Charge Exchange Recombination Spectroscopy (CXRS) on the Neutral Beam Injection (NBI)

(Ladungsaustauschspektroskopie am Neutralheizstrahl)

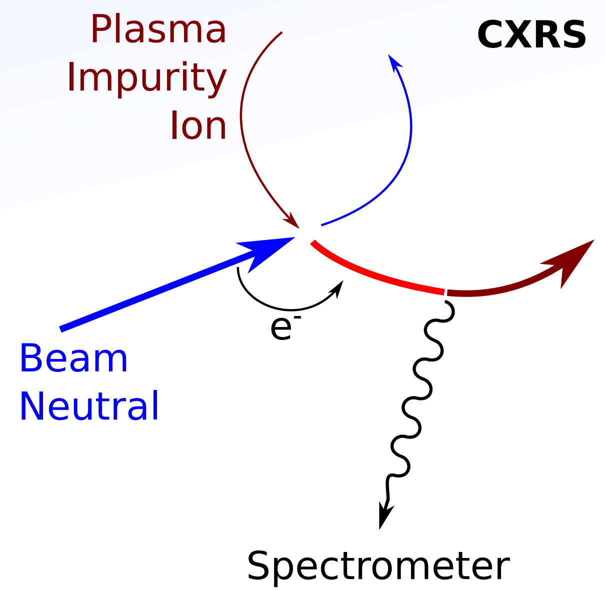
Conceptual Design Review, 19th May 2016

O. P. Ford[1], J. Baldzuhn[1], M. Beurskens[1], C. Biedermann[1], M. Steffen[1], R. Wolf[1]

1: Max-Planck Institut für Plasmaphysik, Greifswald/Garching, Germany

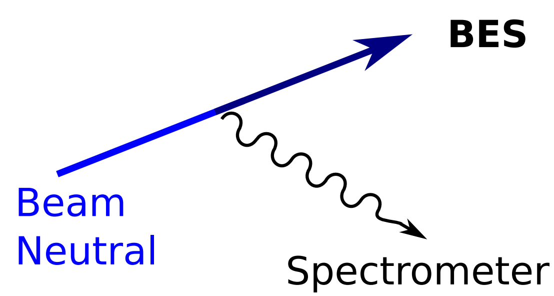
Objectives

Charge Exchange Recombination Spectroscopy (CXRS) physics:
1) Neutral beam particles donate electrons to impurity/plasma ions.
2) Impurity ion left in excited state, emits photon.
3) Spectrum of collected photons give:
   - Impurity Densities (n_Z)
   - Impurity Temperature ~ Ion temperature (T_i)
   - Impurity Bulk Velocity --> Radial Electric Field (E_r) + Toroidal Rotation (w_φ)



+Beam Emission Spectroscopy (BES):
Direction observation of beam neutral emission gives beam density n_b, beam deposition and spatial calibration of optics.

Requires:
- Neutral Beam
- Observation Optics
- Fibres
- Spectrometers



Only diagnostic to give core measurements of:
- Impurity densities n_z (other than Argon)
- Toroidal rotation w_φ
- Beam density/deposition n_b

Supplements line-integrated XICS measurements with localised measurements of:
- T_i: Localised measurements.
- E_r: Localised across most of profile.

Design Base: ASDEX Upgrade CXRS

To avoid too much new development and associated uncertainty, system will be largely based on ASDEX Upgrade (AUG) CXRS. We have the same:

- **o** Same NBI
- **o** Same plasma cross-section (50-60cm core-edge).
- **o** Same spectrometers (start with their design)
- **o** Same fibres (initial design).
- **o** Same Ion temperatures (T_i).

Up to 4x higher electron density (n_e) so:

- Lower signal in core (NBI attenuation)
- Much higher background (Bremsstrahlung)

- Much lower velocities (Er) and higher sensitivity/accuracy required (> 5x better).

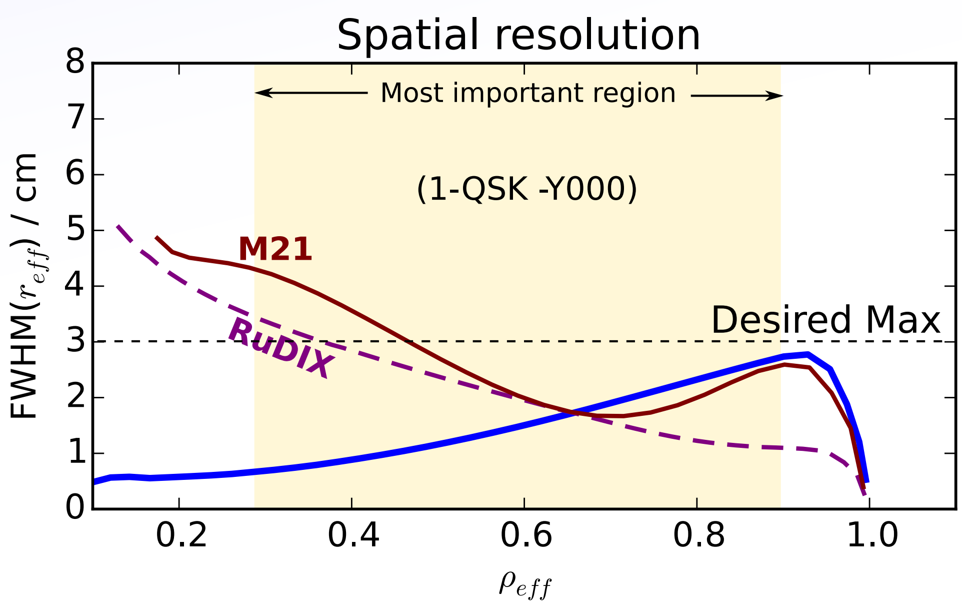
+ Can accept lower time resolution (100ms instead of 10ms).
+ Expect higher carbon content (AUG is W wall), but other impurities will be similar.

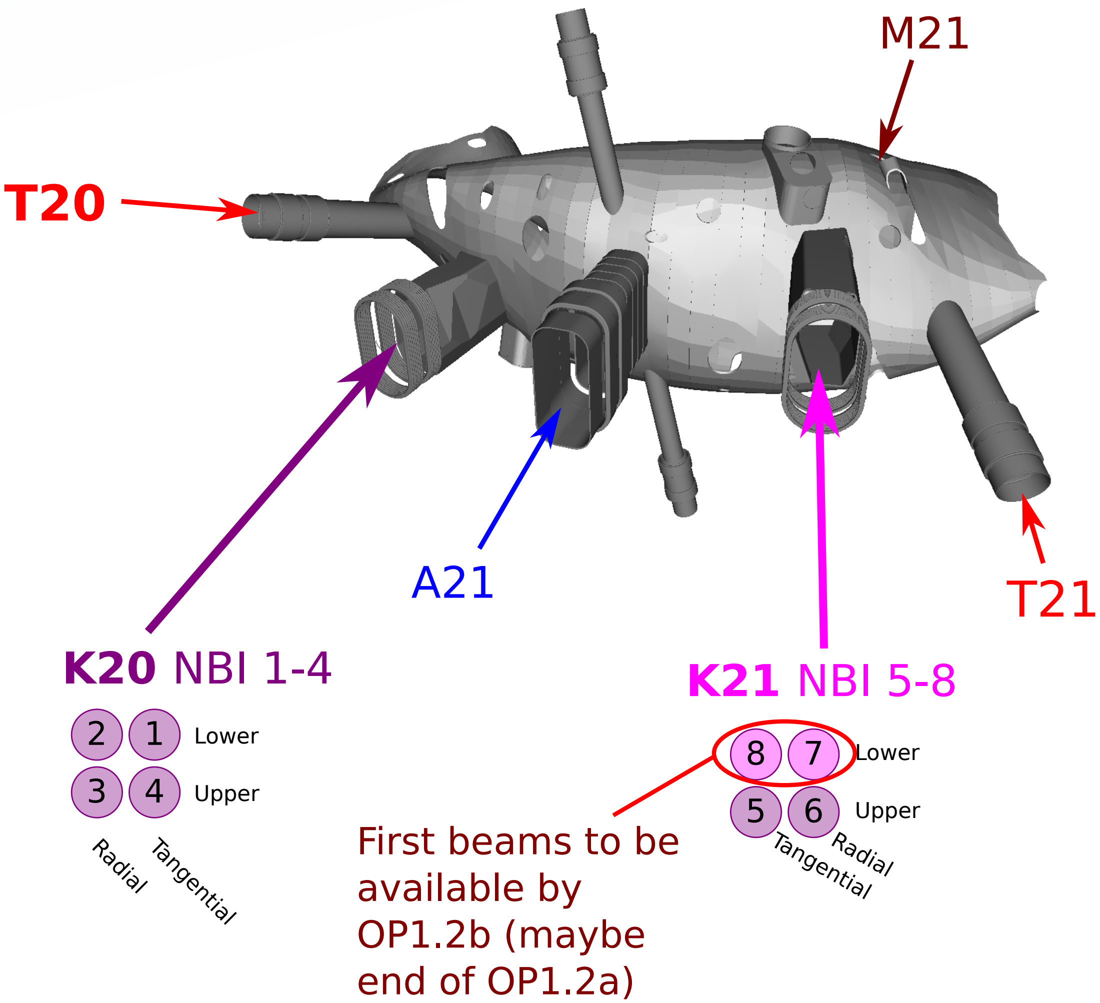
AUG system works well and we have lots of experience inside IPP.

Neutral beams and observation optics

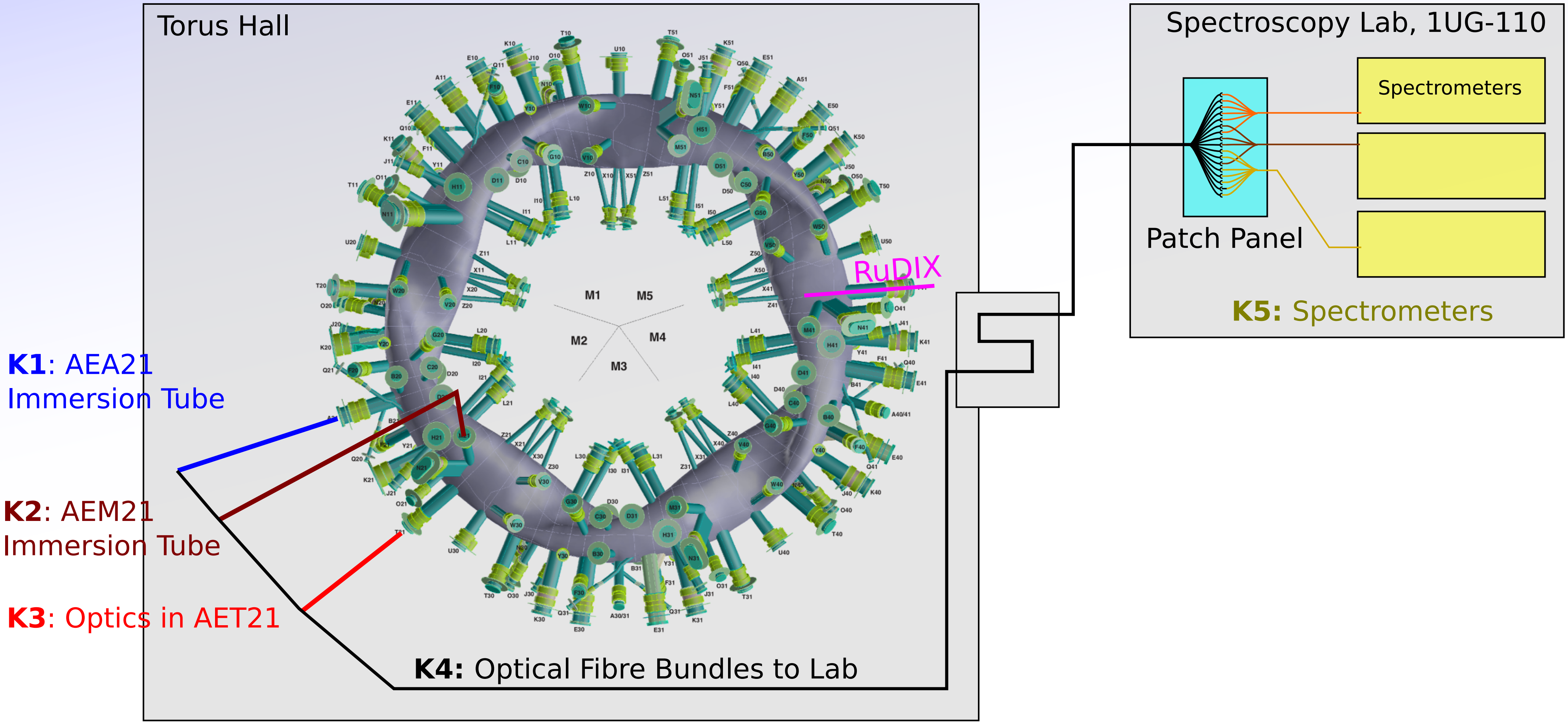
RuDIX diagnostic neutral beam will not be ready for OP1.2.

