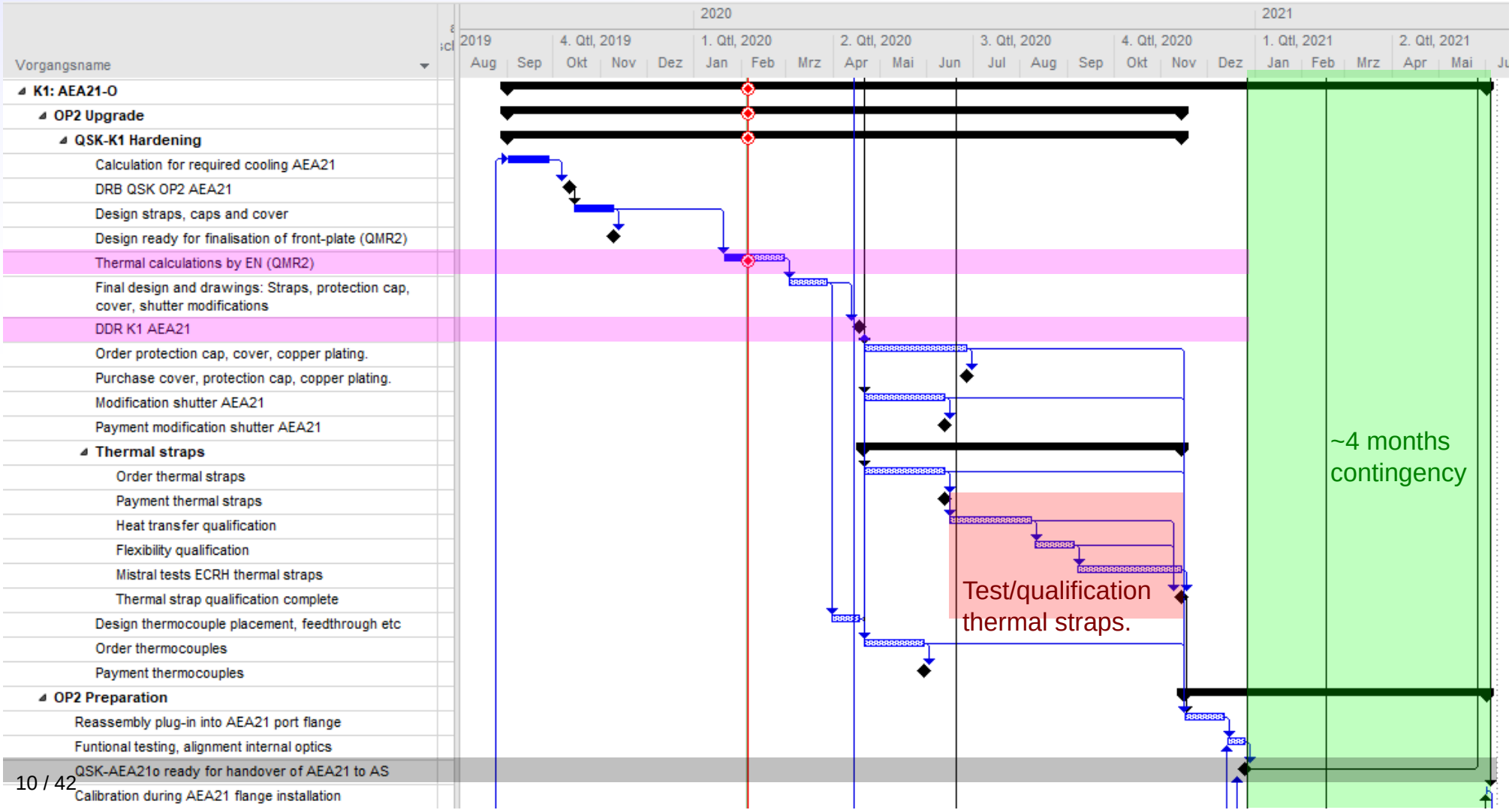
1) With 2 straps and cover, 18GJ is OK by x2
2) 1GJ is OK even with no cover and only 1 strap
Thermocouple will be installed in shutter to monitor temperature rise in OP2.1 --> confirm safety.

QSK AEA21 Cooling - Planning

Funding: 7k€ of 20k€ requested from contingency for QSK hardening.

Time plan:

- Expected DDR ready around April
- AEA21 handover to AS ready around Dec 2020 - giving ~ 4 months buffer as A21 is last flange to be closed.



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Upgrade for OP2 consists of 4 distinct changes:

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2) Add cooling to existing AEM21 components (K2):
- Water-cooled panel.
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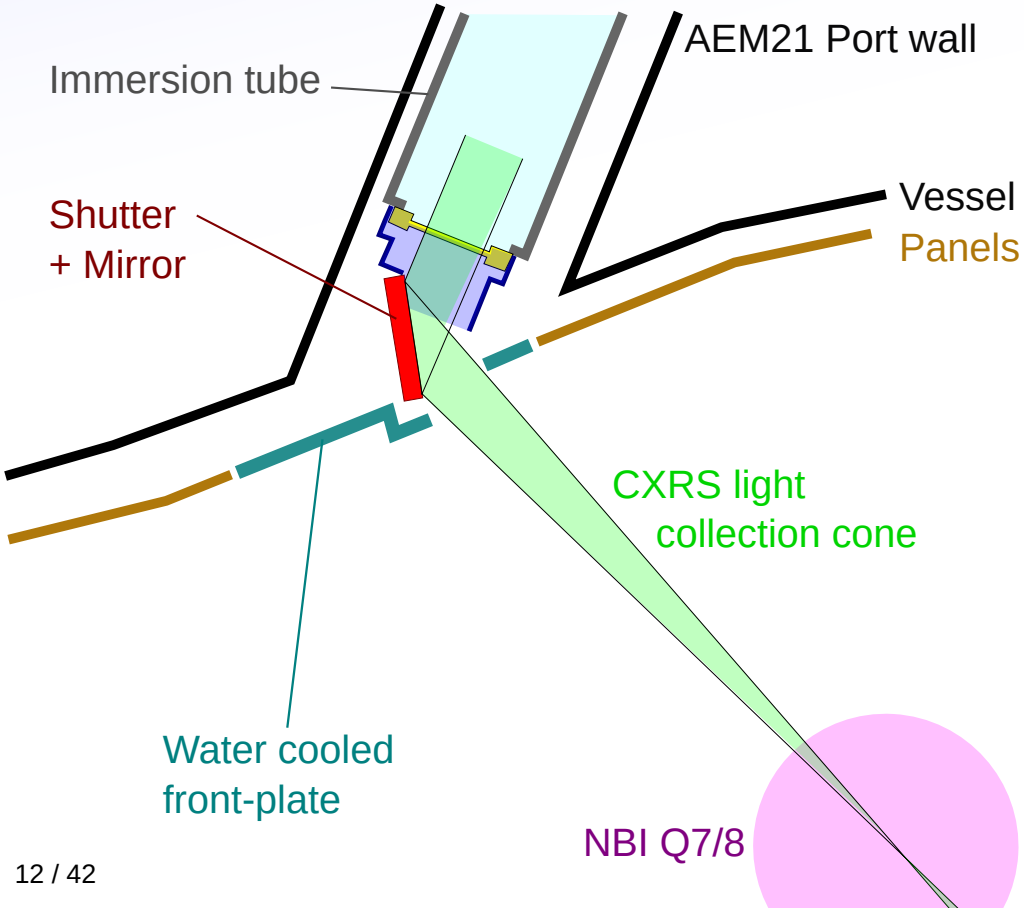
3) Addition of 2nd immersion tube to AEA21 to view NI20.

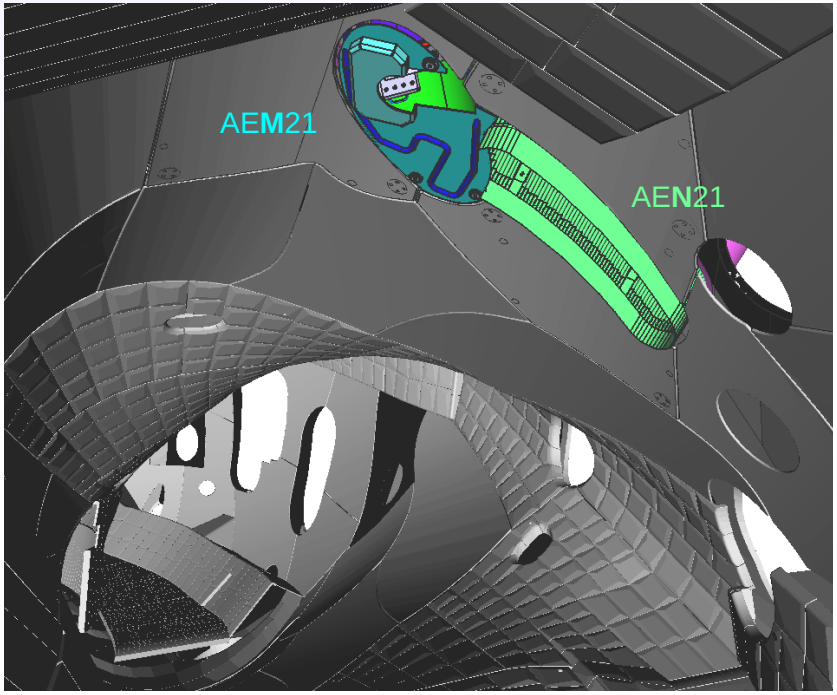
4) Rebuild of AET20/21 tubes (K3) due to redesign of HST.

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.

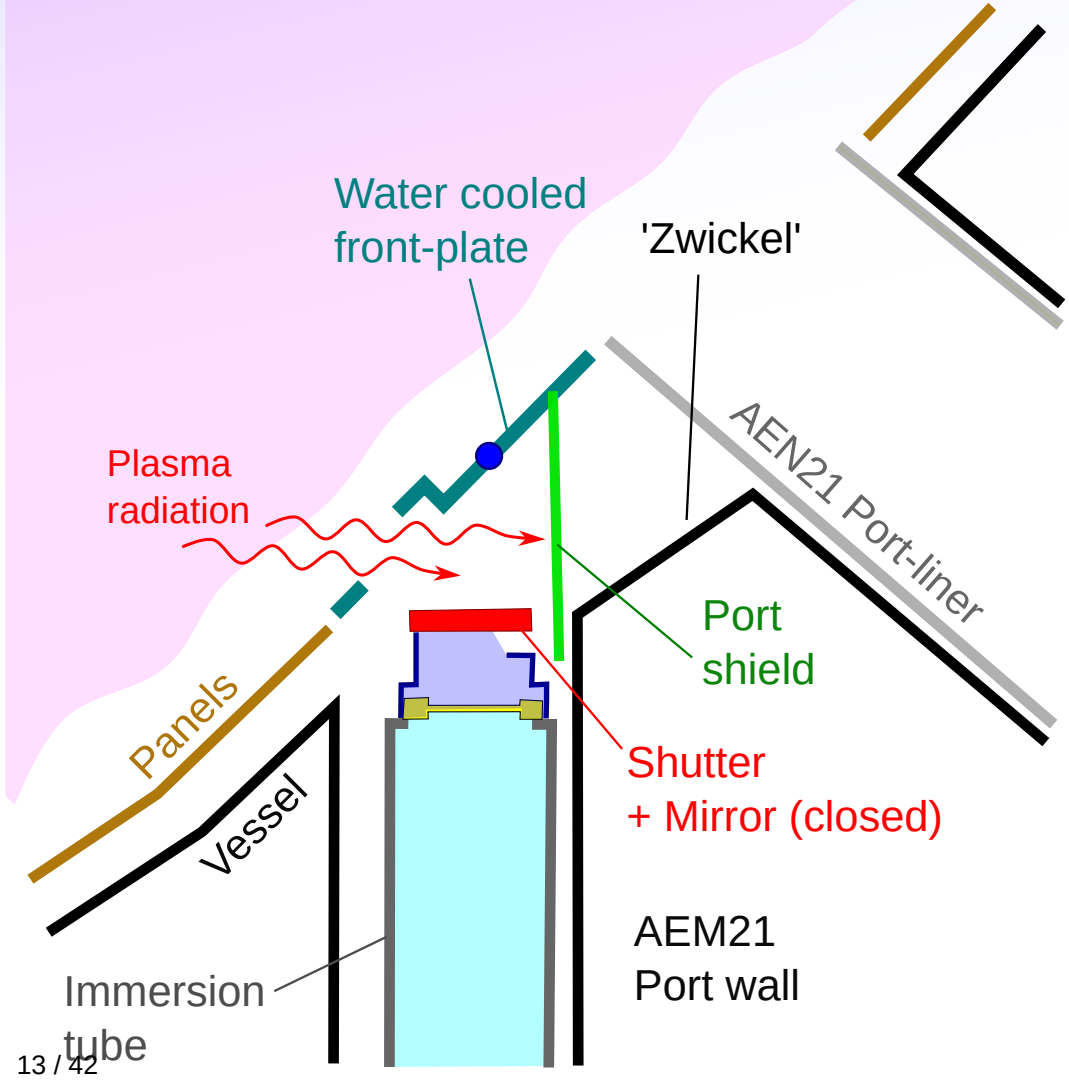


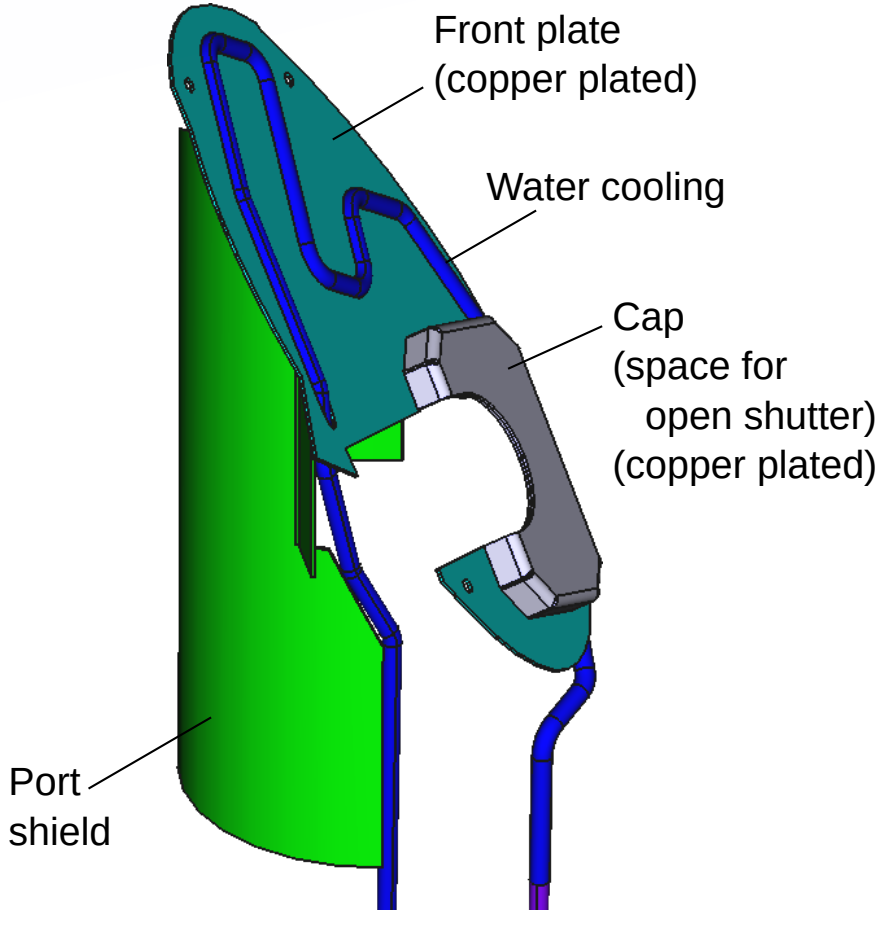


View including neighbouring AEN21 Portliner,

AEM21

Include back surface 'port shield' to protect port wall, 'zwickel' and welding seams. Together with AEN21 port-liner and it's gap protection fins (Spaltshutz/Rohrkragen), blocks most of heat load to vessel/port walls.