- Jan 2016 (E3) : CXRS on RuDIX (QSC) project suspended, focus moved to CXRS on NBI (QSK).
- Feasibility study (1-QSK-Y0000) determined the observation ports for best balance of sensitivity, resolution and technical effort:
- AEA21: Plug-in already reserved, sufficient space, good resolution.
- AEM21: Required for Er. Released by Bulk Spectroscopy Diagnostic (CN in progress)
- AET20/21: Cross-check system. Shared with NBI HST. Poor resolution but very low technical effort.





System Components



Planning priorities:

This CDR gives the general design of the complete system but so far design work has concentrated on the most time critical components.

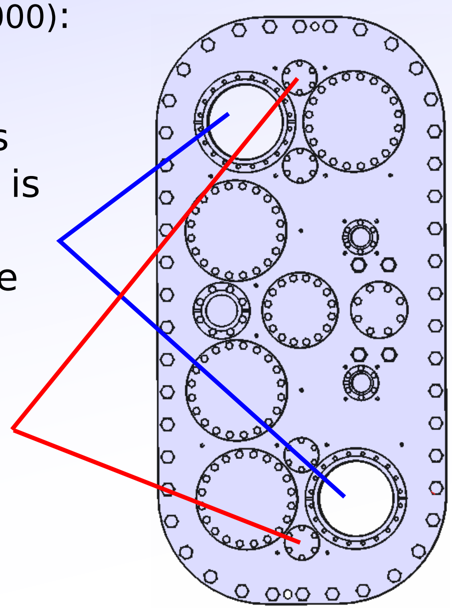
1) **K1**, **K2** - Large effort, need to be ready for vessel closure (Feb 2017?) (and preferably calibration).
2) **K4** - Fibres are in-hall and should be installed before start of operation OP1.2a.
3) **K3** - Low effort and not critical to the project, but needs to be in before AET21 immersion tube is installed.
4) **K5** - Spectrometers and laboratory equipment - can be completed during OP1.2a (before NBI is ready).

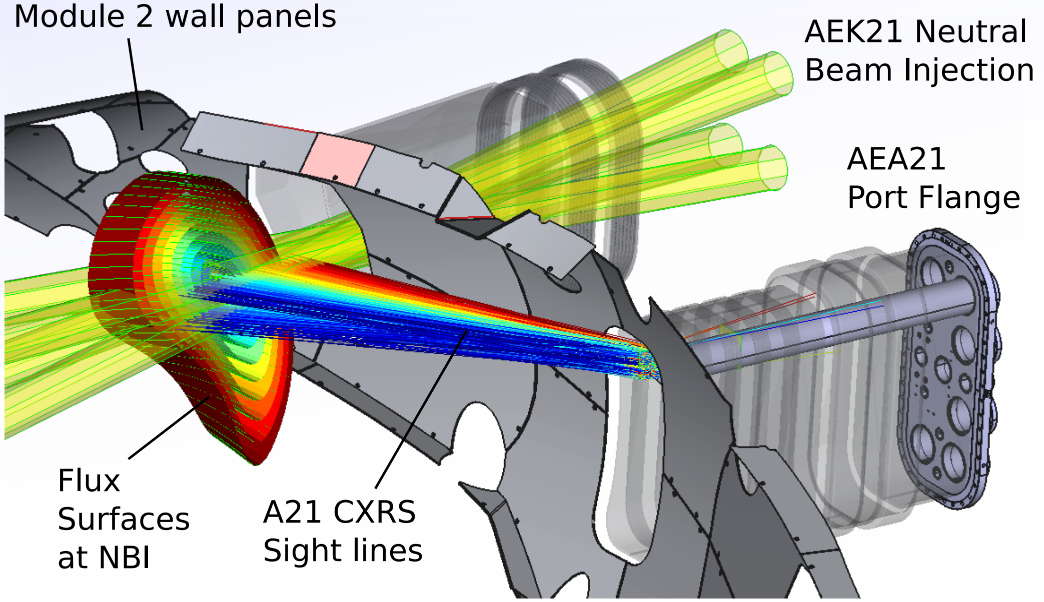
K1 (AEA21): View

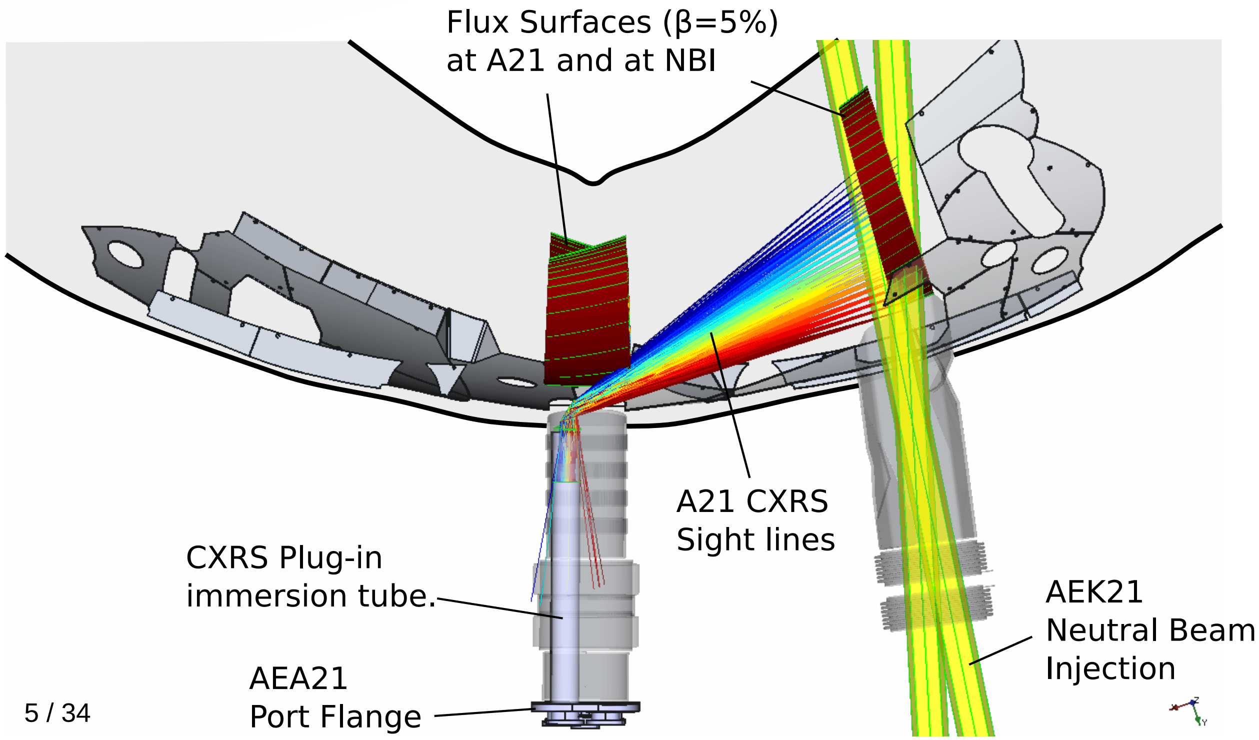
AEA21 Port-Flange (1-QMR2-T0000):

2x 150mm Plug-In tube spaces reserved for CXRS/MSE. Upper is optimal for viewing K21 beam box and lower for K20 (to come later).

Extra flange for vacuum feed-through also reserved.



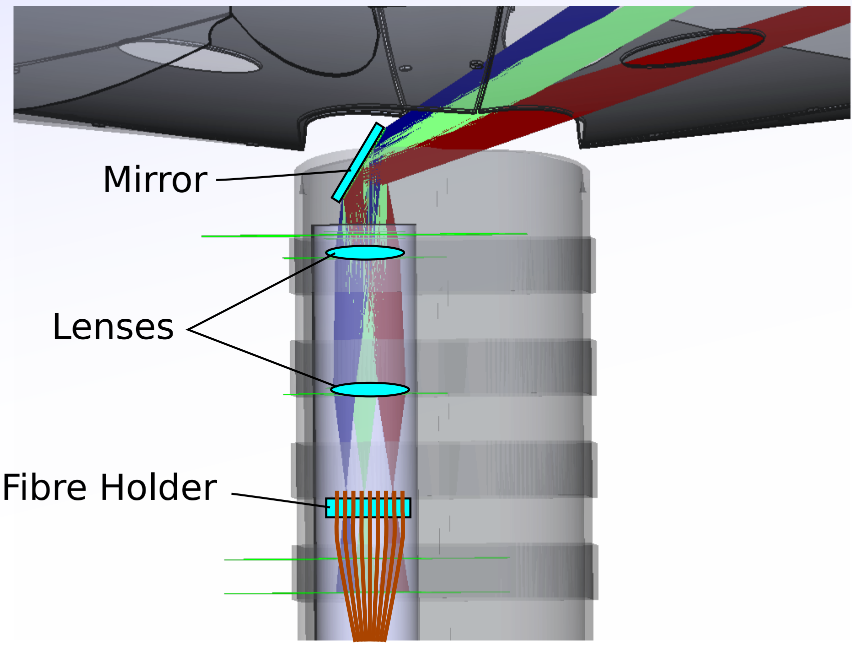




Viewing from AEA21 onto NBI is at ~60° to plug in, so a mirror is required.