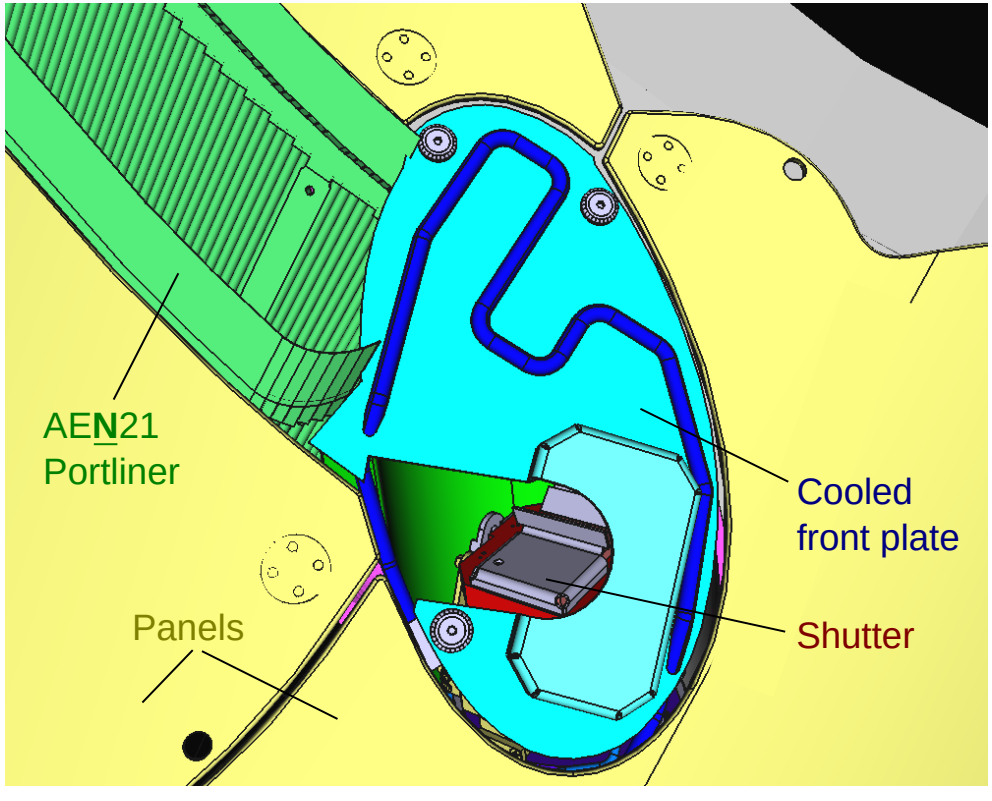


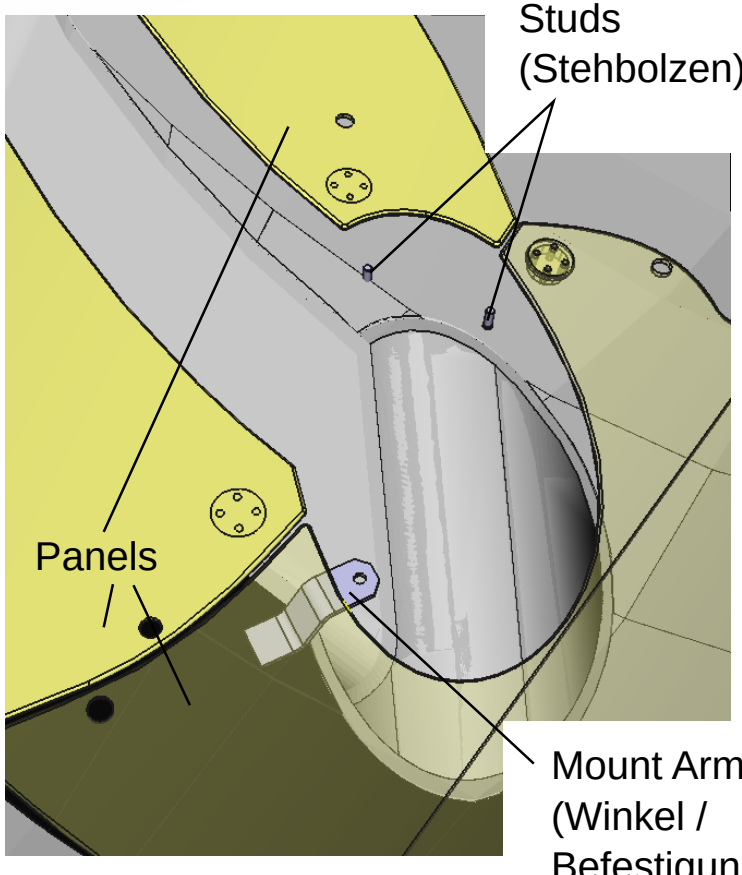


AEM21

- Front plate mounted on two bolts and metal bracket:
- Bolts and bracket to be installed before re-installation of surrounding panels (~Feb 21)
- Discussion with AS-Tech:
  - Need to provide bolts and brackets.
  - Some panel mount pieces available from AS.
  - Need to precisely define positioning.

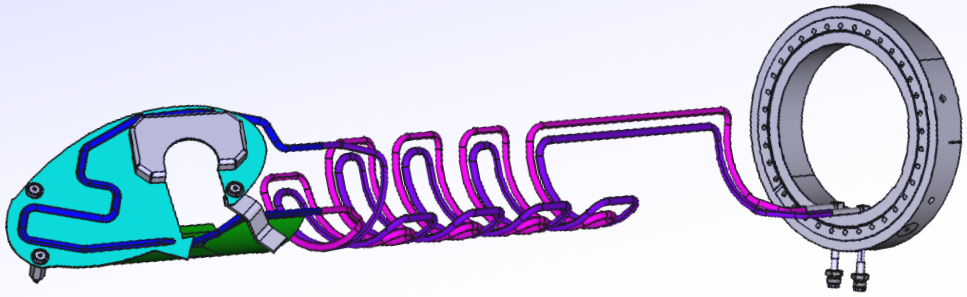
Head-on view (looking up at port from inside vessel):

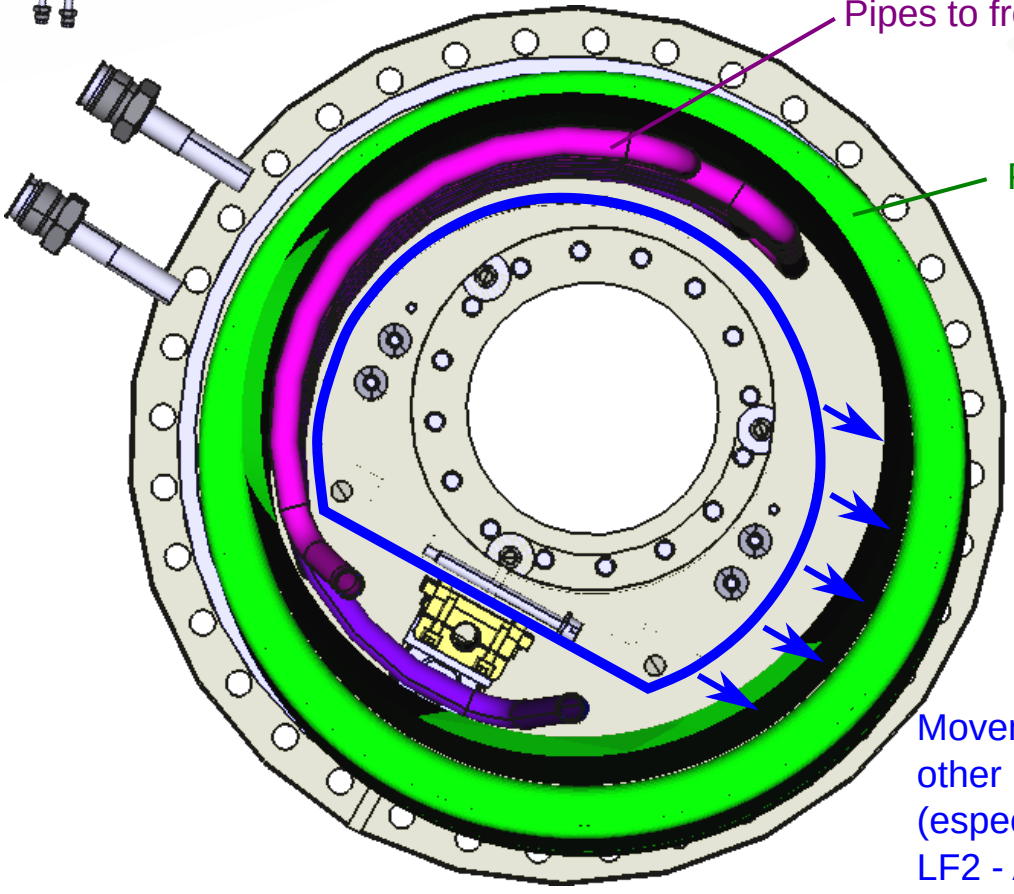


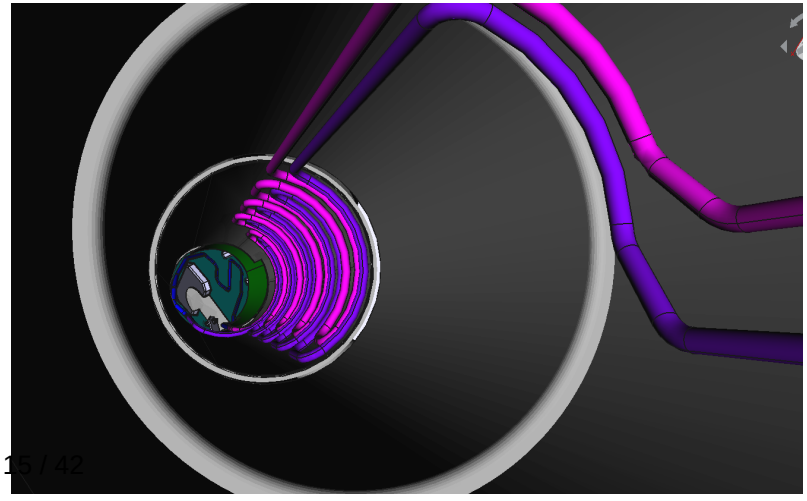


AEM21

- Space for water cooling pipes limited.
- Contact of immersion tube with pipes in LC2 (Ausheizen) --> stress on pipes join to panel.
- Solution: Pipes on side of tube with narrowest as-built gap. Tube moves away in other load cases.