K1 (AEA21): Optics

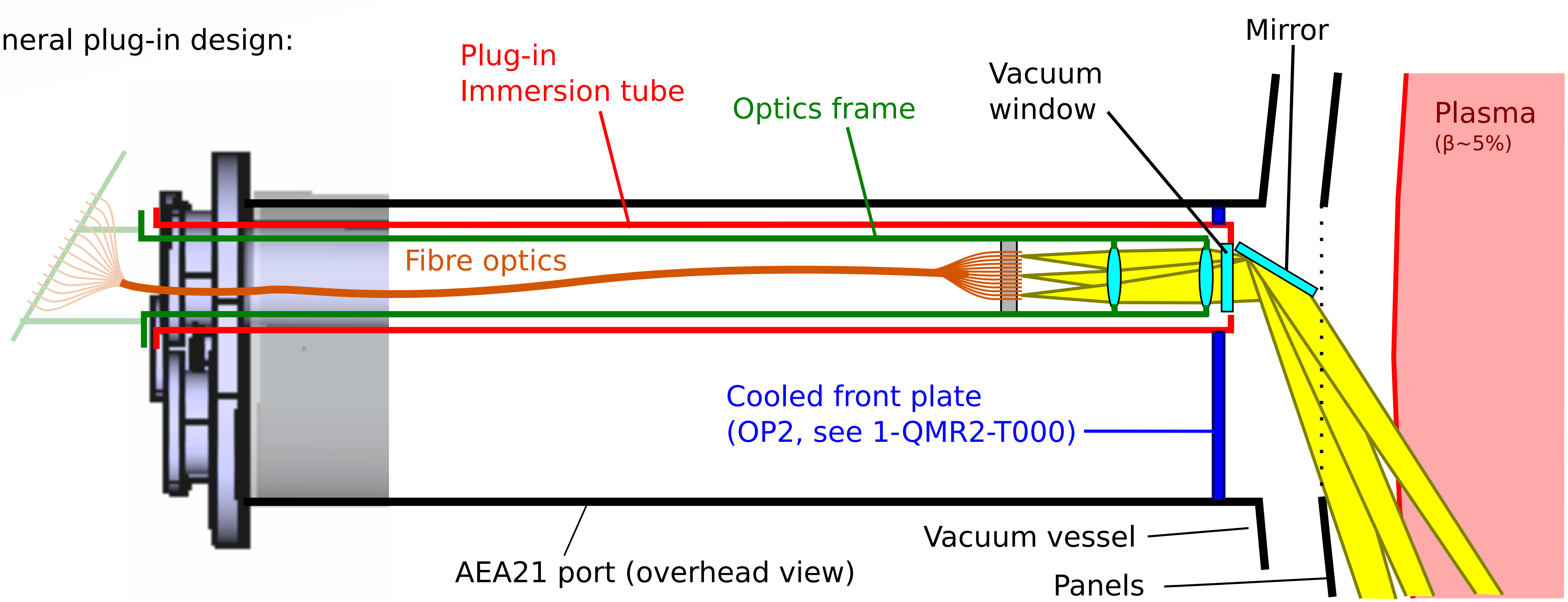
Optics need to image the beam on a fibre bundle, via a mirror. For best light collection (and hence S/N), we want the largest possible mirror, window, lens and image (i.e. fibre holder) size.



Technical requirements:

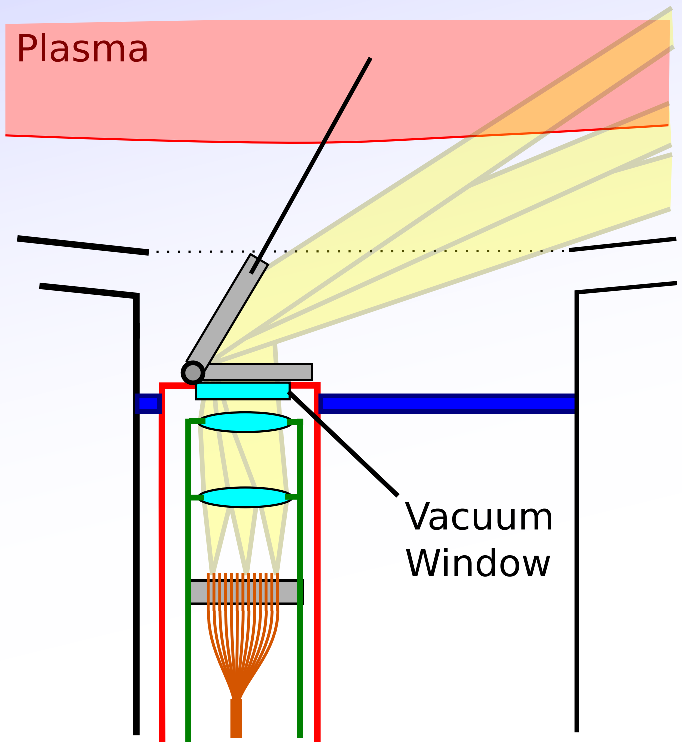
- Vacuum barrier, try to keep optical components on air side.
- Adjustable mirror for optical alignment.
- Shutter for protection of first mirror/window against coatings when diagnostic/NBI is off.
- Cooling of plasma facing components (window, mirror and/or shutter) against plasma and ECRH radiation for OP2.

General plug-in design:

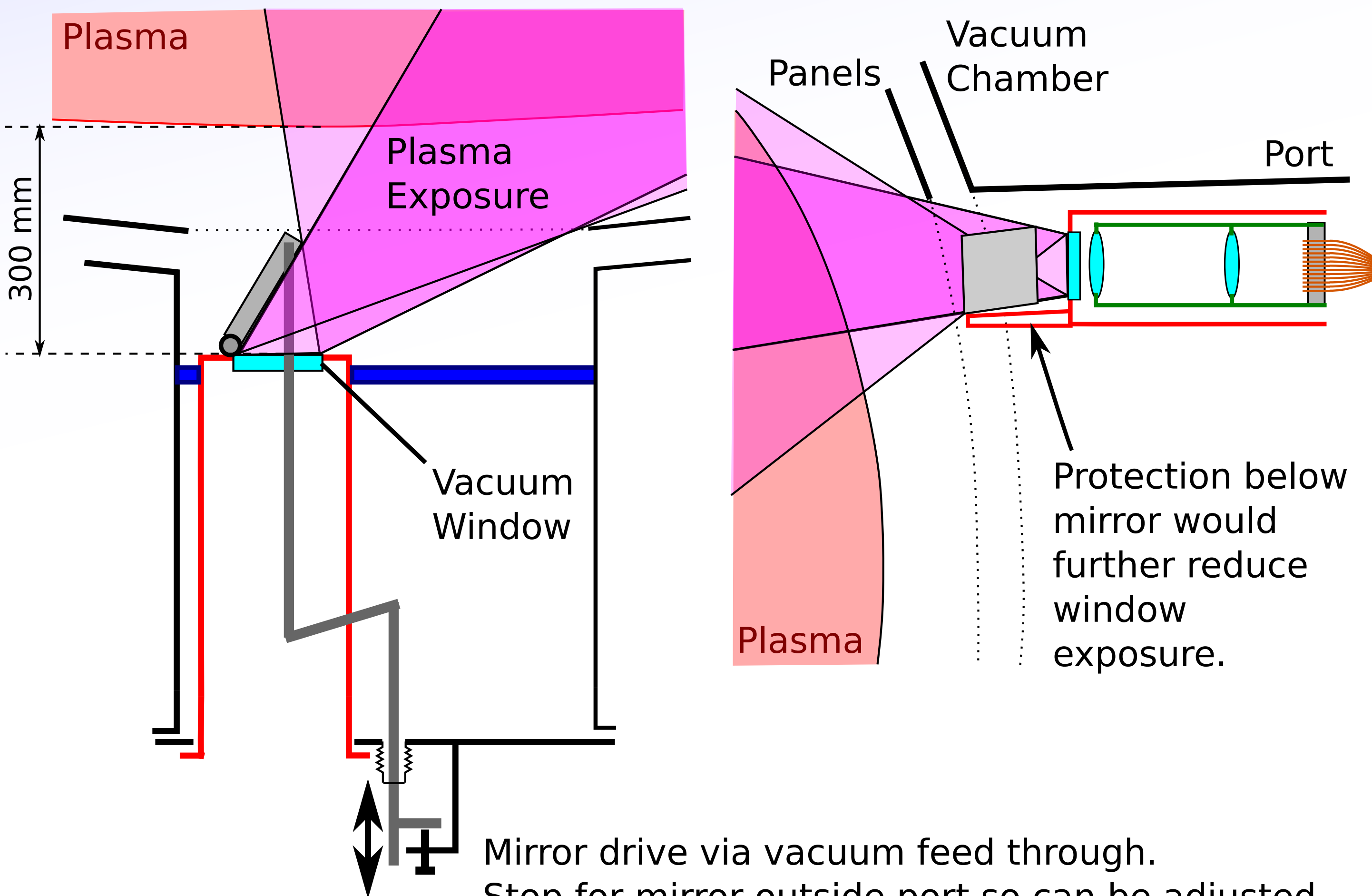


K1 (AEA21): Optics and Protection

Hinged mirror, cooled for OP2:



Reduced window exposure to plasma will reduce cooling requirements:

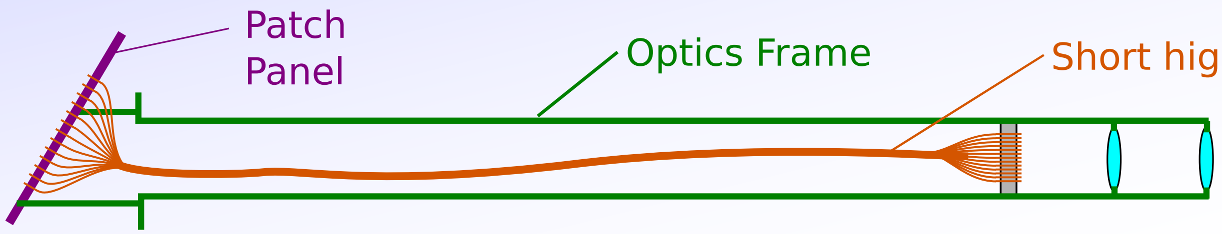


Mirror drive via vacuum feed through.
Stop for mirror outside port so can be adjusted.

- Only cooled mirror required for OP2.
- Shutter only open for max 10s periods (during NBI), otherwise > 30cm from plasma.
- Poor alignment stability - but on-line determination of spatial alignment possible - (see calibration slide).
- Mirror on vacuum side and exposed to plasma during measurements.
- So far as possible design for OP2, but not if design takes longer than required to install immersion tubes for OP1.2.

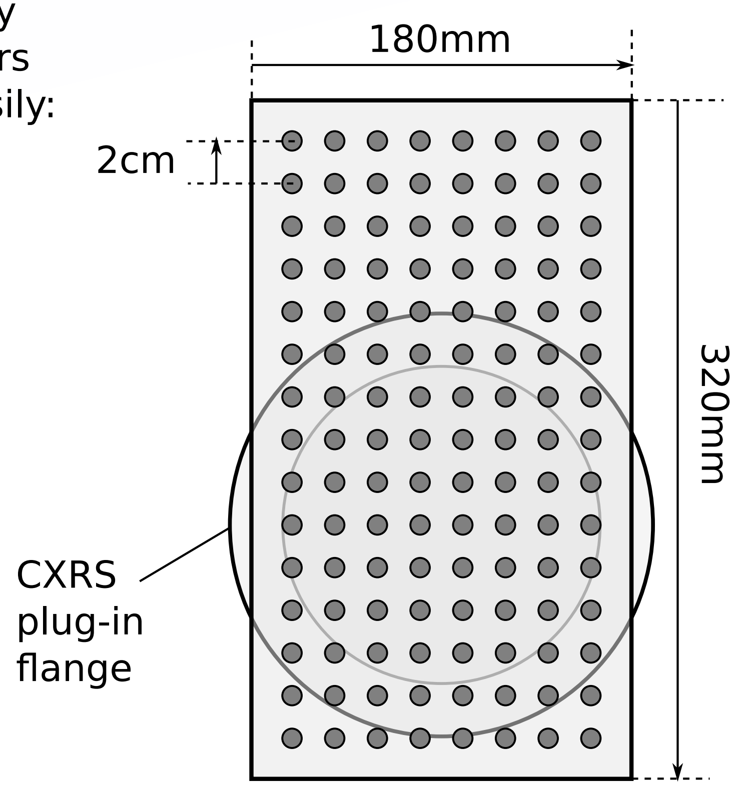
K1 (AEA21): Patch Panel

For flexibility, many more fibres will be installed at the optical head than to spectroscopy lab (expensive).
For fast changes between operation days, a patch-panel will built onto the optics.