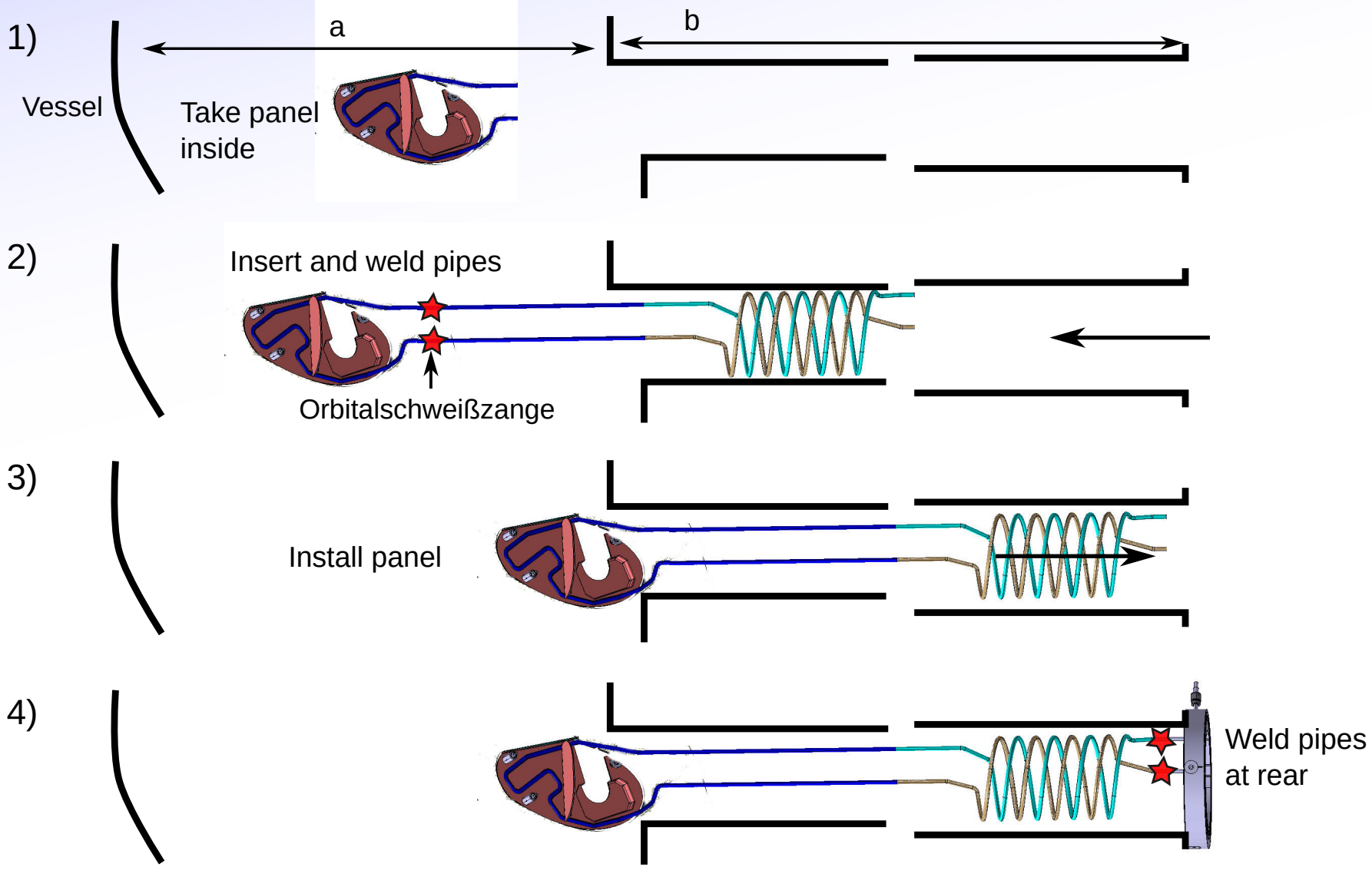






AEM21

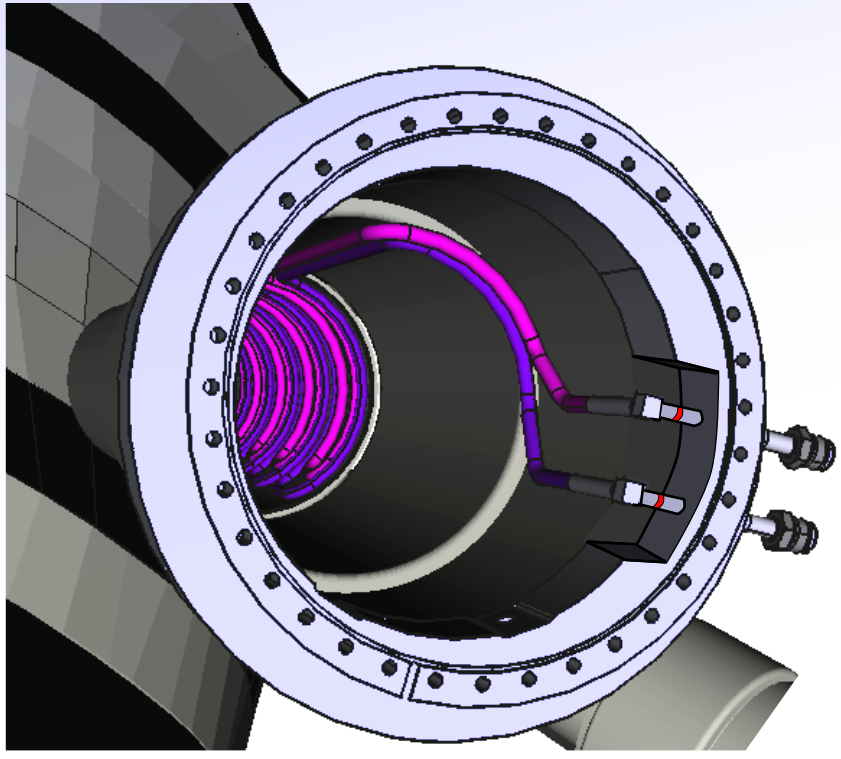
- Installation proceedure complicated by length of pipes:
  a << b: Pipes too long to be installed inside.

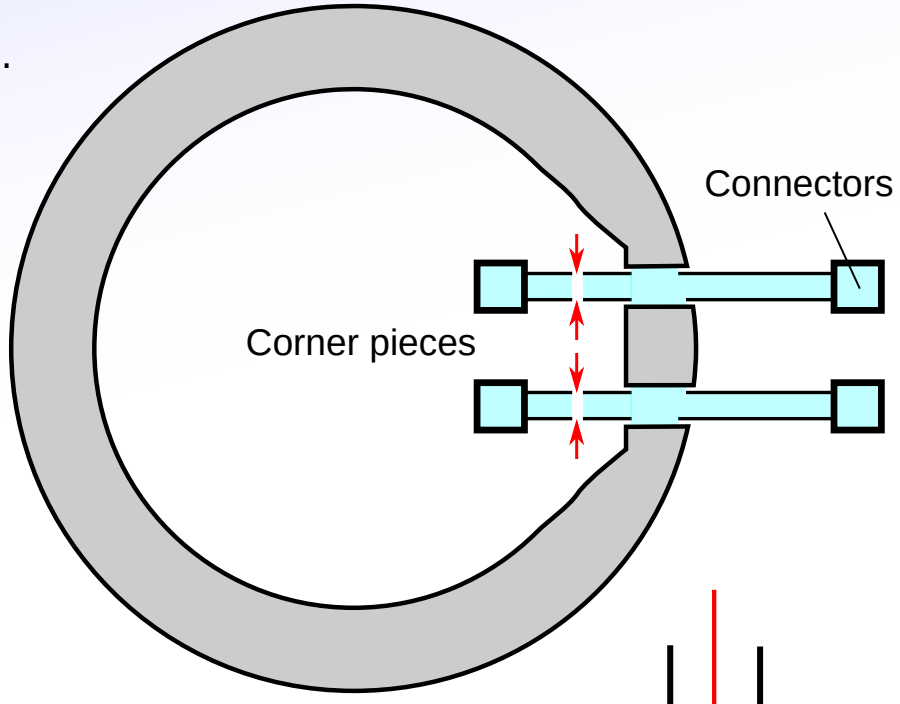


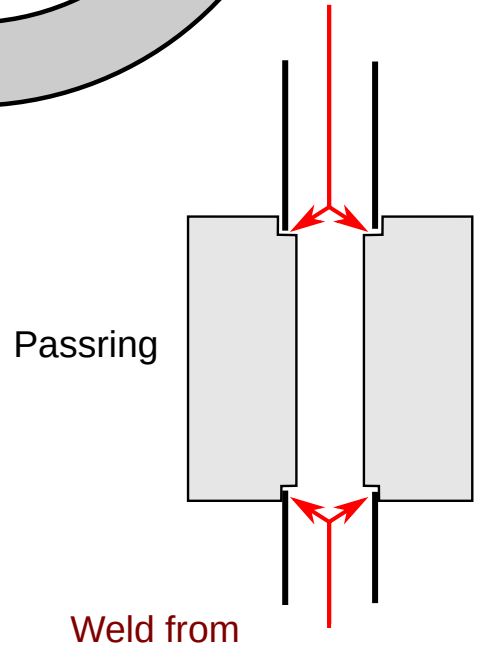
- TODO: Measure some length (b) in as-built port to set length of pipes so they can be installed unloaded.

AEM21 - Welding water lines at passring

Welding of pipes to passring:
- Use 'Orbitalschweißzangen' to weld inside and outside.

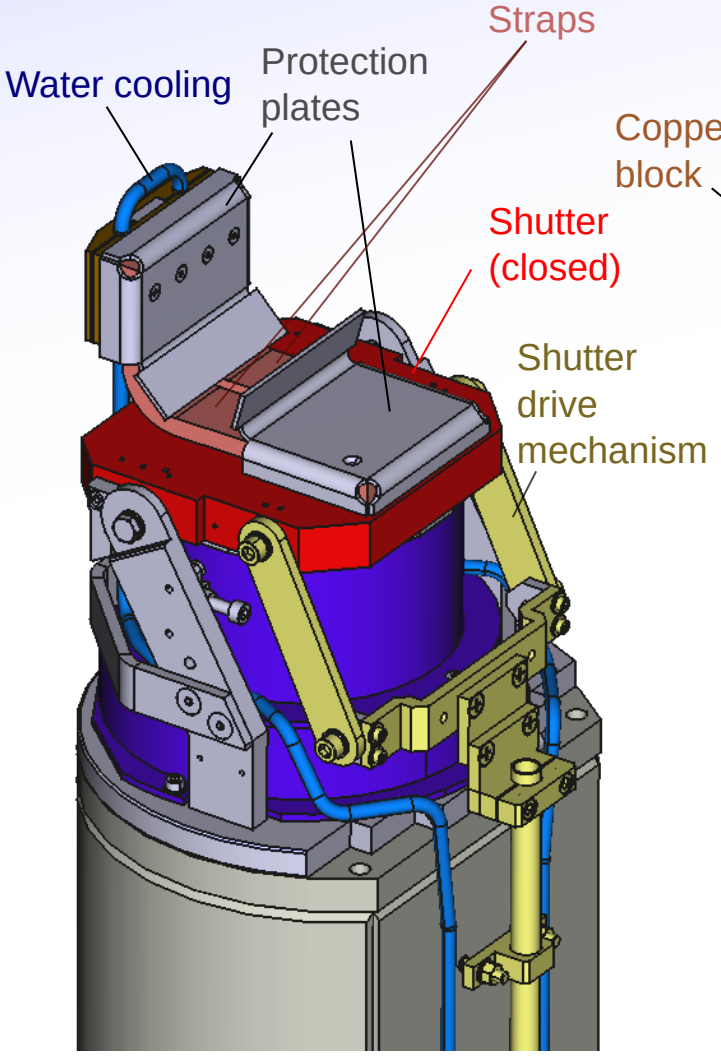


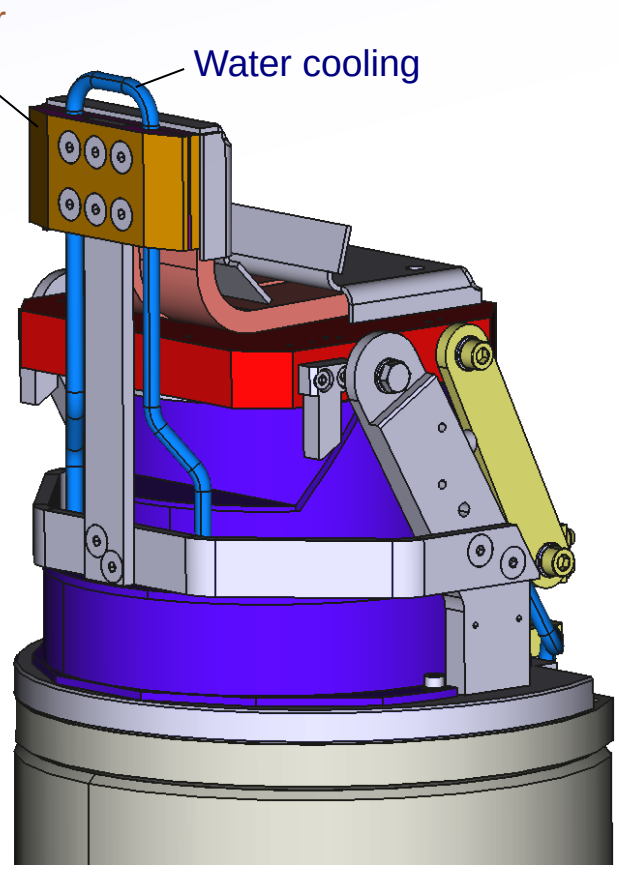


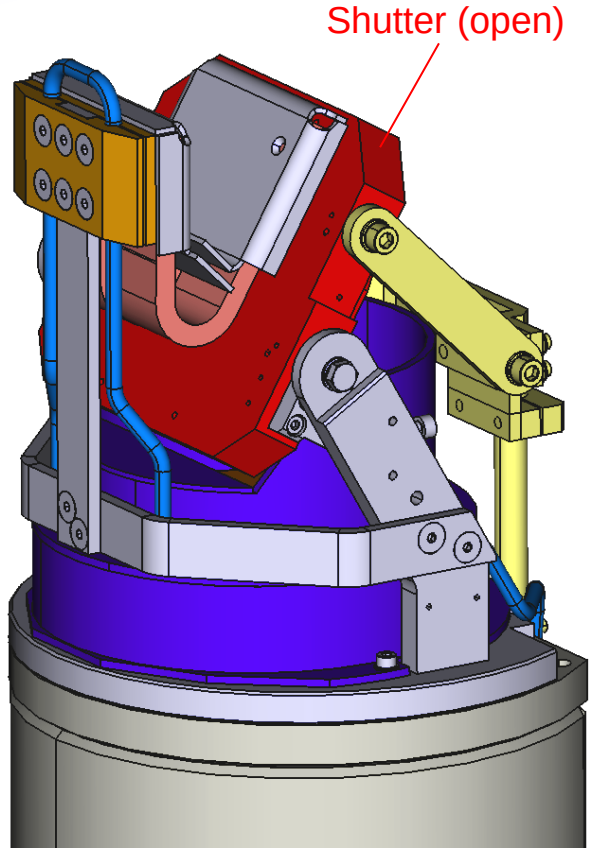


AEM21: Shutter cooling

- Cooling of shutter using 2 straps as for AEA21. Heat load to closed shutter is the same (~200W)
- Connect to copper block with dedicated cooling line.
- Protection plates to avoid exposure of copper straps to plasma.



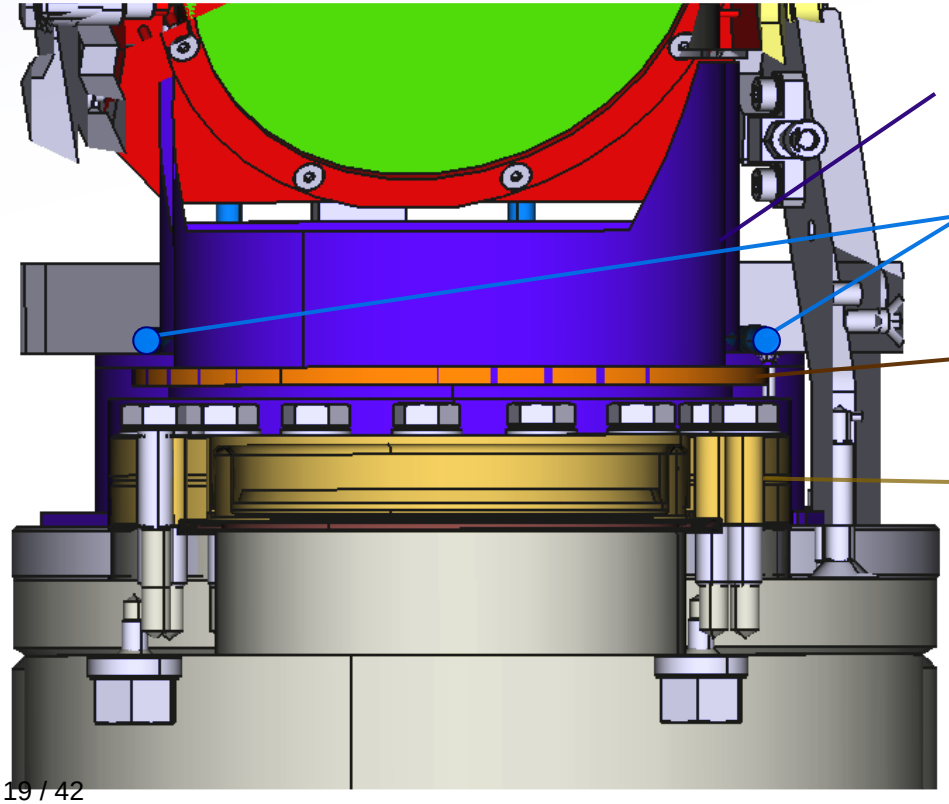


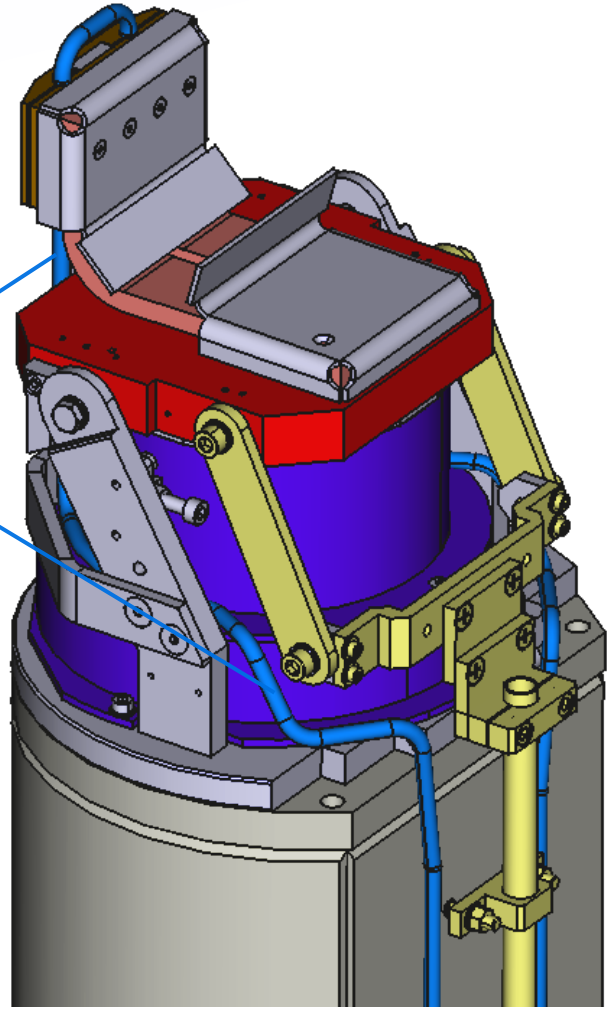


AEM21: Window exposure

- Window exposure also similar to AEA21 ~ 10 - 20W --> **30 K / min >> 2 K / min** specified.

- Install sacrificial window
- Protection collar sub-optimal in OP1.2b (Stahlblech)
  --> Redesign with sacrificial window holder and attached water cooling pipes (which run to shutter cooling block)

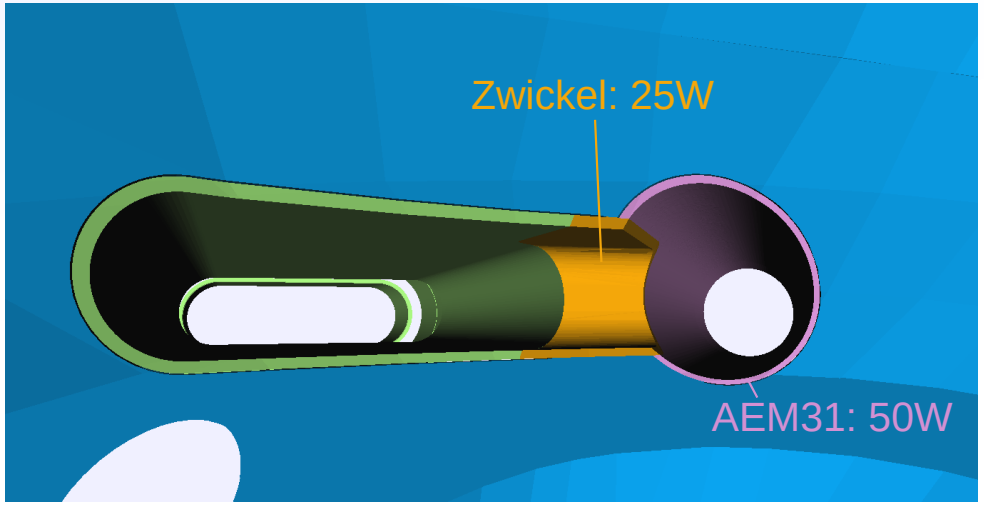




AEM21: Heat load - Vessel/Ports

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

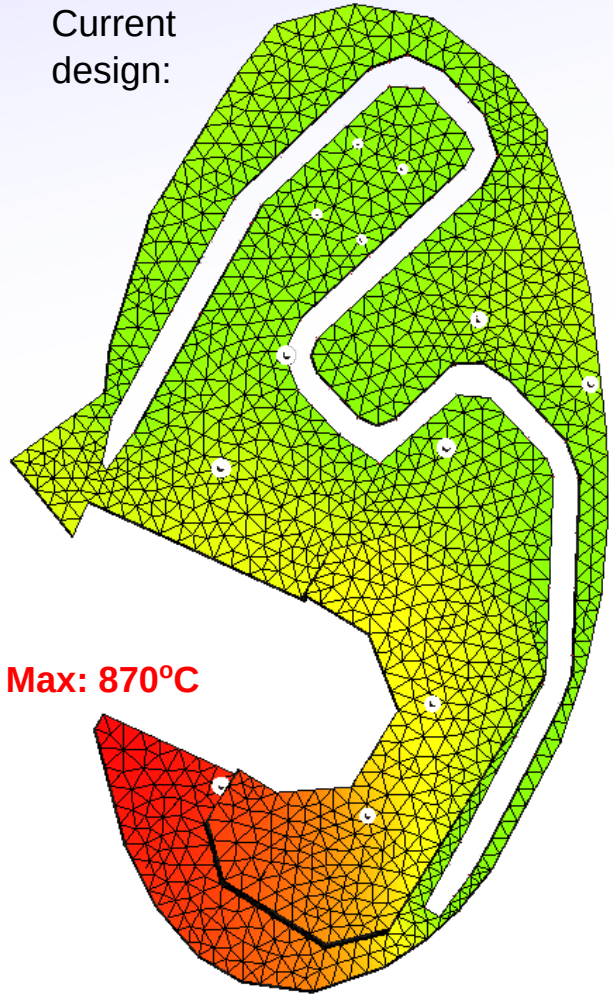
AEM21 port wall: 50 W [radExposure-portWalls (50x50x??)]
Zwickel: 25 W
= 75W to vessel walls



AEM21: Heat load - Front plate

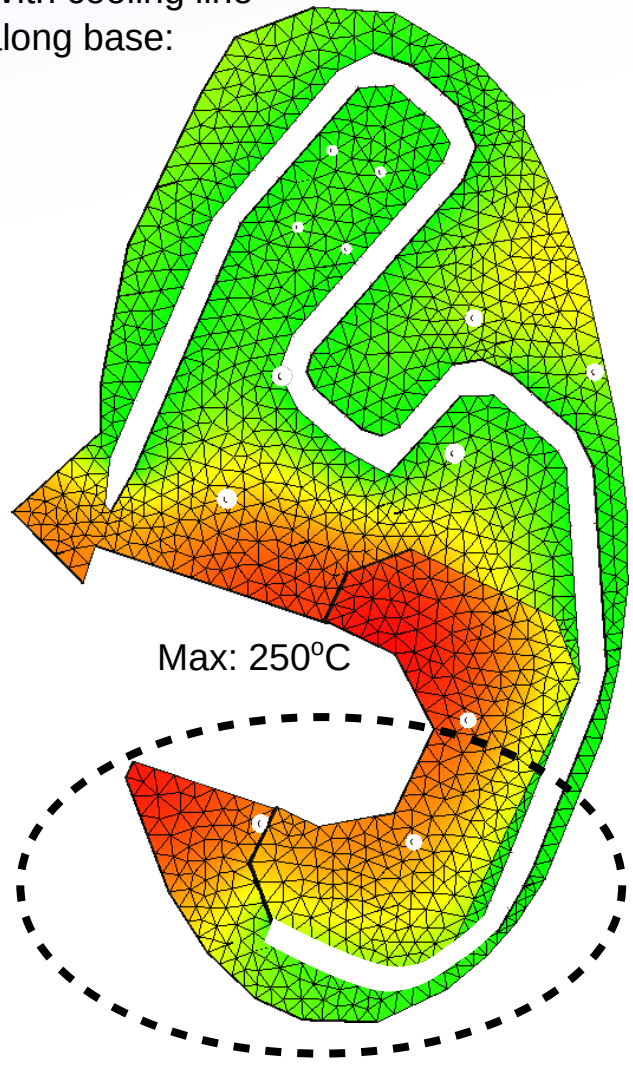
Ray tracing 100 kW m^{-2} from plasma surface to simplified model of all components: [radExposure-all30x30x30]
Total 5 kW heat load (~60 kW m^{-2})
Calculation: 2mm copper, no radiation exchange.

Current design:



Max: 870°C

With cooling line along base:

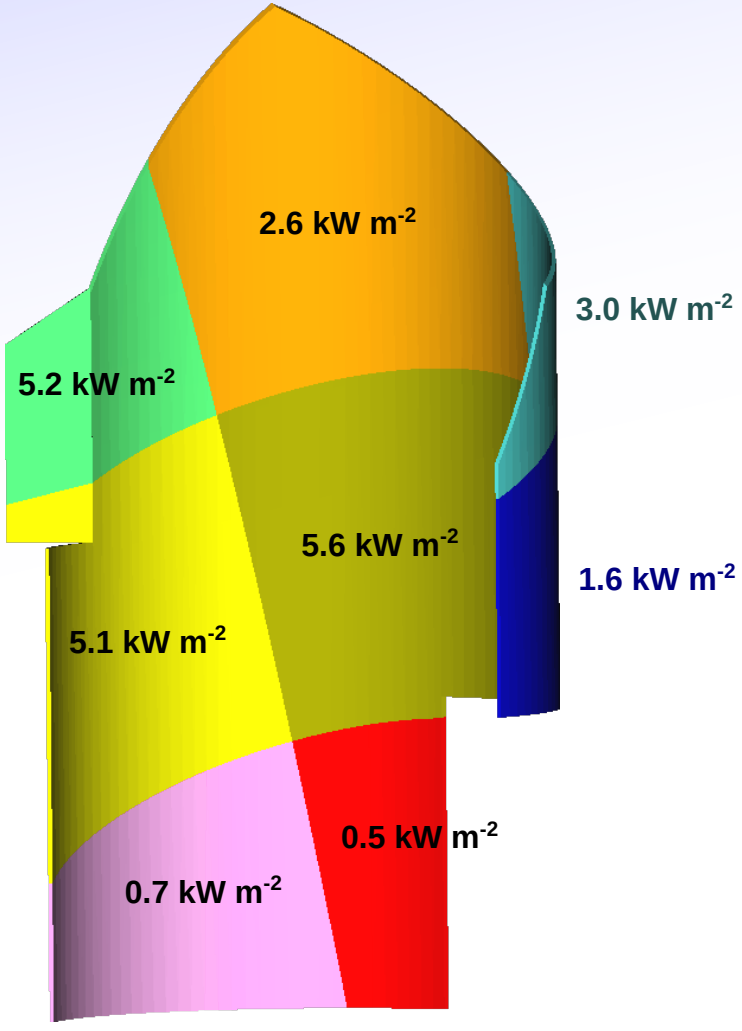


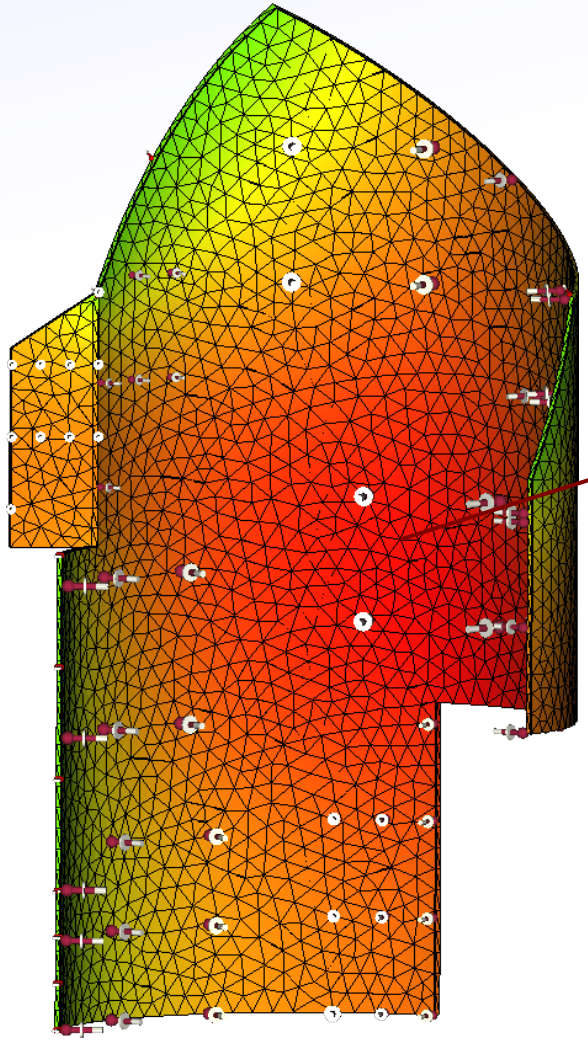
Max: 250°C

--> 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.