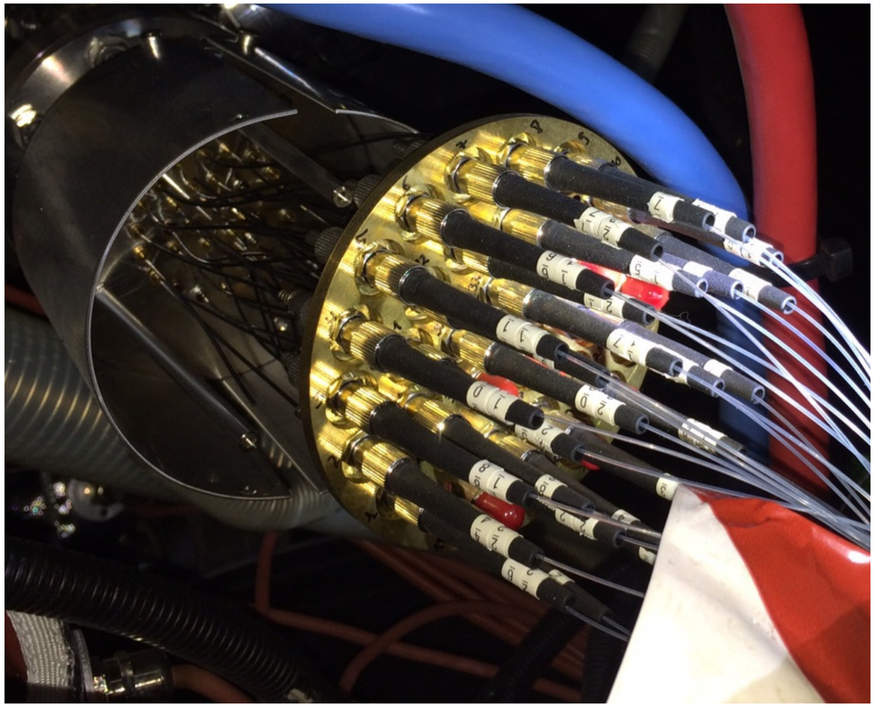


Average geometric resolution ~1.5cm. Accepting 2cm resolution, over 60cm of beam requires 30 channels.
~2 sets required to view all beams, and 2 sets for simultaneous BES and CXRS.
= 120 fibres total on patch panel and we decide which we use later.

A 15x8 array of connectors could fit easily:



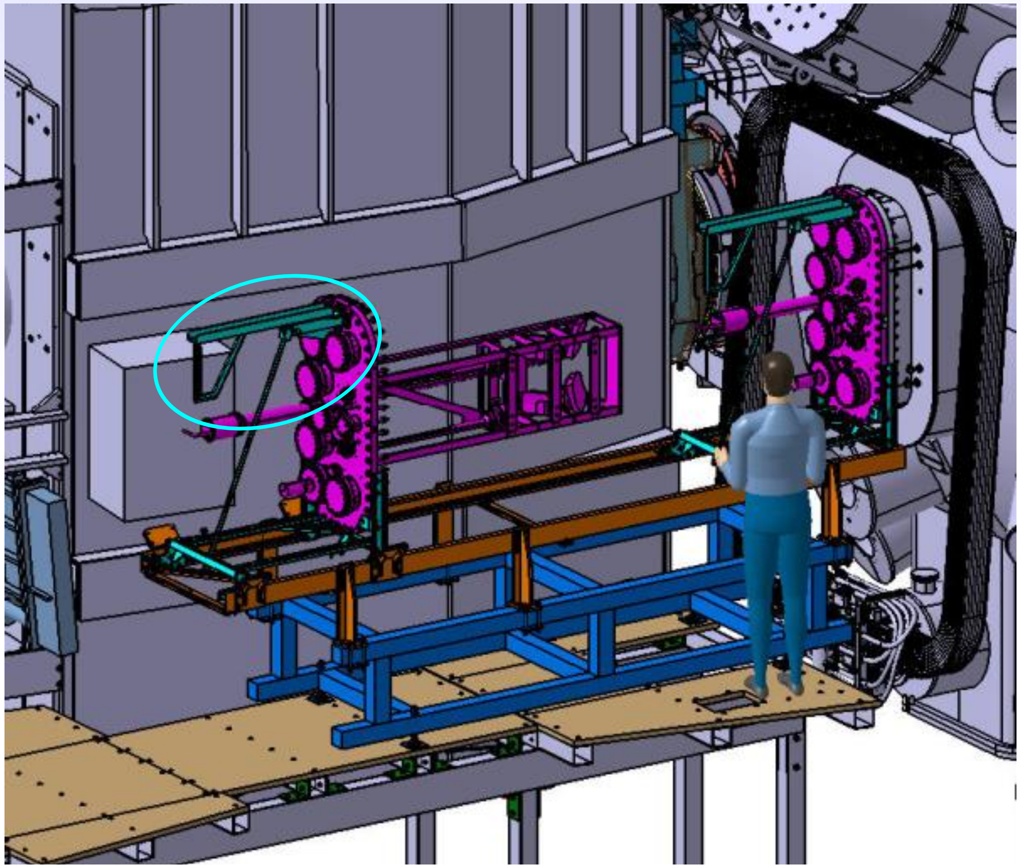
This will be similar to ASDEX Upgrade's vacuum feed-through panels, but with more space:



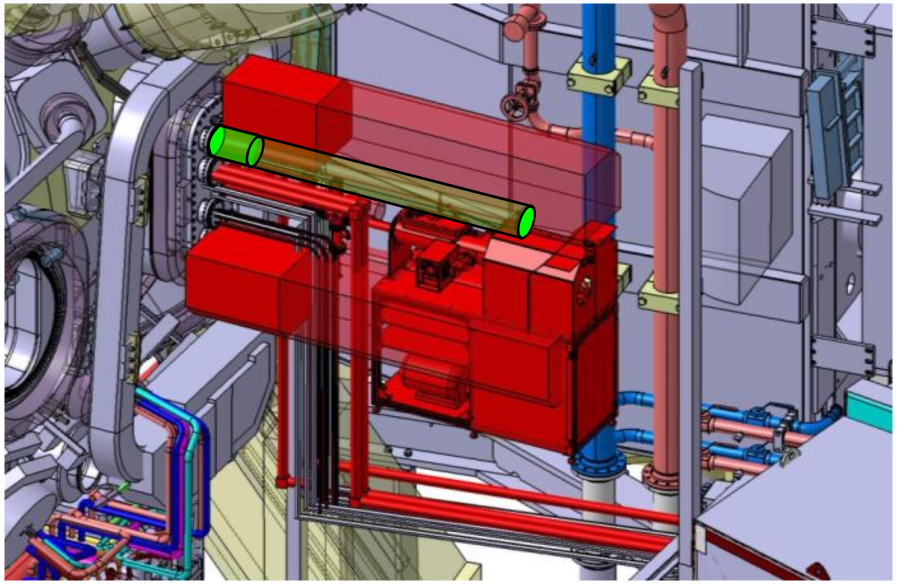
K1 (AEA21): Integration

AEA21 Port has a combined concept (1-QMR2-T0000) for the multiple diagnostic plug-ins.
Access from a platform between NBI boxes.

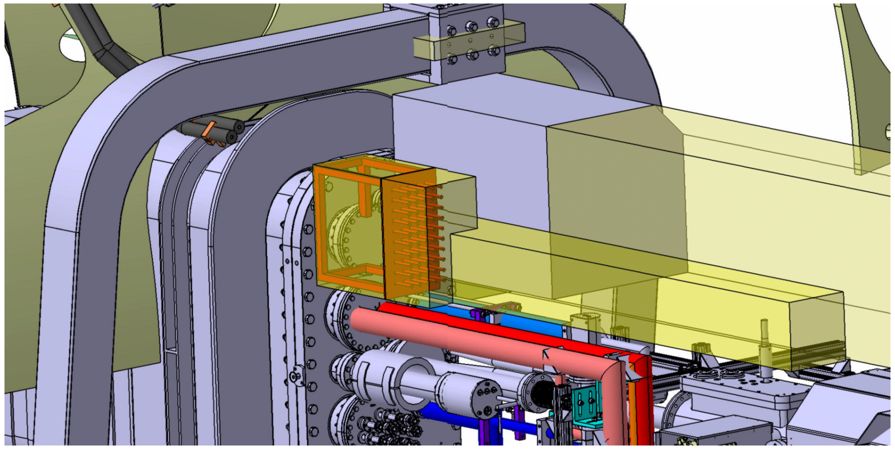
Rail system for insertion/removal of whole port flange:



Space reservation: Existing:



Extended to include patch panel:



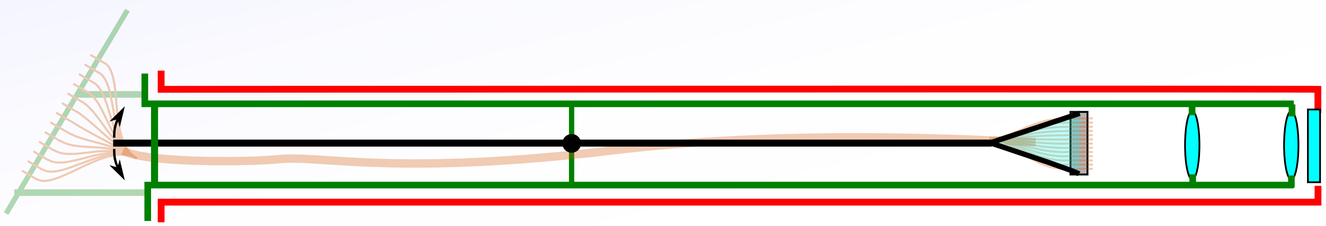
CXRS plug-in installation/calibration to be integrated with port:
- Check construction/maintenance space conflict with assembly tools.
- Flex of fibres during port removal installation - should remain connected.

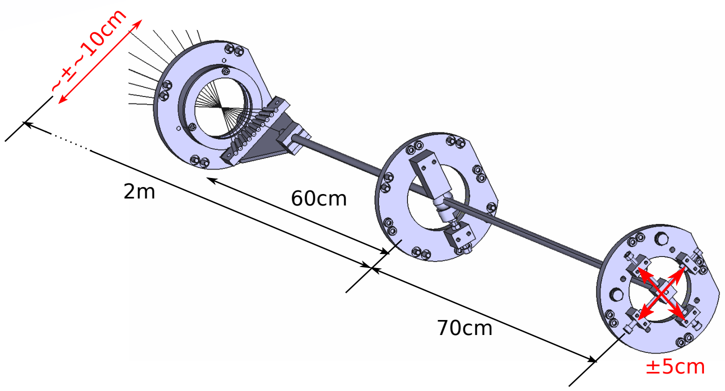
K1 (AEA21): Installation / Calibration

AEA21 Port is entry port, no access to module 2 for in-vessel calibrations with port in place.
Alignment may change on open/close of mirror.

Spatial calibration:

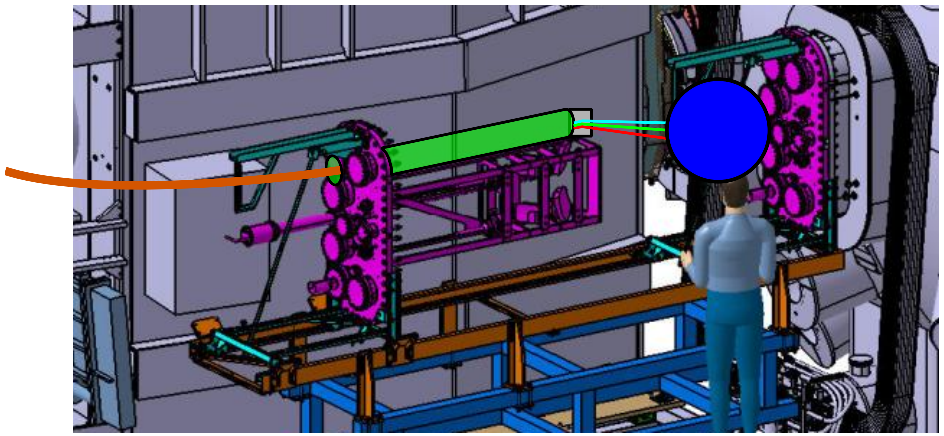
- Approximate mirror position/stop set relative to A-port flange by backlighting fibres in lab/hall.
- Exact position inferred from intensity and BES signals (see later).
- Fine adjustments made by movement of fibre holder (from outside), as AEM41 design (CXRS on RuDIX):
- *[Possibly: Back-light fibres and look for on flux-surface measurement system]*





Intensity calibration:

- Install CXRS immersion tube into A-port flange (lab or hall)
- Connect fibres - In hall, just before final installation of A-port.
- Intensity calibration with Ulbricht sphere.
- Final installation of A-port.