Max 1000°C
(no radiation)

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

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

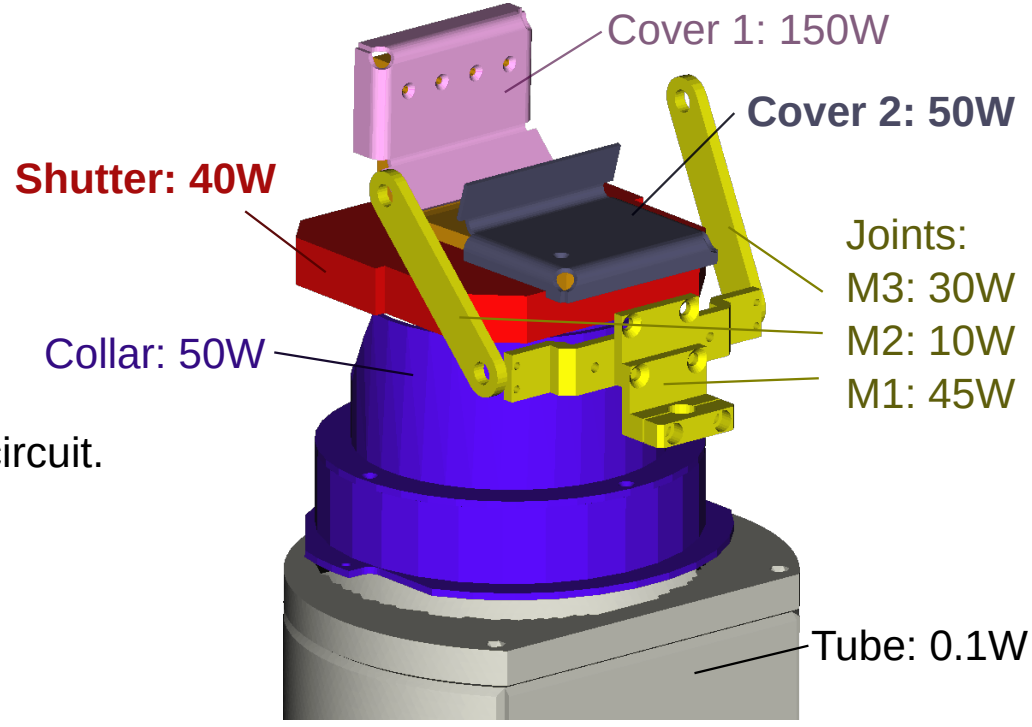
Front plate: 5000 W
Port Shield: 470W
= 5100W to ACK60-PL via front-plate water circuit.

Immersion tube: 0.1W
Protection collar: 50W

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

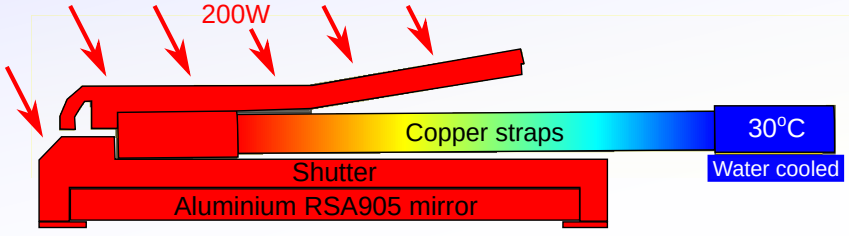
= 250W to ACK60-DIA via immersion tube water circuit.

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

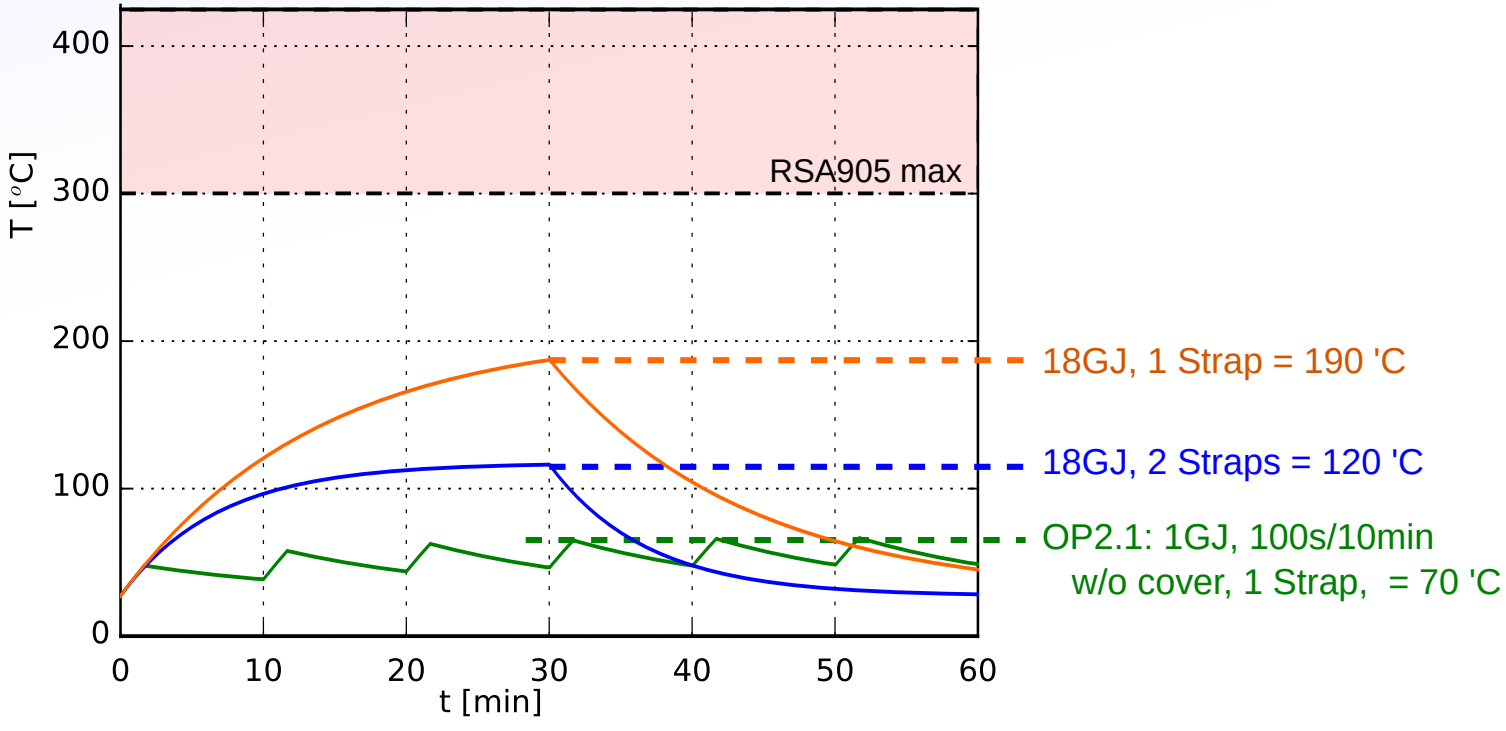


AEM21: Heat load - Shutter

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.

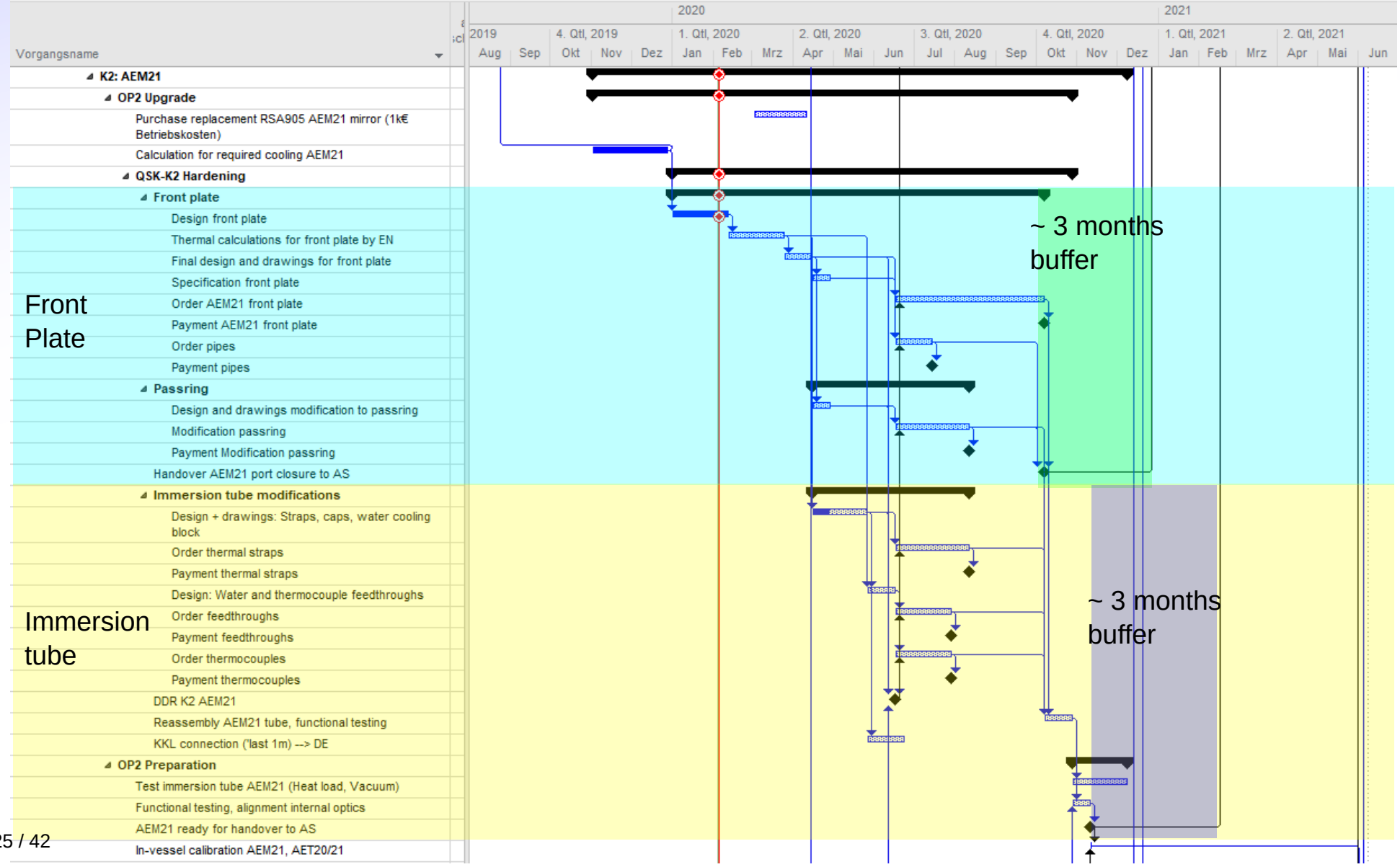


1) With 2 straps and cover, 18GJ is OK by x2
2) 1GJ is OK even with no cover and only 1 strap
3) Thermocouple will be installed in shutter to monitor temperature rise in OP2.1 --> confirm safety.

QSK AEM21 Cooling - Planning

Funding: 11k€ of 20k€ requested from contingency for QSK hardening.

Time plan:



Changes for OP2+

Upgrade for OP2 consists of 4 distinct changes:

1) Add cooling to existing AEA21 components (K1):
   - Thermal straps on shutter.

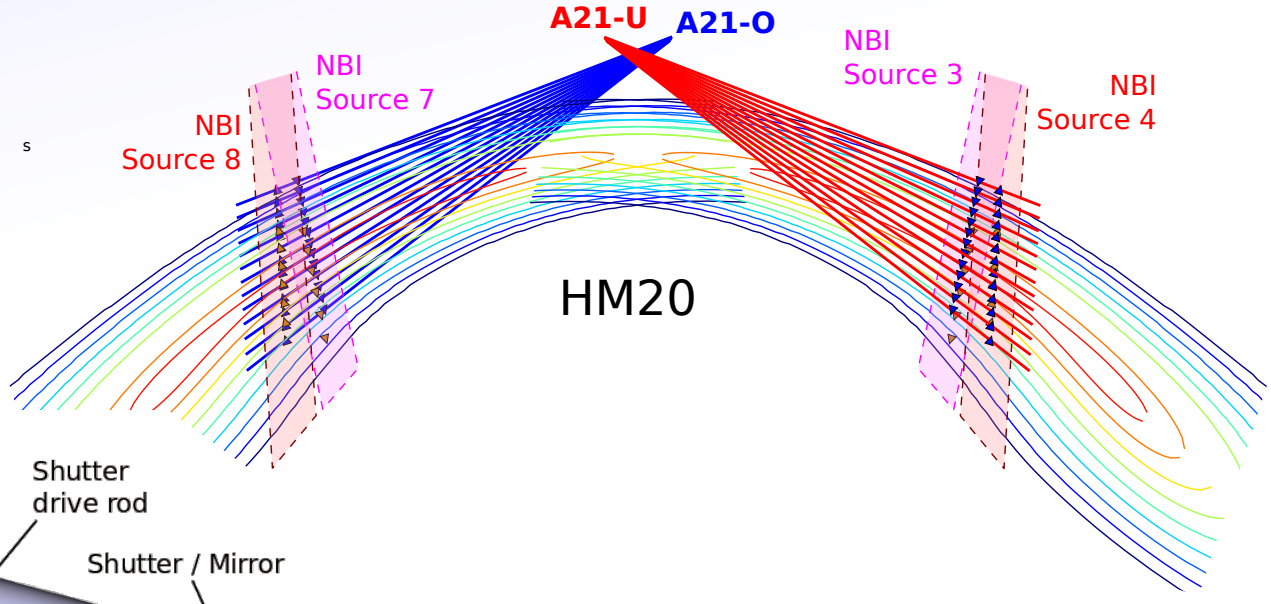
2) Add cooling to existing AEM21 components (K2):
   - Water-cooled panel.
   - Thermal straps on shutter + water citcuit.