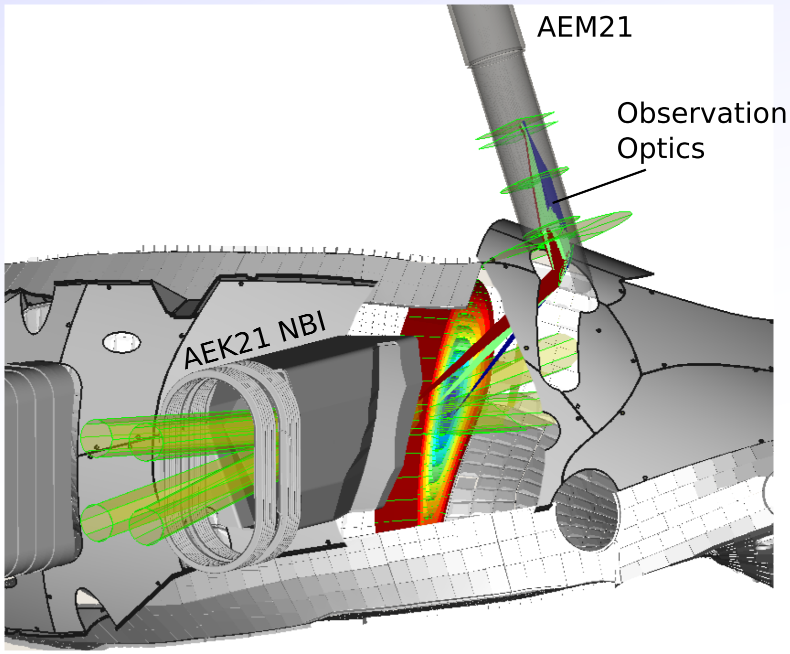


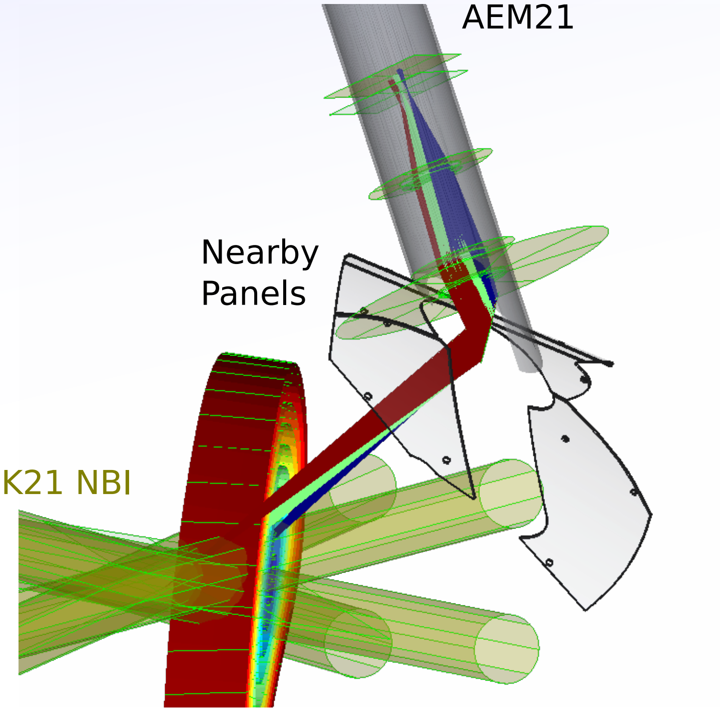
For OP1.2a: Possible only if immersion tube + fibres + 1 spectrometer are ready (unlikely).

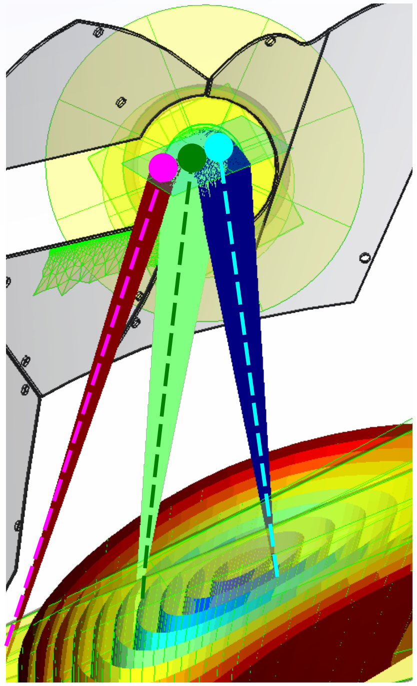
Calibration is strongly desired but not essential for OP1.2a.
If components are not ready, can be abandoned.

K2 (AEM21): View

The AEM21 port was foreseen for bulk spectroscopy but released for CXRS on NBI (CN in progress).
Views K21 from ~45° above for radial electric field (E_r) measurement.







Optimised effective view positions to core/edge.

As A21, optics need to image the beams on a fibre bundle, via a mirror.
Again, we want the largest possible mirror but window, lens and image (i.e. fibre holder) size are not limiting in this case.

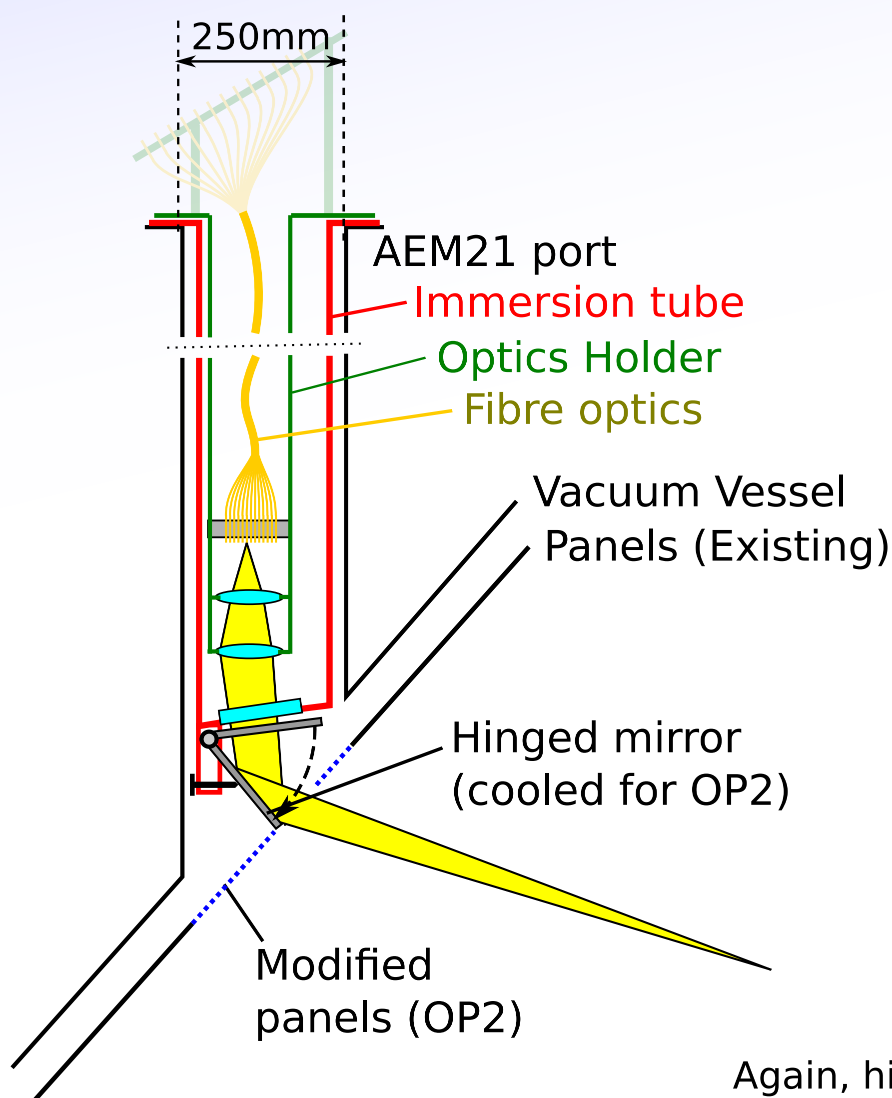
Technical requirements:

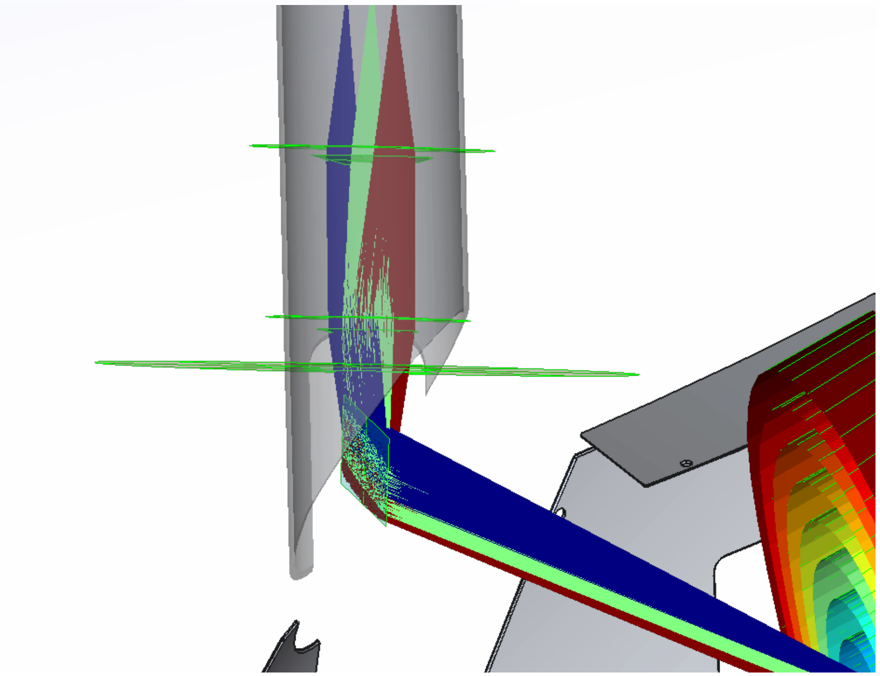
- Vacuum barrier, try to keep optical components on air side.
- Adjustable mirror for optical alignment.
- Shutter for protection of first mirror/window against coatings when diagnostic/NBI is off.
- Cooling of plasma facing components (window, mirror and/or shutter) against plasma and ECRH radiation for OP2.

K2 (AEM21): Optics

Mirror must protrude to within 10mm of the panel level, so air-side mirror not possible.

Collection area is long but narrow so most of the port can be closed for OP1.2 by modifying the cooled panels. This would reduce heat load on mirror and window.

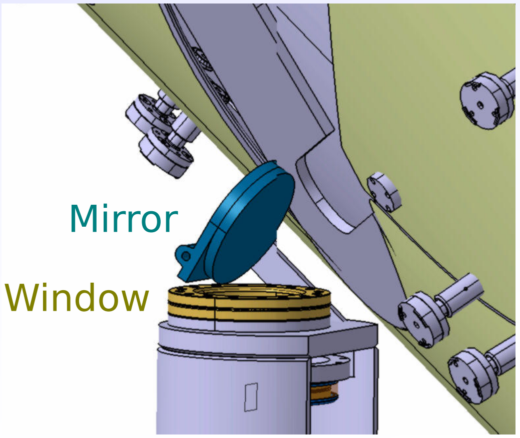


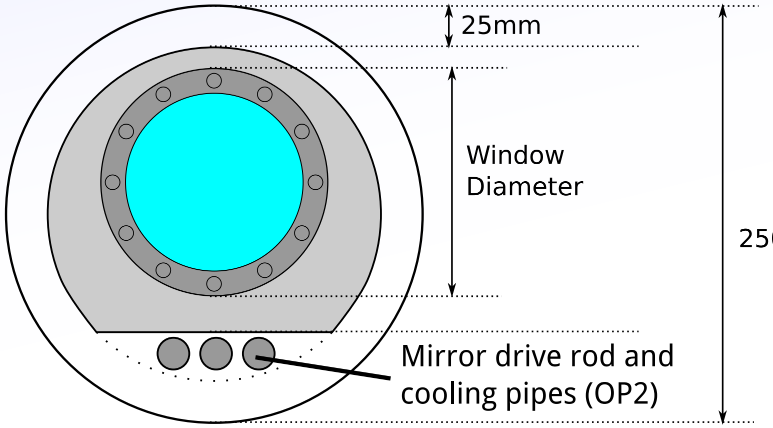


Again, hinged mirror may give relatively poor alignment reproducibility but we can cover this using BES based spatial calibration.

K2 AEM21 Vacuum Window

AEM21 Port tube is 250mm.
Need 25mm space because of inaccuracies and changes during baking.
Also need space for mirror drive rod on one side.
Immersion tube from AEM41 design (CXRS on RuDIX) (built and OP2 tested) but with different head:





Available CF viewports:
DN160CF: 205mm, 136mm aperture
DN100CF: 152mm, 90mm aperture
DN

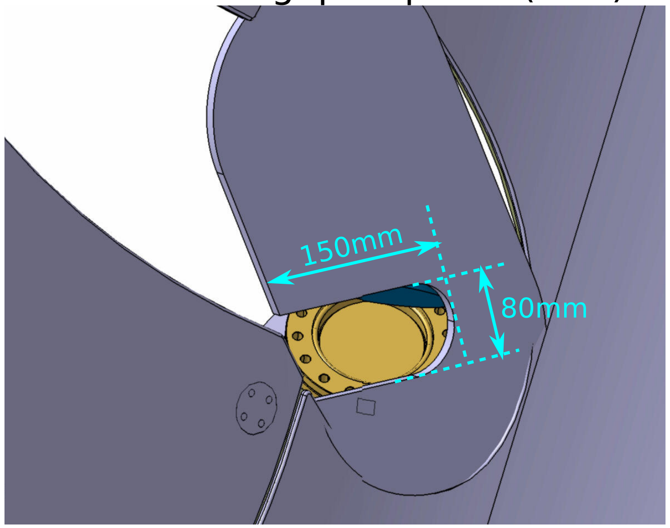
Required window size depends on optical fibres, spectrometers, desired imaging resolution etc.

Window aperture must be at least 70mm to overfill fibres and give flexibility for exact optical design.

Options with sufficient aperture:
- DN100CF standard flange (90mm)
  - Simple and fast to order for OP1.2.
  - May not tolerate OP2 heat load.

- Design of AEM41:
  - Fully OP2 tested with full exposure.
  - Complex to build, but already designed.

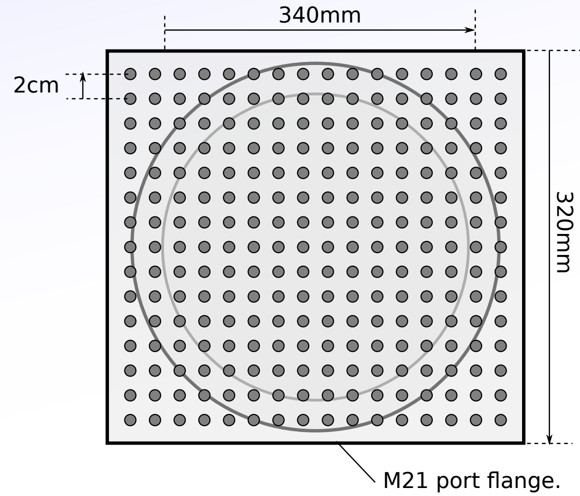
Panel closure gap required (OP2):

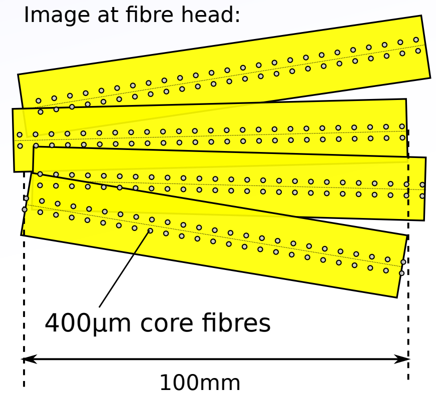


K2 (AEM21): Outside Port

As with A21, we need to reserve space for the patch panel and for the port to be removed with it.

Maximum requirement:
For M21, each beam much be separately imaged.
240 fibres = 15*16 grid which would be
340x320mm, just larger than port flange:

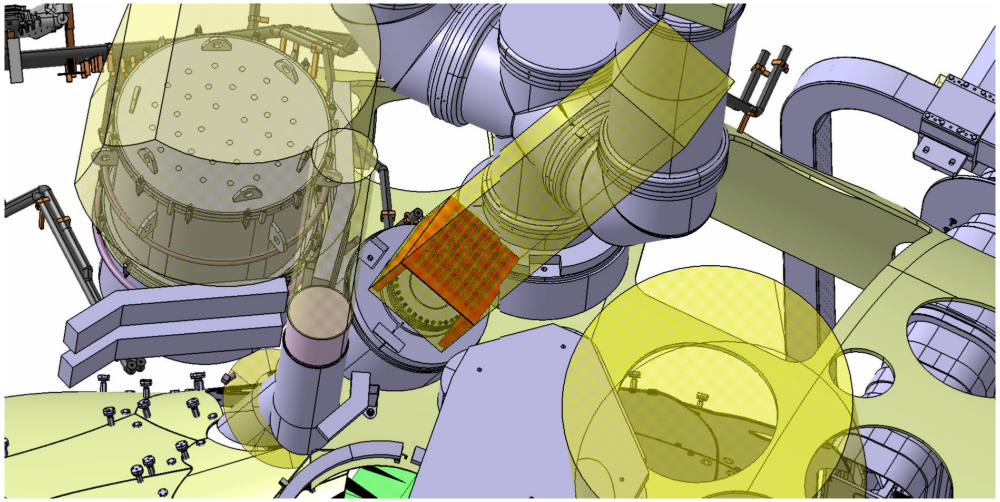




Installation:
Need to agree installation concept with Assembly.
Existing are:
- AEM31 (Thomson Scattering): Lowered by crane, rod connected to front to guide in from inside vessel.
- Hα F-ports (Cameras): Lowered by crane with counterweight at back to balance in correct angle.

Access:
- Platform required for access during campaigns to switch fibres at the patch panel or adjust alignment.

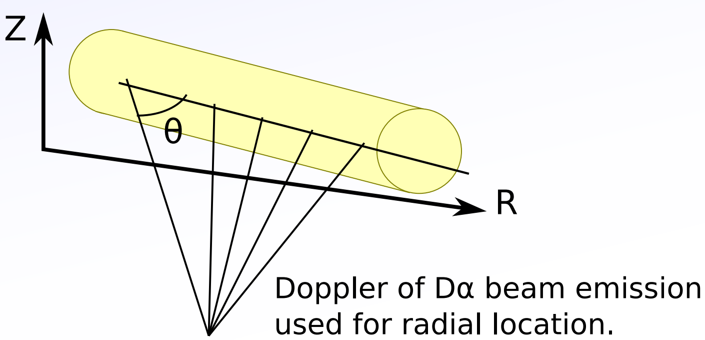
Space reservation extended to 40x40cm to include extraction/installation with patch panel:



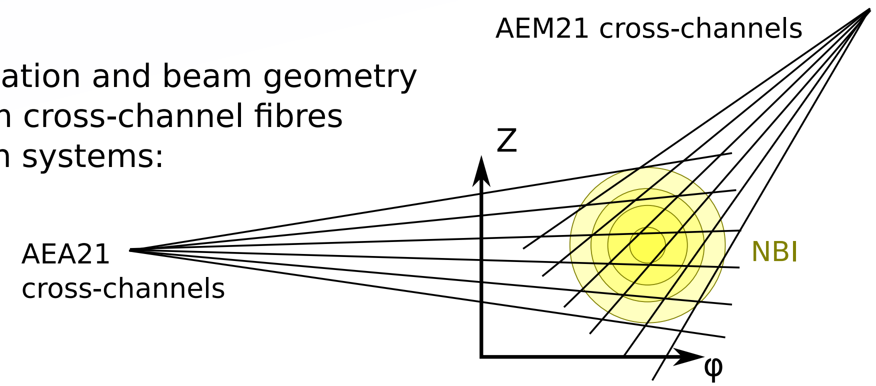
AEM21: Installation and Calibration

- AEM21 can be adjusted and calibrated in vessel (spatial + intesity).
- Movable mirror will allow spatial calibration to change.
- Beam geometry is likely to anyway be unknown.

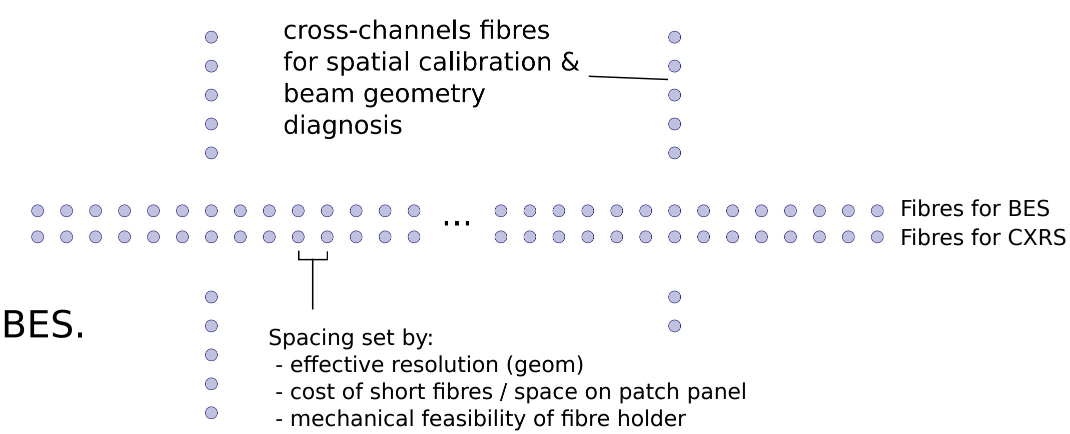
Auto spatial calibration: Plasma measurements give information about spatial positioning:
- Doppler shift of BES (Hα) measurements gives the angle to the beam very accurately --> Radial positioning.
- Intensity variation across beam gives the perpendicular channel position or the beam position.



φ/Z location of observation and beam geometry can be measured from cross-channel fibres of the two observation systems:



Modify fibre layout to allow for this calibration:

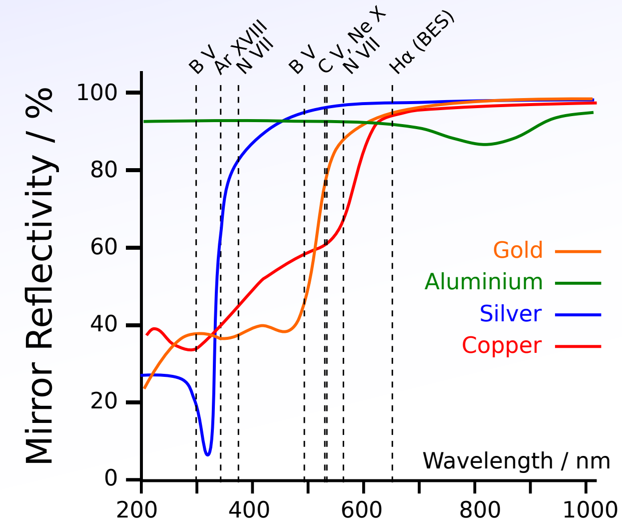


Intensity calibration:
- Should be done in-vessel if possible.
- ITER-like spectrometer claims it can be inherent from BES.
- Can check with optics model and Bremstrahlung.