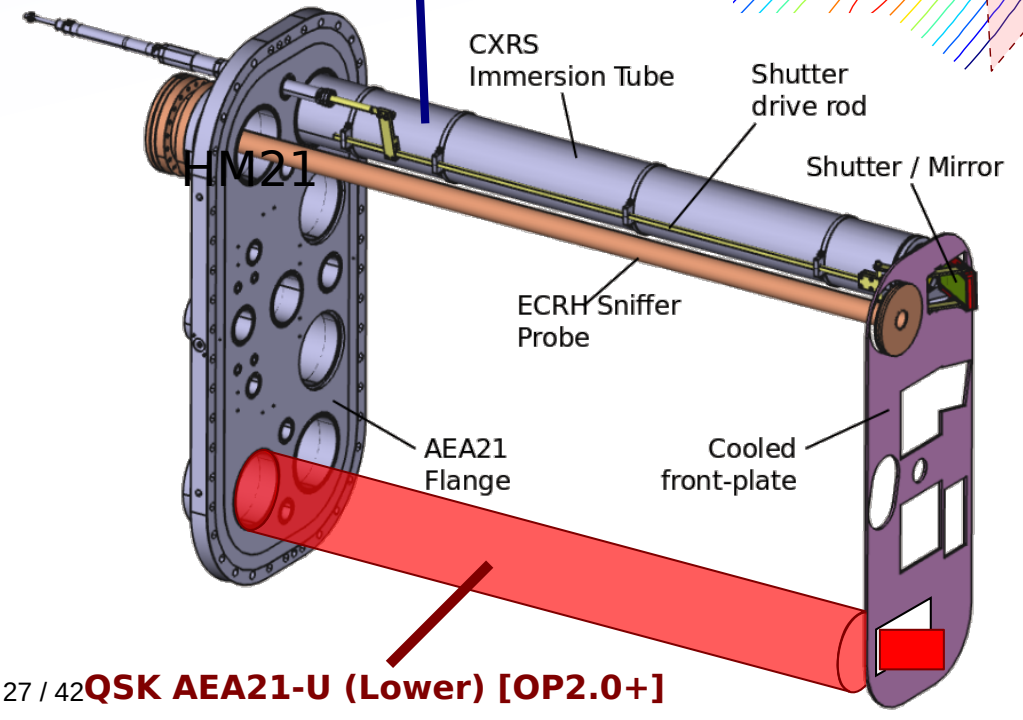
3) Addition of 2nd immersion tube to AEA21 to view NI20.

4) Rebuild of AET20/21 tubes (K3) due to redesign of HST.

CXRS Immersion tube AEA21 -U

- Copy AEA21 immersion tube for lower-left of AEA21 flange, for observation of NI20.
- Originally reserved for CXRS on NBI (no CN required?).





CXRS Immersion tube AEA21 -U

- All vacuum-interface components identical to AEA21-O.
- Resubmit specification and contract to Trinos (Pfeifer Vacuum).
  Includes vacuum tests (+Restgasanalyse)

Additional resources:
- 1x extra Shutter (Shutter-Schieber Steuerung)
  Common SPS --> No speacial CoDAC integration required.
- ~10k€ for tube and parts.
- Some TD manufacturing.
- Vacuum test of assembled shutter drive (DN40 CF) - (As chit #18 of OP1.2b DRB)

- No DE requirement.
- No EN requirement.
- No CoDAC requirement.

CXRS Immersion tube AEA21-U

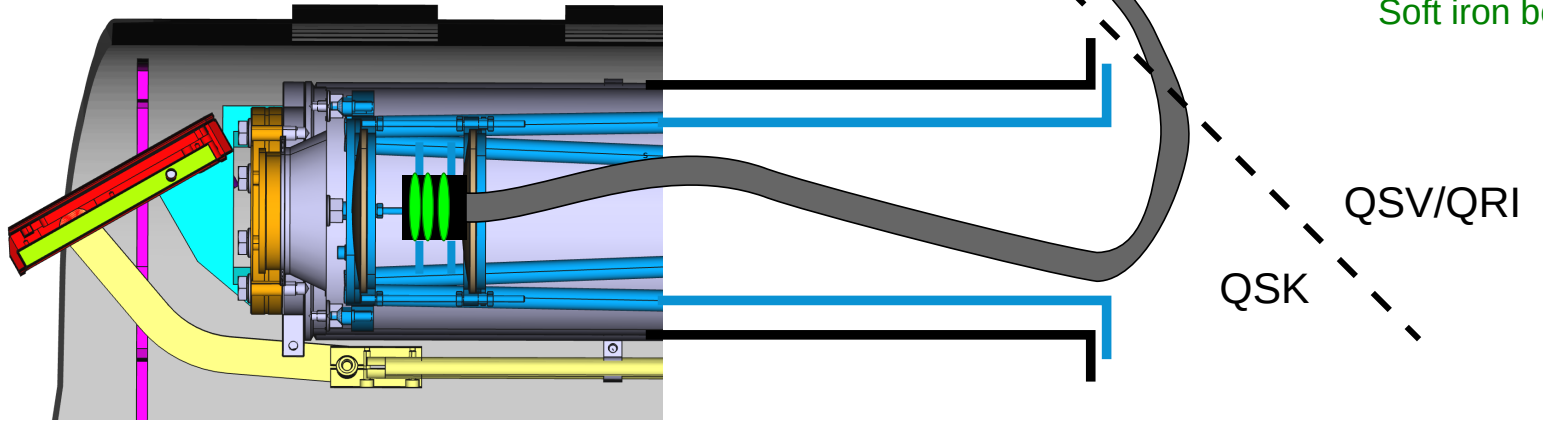
Optics:

Plan is to use this toroidal view for QRI/QSV, replacing AEQ21 toroidal port that was used in OP1.2, but now needs a pinhole.
Add fibres or advanced CXRS measurements inside QSV/QRI soft iron box.

Details still need to be agreed with QRI/QSV, will be presented later.
- Present at DDR?

Projects:
QSV/P042 - Fast Video - R.O.: Marco Krause (E4)
QRI/P143 - Coherence Imaging - R.O. Dorothea Gradic (E4)

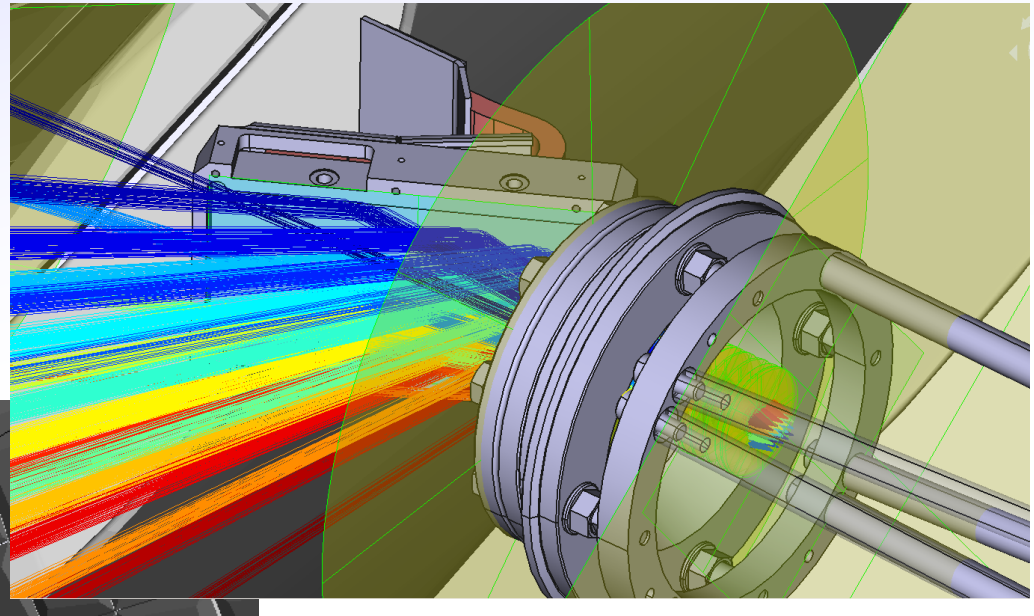
For info only:
Objective lens on end of fibre bundle (as used in AE21Q OP1.2b), fibre bundle to repositioned QSV/QRI soft iron box.

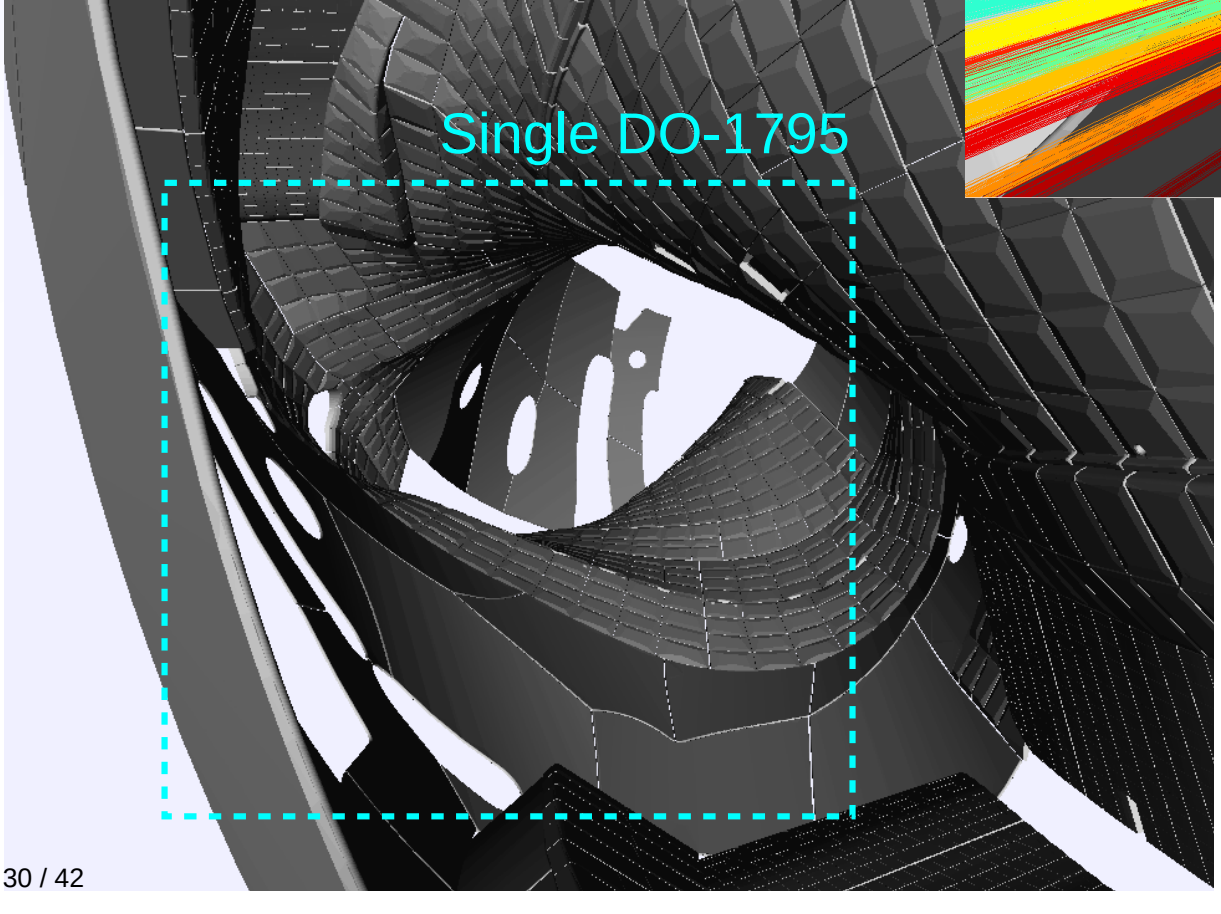


AEA21-U - Optics

Preliminary ray-tracing shows basic optical concept works for QSV/QRI.

- Single 17mm F/1 objective gives required FOV.

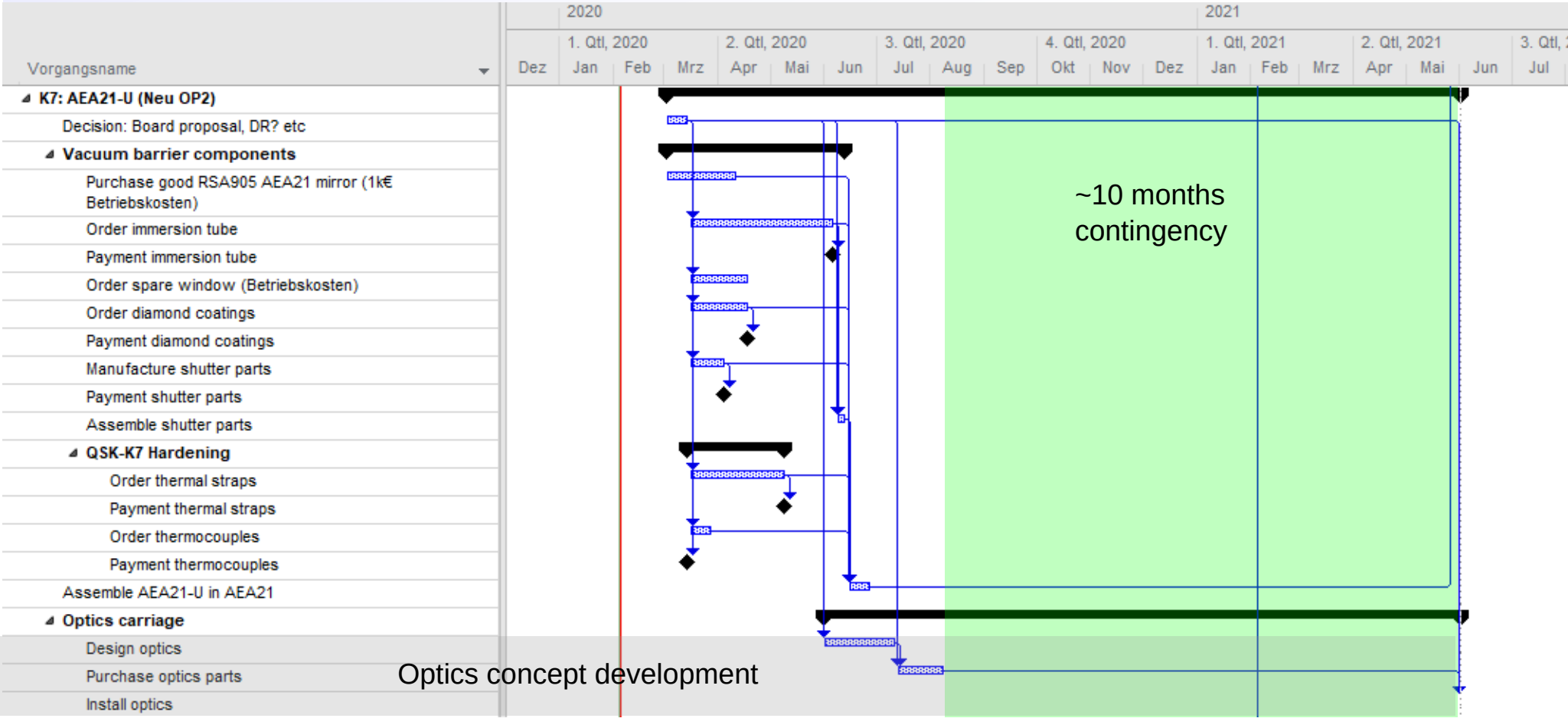




QSK AEA21-U - Planning

Funding:
9k€ from existing QSK funds.
5k€ of 20k€ requested from contingency for QSK hardening.

Time plan:



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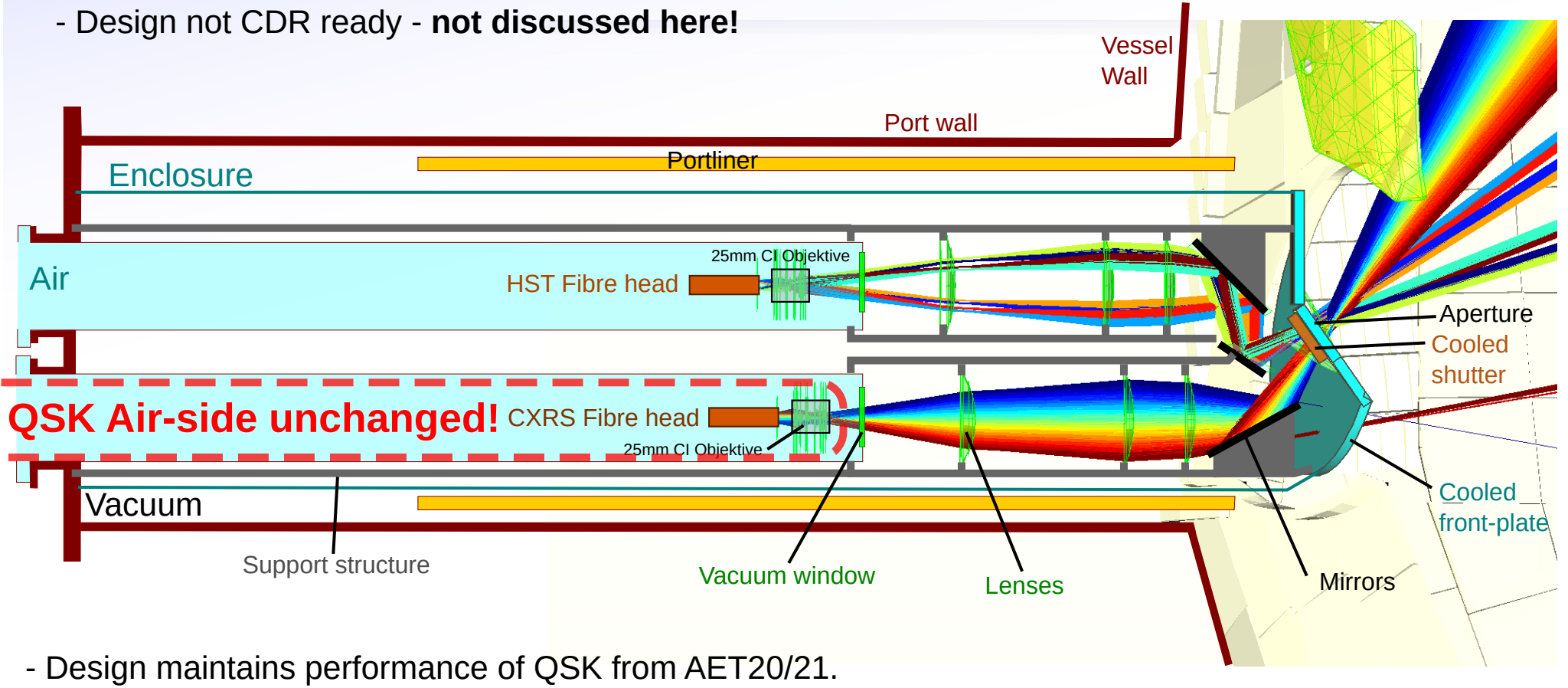
   - Thermal straps on shutter + water citcuit.

3) Addition of 2nd immersion tube to AEA21 to view NI20.

4) Rebuild of AET20/21 tubes (K3) due to redesign of HST.

AET20/21 - Redesign of HST

- QSK had optics in one window of AET20/21 immersion tubes of QYB/P008 (Heat Shield Thermography) during OP1.2.
- Immersions tube require complete redesign for OP2.
- Combined system under development (pre-CDR) for QYB/QSK.
  - Design not CDR ready - **not discussed here!**



- Design maintains performance of QSK from AET20/21.
- Immersion tubes, vacuum components, safety etc, all part of QYB --> P008 CDR, DDR
- Air-side optics remain as in OP1.2b.
- Resulting changes to QSK air-side mechanics will be presented in QSK DDR.

Changes for OP2+

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3) Addition of 2nd immersion tube to AEA21 to view NI20.

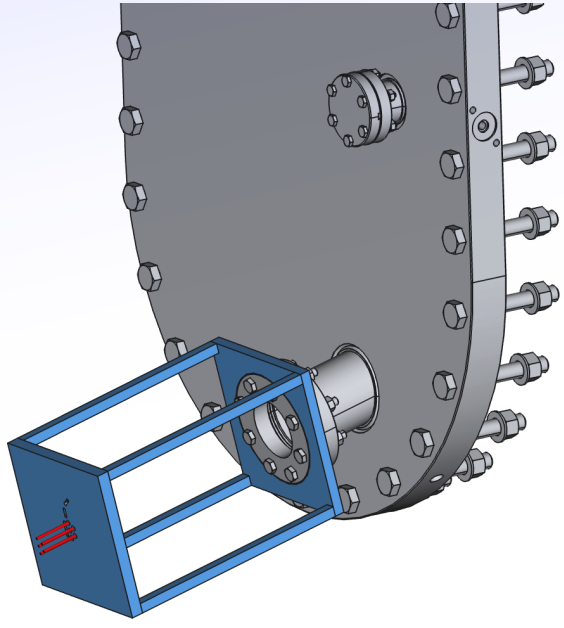
4) Rebuild of AET20/21 tubes (K3) due to redesign of HST.

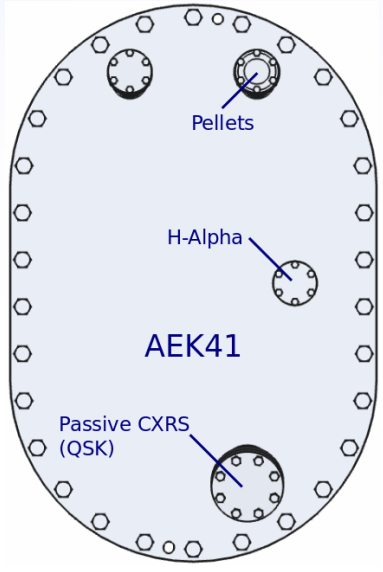
5) Consideration of passive CXRS (AEK41) for OP2

Passive CXRS - AEK41

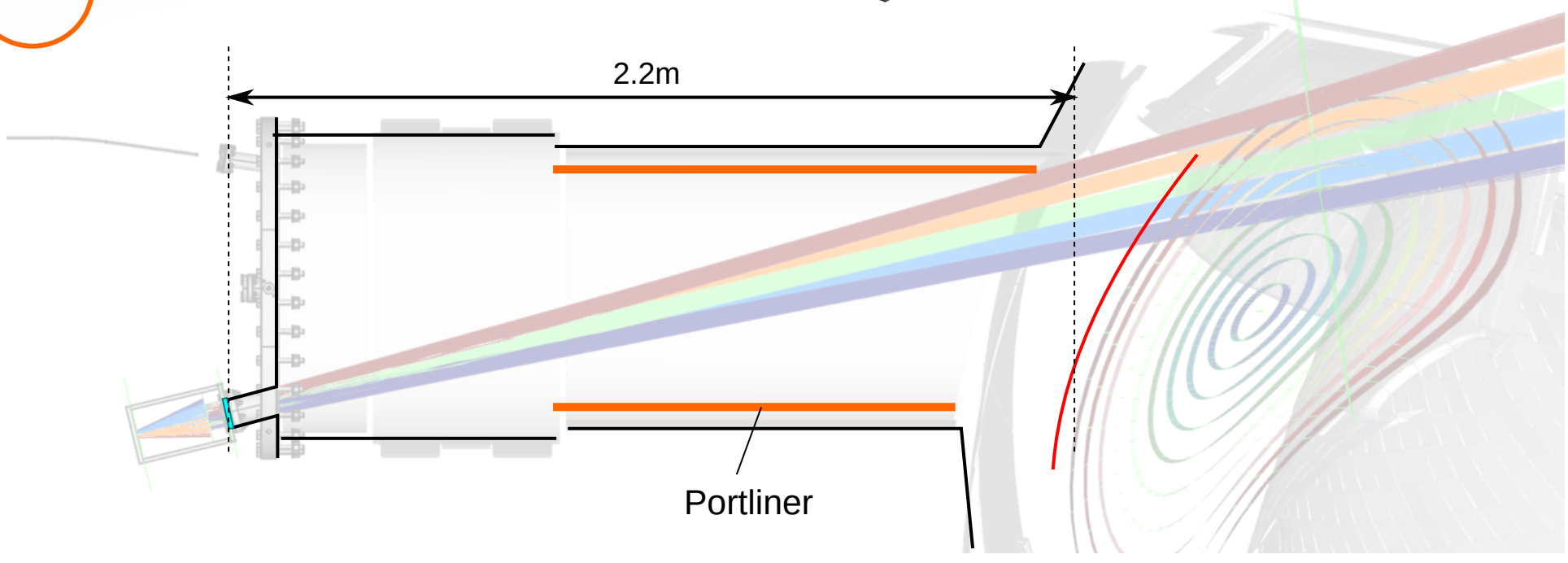
'Passive CXRS' system on AEK41 will remain as in OP1.2, but we need to consider heating of window:

650x350mm * 100kW m^{-2} = 23kW into port.
22kW on 6cm window at 2m distance = **2W**
On port area (720x400mm) = 200W

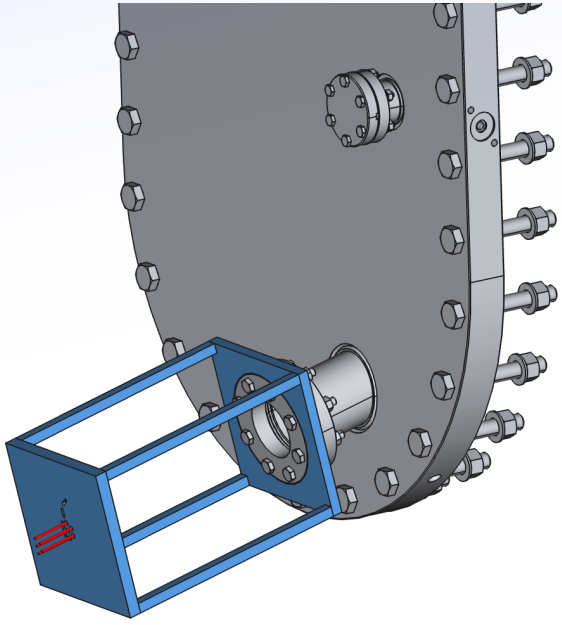




AEK41 Portliner =
650x350mm (inside)



Passive CXRS - AEK41 - Window heating



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

Power = 2W
Diameter = 60mm
Thickness ~ 6mm
Material = Fused Silica
Density = 2.2 g cm^{-3}
Mass = 37g
Specific heat capacity = 740 J kg^{-1} K^{-1}
Heating rate = 4 K / min
Max heating rate = 25 K / min (manufacturer specification).

--> Assumes volumetic heating of glass, but 2W is low enough to not pose a significant risk.

Power to flange = 200W.
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 = **0.2 K / min**
+ Air side of flange is convectively cooled
--> Flange will stay effectively room temperature.