K1-3: Mirrors and windows

Mirror material:

- For CXRS a solid-metal mirror is sufficient with coating to cover visible range and into UV (down to 300nm).
- Copper & Gold: both fall off before 400nm.
- Silver: OK at 400nm but no further so we lose some UV lines (e.g. B, Ar).
- Some aluminium coatings go down to 300nm.
- **'Protected Aluminium'** (i.e. coated) so it can be cleaned during openings.
- Needs to survive baking to 150'C and heating by plasma.

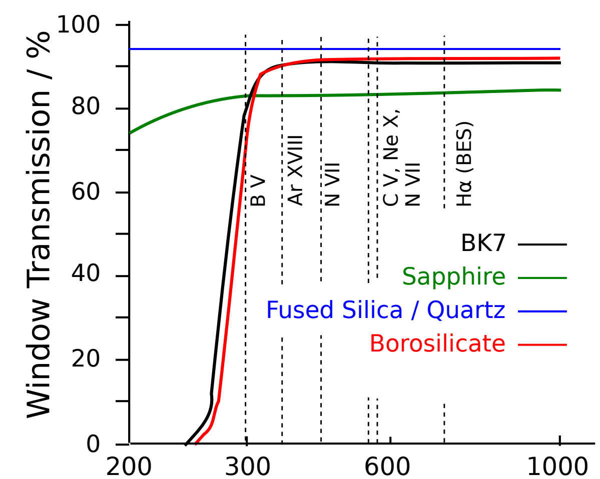


Vacuum window:

Glass: We would like to keep UV to 300nm as much as possible.

- **Optical grade Fused Silica:** is slightly higher transmission and better tolerates rapid thermal variations than Sapphire.

(Thomson Scattering: 200mm Fused Silica at roughly same distance from plasma and more exposed)



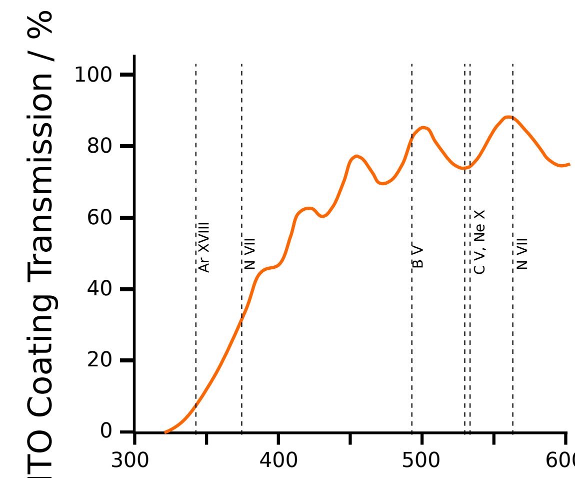
For ECRH stray radiation protection:

1) ITO coating:

+Simple solution
- Lose Ar XVIII line, low N VII line.
- Strong local deformations to tranmission curve.

2) Protect everything in air-side:

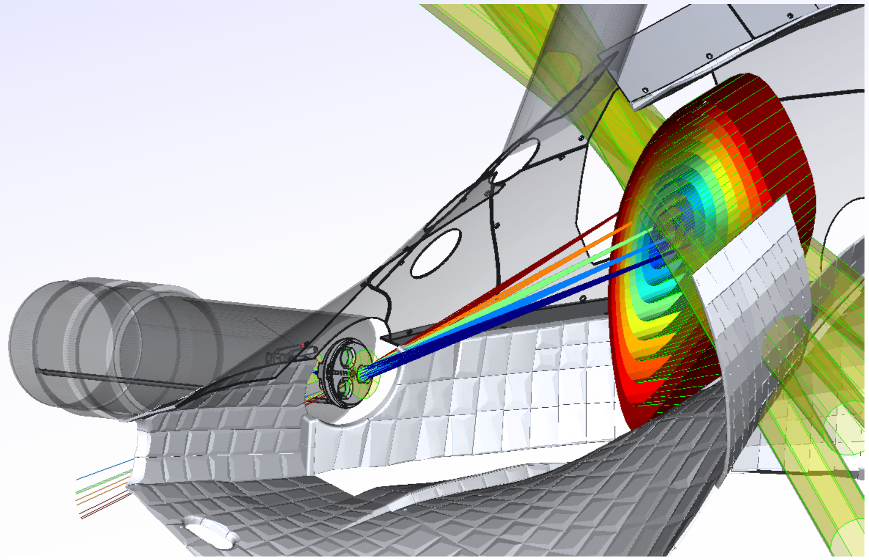
+Can still measure Ar XVIII, N VII.
- Must protect/check everything airside (lenses, fibres, holders, glue etc).

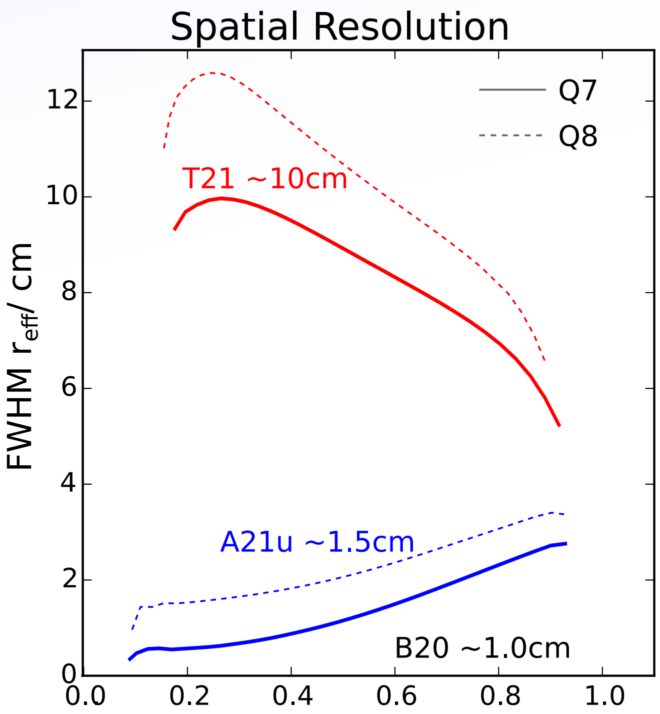


Purchase window with and without ITO coating.

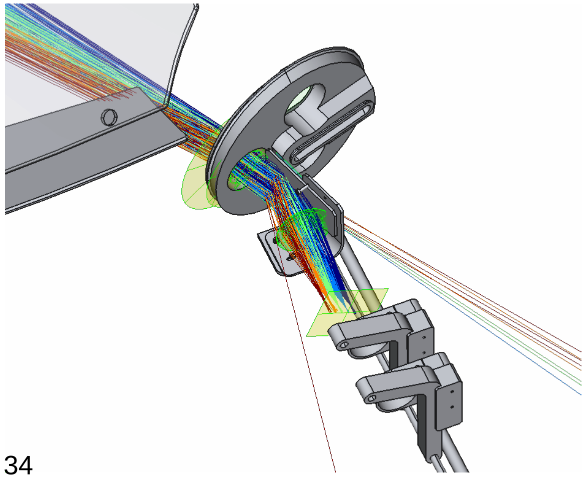
K3: AET21 optics

- AET21 port is primarily for the Heat Shield Thermography (HST) for the NBI.
- H-Alpha type 2 immersion tube already built with 3 windows, one can be used by CXRS.
- Very poor spatial resolution, but good Er cross check due to opposing view to AEM21.





Optics:



- View of beam can be achieved with a simple fixed mirror and prism against the existing window.
- Immersion tube, shutter etc all handled by HST.
- Only simple air-side optics required for CXRS.
- Relatively low benefit but very low effort additional view.

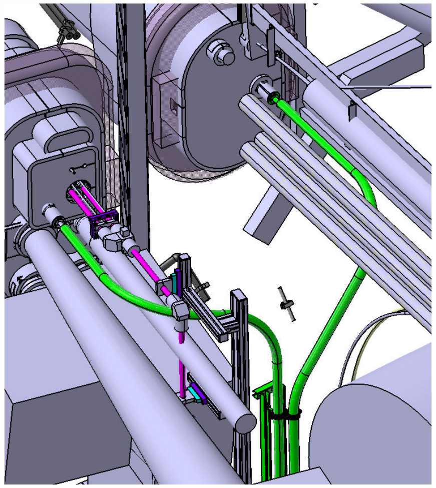
~8 spatial channels x2 beams = 16 fibres.
- Small patch panel within existing port tube dimensions.
  (No extra space reservation required)

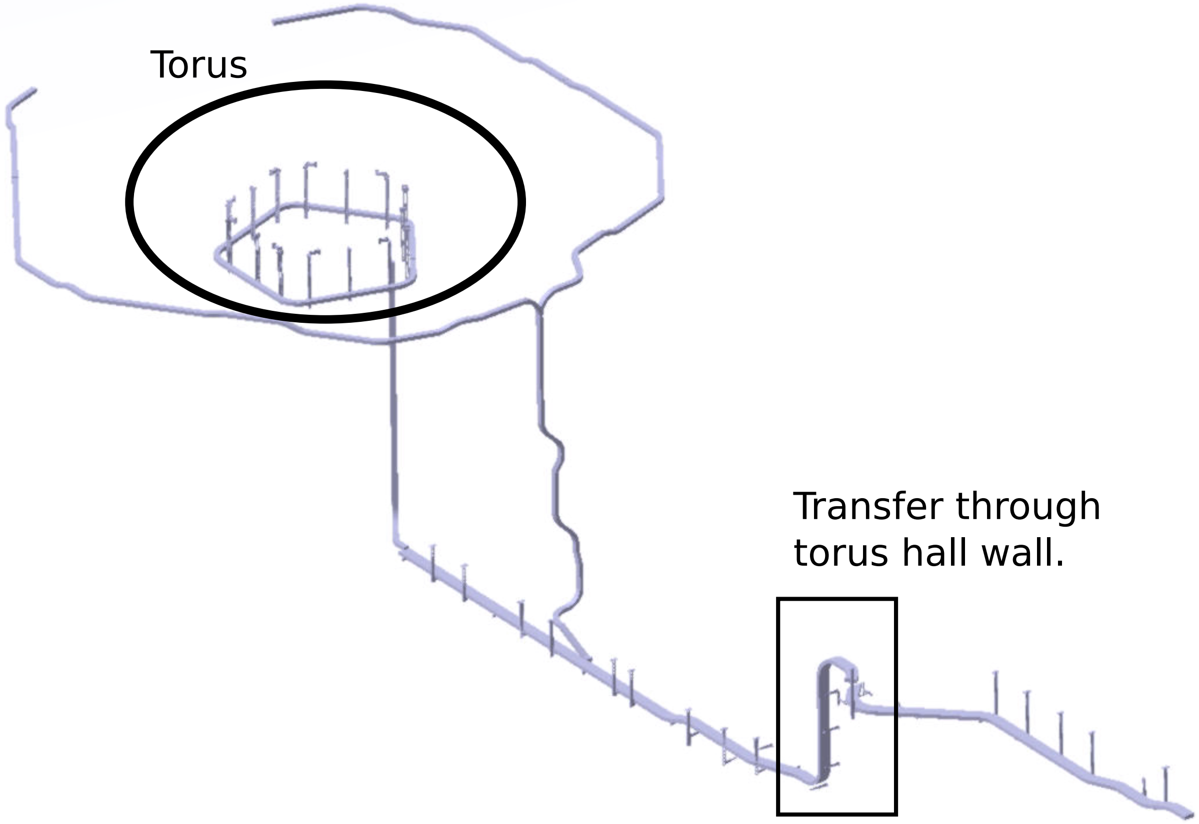
K4: Optic fibre transfer to lab

Fibres bundles need to be routed from ports to spectroscopy Lab (UG1-109/110).
Cable tray design combined for many spectroscopy diagnostics (see Pflichtenheft 1-GDL30SR022-S0002.3) and includes space for 4x 25mm fibre bundles for CXRS on NBI.
An additional bundle was foreseen for CXRS on RuDIX and can be transferred to CXRS on NBI.
A further 30% increase is within the planning.