Documentation

- 1-QSK-S0002.1: Projektspezifikation - *~ready*
- 1-QSK-T0003.1: Safety analysis - *~ready, update with cooling calculations at DDR*
- 1-QSK-P1000: WBS - up to date
- CNs: 1-QSK-C0008: AEM21 PL --> Frontplate, *~ready*
  AEK41 Change of QSC to QSK
  Addition of AEA21-U - *Is CN Required?*
  1-Q-C0010: Addition of Shutter AEA21-U

- QAAPs: Reassembly AEA21 - *Copy 1-QSK-Q0001*
  Installation/calibration AEA21 - *Copy 1-EGG21-Q2418*
  Calibration for AEA21-U - *After planning with QSV/QRI. Integrate in 1-EGG31-Q2418 copy for OP2.0*
  Installation AEM21 Frontplate - ***New. To be made with AS.***
  Installation AEM21 Tube - *Copy 1-EGG21-Q2283 with modification for presence of front plate.*
  Calibration AEM21, AET2x - *Copy 1-EGG21-Q2383.*

- Sonderfreigaben: AEA21-U mirror: *Repeat 1-QSK-Q0009*
  AEA21-U objective: *After design of A21-U optics.*

CAT - To be developed for OP2.0 start up.

- Interfaces: As OP1.2,
  + QMR for cooling via AEA21 front plate.
  + ACK60 for water cooling of AEM21 PL + DIA.
  + QSV/QRI for sharing of new immersion tube AEA21-U.

- Media: Water cooling from ACK60

Resource requirement

E3:
- Design and assembly of all components.
- 20k€ for cooling (from risk budget, K1/K2)
- 15k€ for AEA21-U (K7).
- 2k€ for parts in AET2x (K3)
- Hot leak test AEM21 Immersion tube

Outside E3, very low-resource demand:

TD:
- Multiple small parts for cooling components and extra components for K7 and K3.
  ~ 100s hours.

AS:
- More complex installation of front plate than PL ~ 4 days.
- Laying of cables/lines to 1 extra shutter.
- Installation AEM21 immersion tube ~ 4 hours.

EN:
- Thermal calculations AEA21 (K1) front plate (assigned to QMR, in progress)
- Thermal calculations AEM21 ~ 3 weeks.

CoDAC:
- Connection of 1 extra shutter to Shutter/Schieber Steuerung.
- Nothing required for control, data acqusition or data processing.

DE:
- Routing of cables/lines to 1 extra shutter.
- Routing ACK60 'last 1m' for diagnostik + front plate on AEM21.

Summary

1) Add cooling to existing AEA21 components (K1):
   - EN calculations (by QMR - now)
   - Purchase and test straps
   - DDR

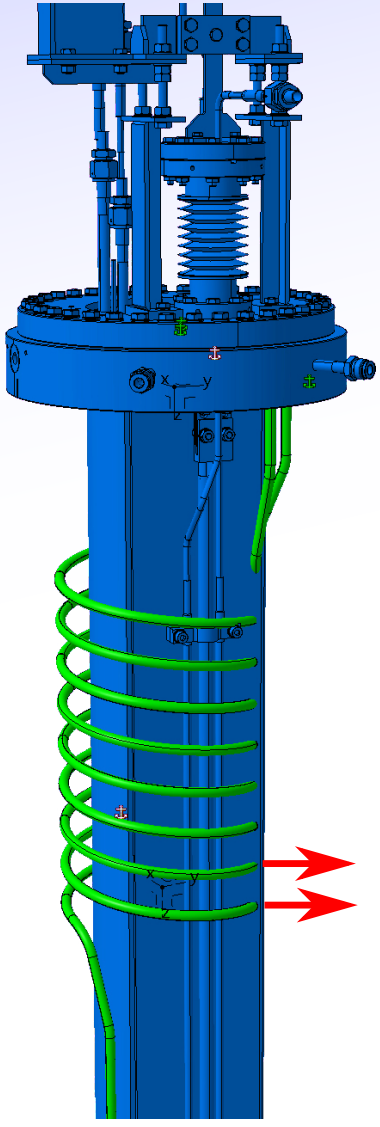
2) Add cooling to existing AEM21 components (K2):
   - Water-cooled panel: Calculations (EN?), DDR, Find supplier
   - Thermal straps on shutter + water citcuit.

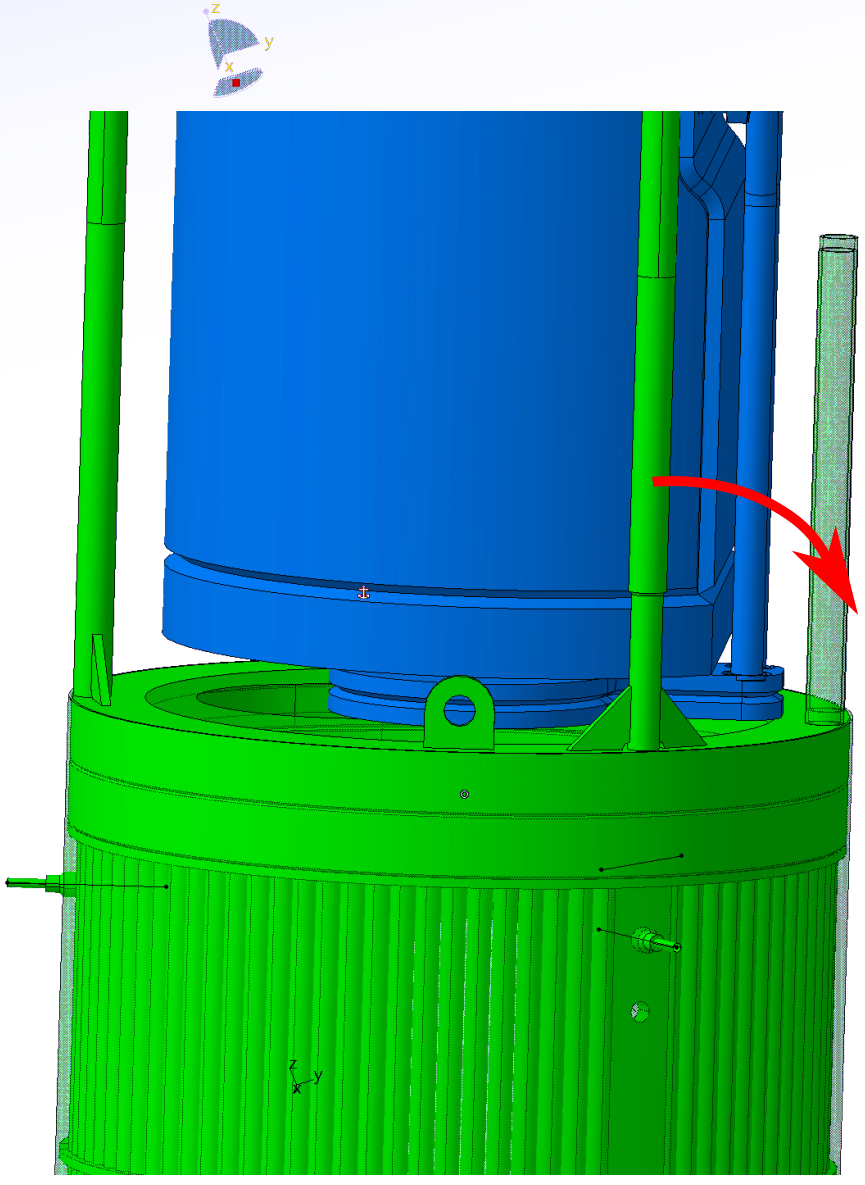
3) Addition of 2nd immersion tube to AEA21 to view NI20.
   - Ready to order immersion tube, the rest progresses with #1
   - Optics integration with QSV/QRI (next week) --> present at QSK DDR.

4) Rebuild of AET20/21 tubes (K3) due to redesign of HST.
   - Vacuum hardware at QYB CDR
   - Optics integration at QSK DDR.

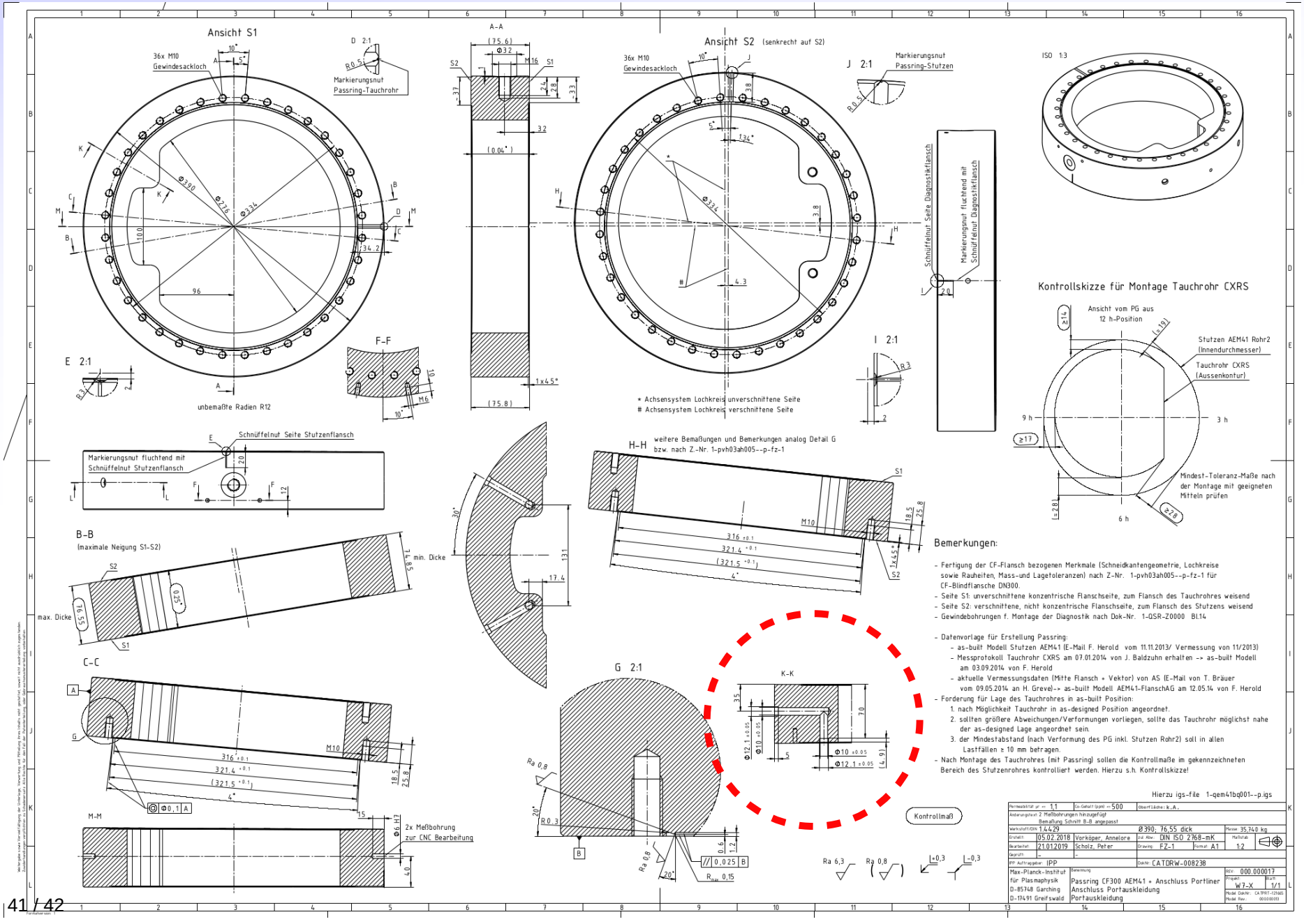
5) AEK41
   - No changes. Accepted?, otherwise calculations by EN.

AEM41 - Why not spiral pipes?





AEM41 - Pipe welding



Bemerkungen:

- Fertigung der CF-Flansch bezogenen Merkmale (Schneidkantengeometrie, Lochkreise sowie Rauheiten, Mass-und Lagetoleranzen) nach Z-Nr. 1-pvh03ah005--p-fz-1 für CF-Blindflansche DN300.
- Seite S1: unverschnittene konzentrische Flanschseite, zum Flansch des Tauchrohres weisend
- Seite S2: verschnittene, nicht konzentrische Flanschseite, zum Flansch des Stutzens weisend
- Gewindebohrungen f. Montage der Diagnostik nach Dok-Nr. 1-QSR-Z0000 Bl.14

- Datenvorlage für Erstellung Passring:
  - as-built Modell Stutzen AEM41 (E-Mail F. Herold vom 11.11.2013/ Vermessung von 11/2013)
  - Messprotokoll Tauchrohr CXRS am 07.01.2014 von J. Baldzuhn erhalten -> as-built Modell am 03.09.2014 von F. Herold
  - aktuelle Vermessungsdaten (Mitte Flansch + Vektor) von AS (E-Mail von T. Bräuer vom 09.05.2014 an H. Greve)-> as-built Modell AEM41-FlanschAG am 12.05.14 von F. Herold
- Forderung für Lage des Tauchrohres in as-built Position:
  1. nach Möglichkeit Tauchrohr in as-designed Position angeordnet.
  2. sollten größere Abweichungen/Verformungen vorliegen, sollte das Tauchrohr möglichst nahe der as-designed Lage angeordnet sein.
  3. der Mindestabstand (nach Verformung des PG inkl. Stutzen Rohr2) soll in allen Lastfällen ≥ 10 mm betragen.
- Nach Montage des Tauchrohres (mit Passring) sollen die Kontrollmaße im gekennzeichneten Bereich des Stutzenrohres kontrolliert werden. Hierzu s.h. Kontrollskizze!

Hierzu igs-file 1-qem41bq001--p.igs

Werkstoff/DIN 1.4429		Ø390; 76,55 dick	Masse: 35,740 kg
Erstellt: 05.02.2018	Vorköper, Annelore	Zul. Abw. DIN ISO 2768-mK	Maßstab 1:2
Bearbeitet: 21.01.2019	Scholz, Peter	Zeichnung: FZ-1	Format: A1
PP Auftraggeber: IPP		Dokument: CATDRW-008238	
Max-Planck-Institut für Plasmaphysik D-85748 Garching D-17491 Greifswald	Bemerkung: Passring CF300 AEM41 + Anschluss Portliner Anschluss Portauskleidung Portauskleidung		REV: 000.000017 Projekt: W7-X Blatt: 1/1