For OP1.2, a single bundle of ~100 400µm fibres each to AEA21 and to AEM21, and an additional small bundle of 12 fibres to AET21 will be sufficient.

The design includes the concept of guide tubes from the cable tray to the ports:





The guide tube to AEM21 is currently not included, and must be added or covered within this project.

K5: Spectrometers

Spectrometers will be placed on optical benches and/or shelves in the spectroscopy laboratories UG1-110/109.
Space is limited so a rack will be investigated to allow more spectrometers later.

Two electrical cubicles have been ordered for UG1-110. Water cooled.
Water cooling circuit for both labs is needed.

Initially foreseen spectrometers:

Jülich ITER-like spectrometer (0k€)
(on loan from Jülich in collaboration with Eindhoven)

+ Well understood, reliable, well-tested system, used at ASDEX Upgrade until now.
+ Carbon, Helium and H-alpha (BES) in one.
+ Very high étendue (Good Signal/Noise).
+ (Comes with a student)
- Large footprint.
- Fixed wavelength/no other impurities.
- 3 CCDs, of different types.

ASDEX Upgrade 'R.Dux' Spectrometer.
Rebuild to design (40k€ + 30k€/CCD)

+ Well understood, reliable, well-tested system, experience inside IPP.
+ Variable wavelength / impurity.
+ High étendue (F/2.7) (Good Signal/Noise).

- Design available but we need to have them built.

K5: Spectrometers

Other possibilities:

Czerny-Turner spectrometers (Greifswald)
from W7-AS etc, need new CCD cameras (30k€ each)

+ In IPP Greifswald. We have already:
  2x 500mm (F/4)
  3x 750mm (F/6)
  2x 1000mm (F/8)
  2x 1250mm (F/9)
  +(1x 500mm + 1x750mm foreseen for RuDIX CXRS)

+ Variable wavelength / impurity
- Lower étendue (lower Signal/Noise per fibre).
- Require new CCDs (existing ones not supported by CoDAC)
  fitting, testing etc.

USB Spectrometers (3-5k€)

+ Complete ready units to purchase for < 5k€.
- Very low resolution, good for intensity/survey only.

System plan 1

Spectrometer types, costs and numbers are not yet fully determined. Current plan is to have many more than the required fibres to allow flexibility for upgrade and reconfiguration in the lab during OP1.2.

Optical Heads

AEA21
2 beam positions.
30 channels min.
BES+CXRS.
= 120 fibres *(60 for OP1.2)*.

AEM21
4 beam positions.
30 channels min.
BES+CXRS.
= 240 fibres *(120 or OP1.2)*

+BG channels?

AET21:
2 beams, 8 channels.
= 16 fibres

Total 376 available fibres.

Fibre Bundles

[e.g. RuDIX CXRS is a bundle of 540x 100µm fibres, bundle diameter ~12mm. 13k€ ~30m.]

Space in trays for 5x 25cm bundles, so can fit easily > 500 fibres.

Estimate:
AEA21: 1x 80 fibre bundle.
AEM21: 1x 80 fibre bundle.
AET21: 1x 8 fibre bundle.

168 fibres x 90m x 6€ = 90k€

Basic cost: 230k€ (105% of budget)
Delivered measurements: 80
3cm resolution
Ti, Er, ωφ, n_b,
n_z Carbon, Helium, Boron.

Single beam only.

Spectrometers

Current planning:

Jülich ITER Spectrometer (collab)
- 57 x 400µm fibres (30 chans)
- Carbon & He (CXRS) + Hα (BES)

2x AUG Spectrometer (2x 40k€)
- 25 x 400µm fibres (8mm CCD).
- Variable wavelength
- 16ms full frame (all channels)
+ 2xCCDs (2x 30k€)

= 80 measurements 140k€

Others can use fibres:
+1x AUG Spectrometer for FIDA (70k€)
- 20 x 400µm fibres.
- Variable wavelength

USB Spectrometers (~5k€ each)
Z_{eff}, collaborations etc.

System plan 2

With 50% greater budget we can purchase CCDs for the existing Czerny-Turner spectrometers (~30k€ each), and use more of the fibres. No change to in-hall components required.

Optical Heads

AEA21
2 beam positions.
30 channels min.
BES+CXRS.
= 120 fibres *(60 for OP1.2)*.

AEM21
4 beam positions.
30 channels min.
BES+CXRS.
= 240 fibres *(120 or OP1.2)*

+BG channels?

AET21:
2 beams, 8 channels.
= 16 fibres

Total 376 available fibres.

Fibre Bundles

[e.g. RuDIX CXRS is a bundle of 540x 100µm fibres, bundle diameter ~12mm. 13k€ ~30m.]

Space in trays for 5x 25cm bundles, so can fit easily > 500 fibres.

Estimate:
AEA21: 1x 80 fibre bundle.
AEM21: 1x 80 fibre bundle.
AET21: 1x 8 fibre bundle.

168 fibres x 90m x 6€ = 90k€

Basic cost: 330€ (150% of budget)
Delivered measurements: 143
2cm resolution
Ti, Er, ωφ, n_b,
n_z Carbon, Helium, Boron
+Nitrogen/Neon/Argon + FIDA
+Edge optimised systems.
+both beams.

Spectrometers

Current planning:

Jülich ITER Spectrometer (collab)
- 50 x 400µm fibres (30 chans).
- Carbon & He (CXRS) + Hα (BES)

2x AUG Spectrometer (2x 40k€)
- 25 x 400µm fibres (8mm CCD).
- Variable wavelength
- 16ms full frame (all channels)
+ 2xCCDs (2x 30k€)

+3x Czerny-Turner Spectrometers (0€)
- 20 x 400µm fibres.
- Variable wavelength
- F/4, F/6, good for edge,
- need CCDs (3x 30k€)

+3x USB Spectrometers (3x 4k€)

= 143 measurements 240k€

Others can use fibres:
+1x AUG Spectrometer for FIDA (70k€)
- 20 x 400µm fibres.
- Variable wavelength

Z_{eff}, collaborations etc.

Control, Media and CoDAC Requirements

Defined and summarised in Lastenheft (1-QSK-L0000).
Generally very simple requirements with very few in-hall components.

OP1.2 Required

-AEA21 and AEM21 immersion tube mirror/shutters need to be integrated into central central control system. Segement control for: open, closed, automatically with NBI.

- Open/closed state switches for shutters. Connected outside port.

- Standard PCs for each CCD, initially 6x.

Trigger/Timing module: Configurable trigger series, 1 trigger per image, with timestamp stored.
[If not possible, CCDs can run from single start trigger, but time-stamps need to be stored]

OP2 Required

Water coolant supply for immersion tubes, shutter/mirror etc.
- Temperature + flow measurements as with other diagnostics.

Desired

Data acquisition from CCDs, control of spectrometers, writing to database etc.
Initially foreseen to be done with ASDEX Upgrade software, by RO, or as part of collaboration for ITER-like spectrometer.

2x Electric cabinets have been ordered for UG1-110 with water cooling.

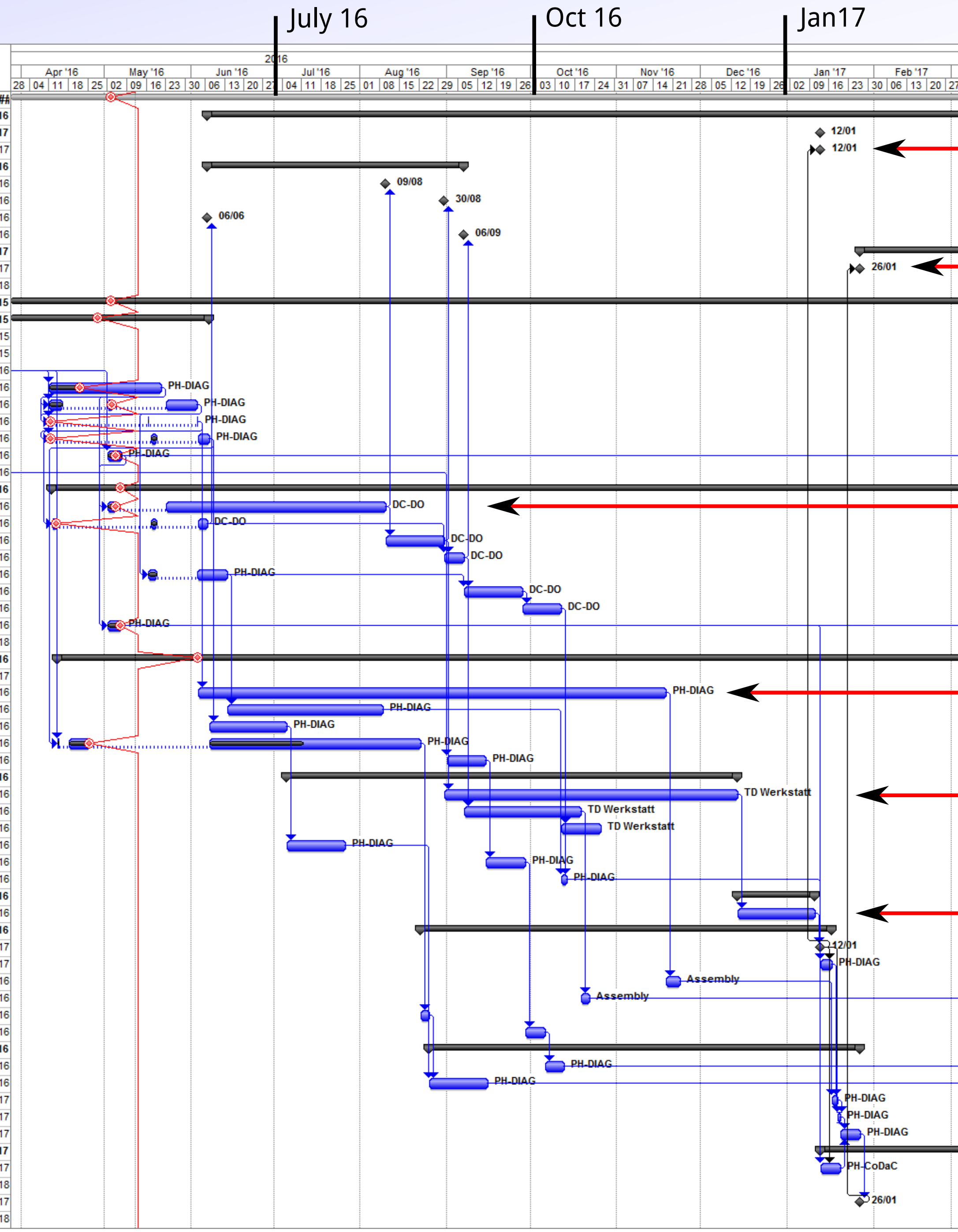
Time plan

- Time plan is very tight - project started late.
- First priority is the design, ordering and manufacture of in-vessel components K1, K2.
    - Try to achieve by OP1.2a vacuum closing, otherwise install for OP1.2b.
    - Prioritise K2 (AEM21) over K1 if only one can be achieved (for Er measurement).

- Second priority is ordering fibre bundles - try to have ready by start of OP1.2a.
- Remaining work can be done during OP1.2a, as NBI will most likely not be ready until late in campaign.
- Organising ITER-like spectrometer delivery for ~Nov2016.

WBS Time plan

ID		Name	abge-schlossen in %	Duration	Start
0		**1-QSK-P1000_CXRS_an_NBI**	**22%**	**661 d?**	**##########**
1		**Liefertermine (LT) - Bedarfstermine (BT) / Meilenstein**	**0%**	**483.3 d**	**Mon 06/06/16**
2		**Liefertermine (LT) von QSK an AS**	**0%**	**0 d**	**Thu 12/01/17**
3		Immersion tubes ready to install (OP1.2b at the latest)	0%	0 d	Thu 12/01/17
4		**Liefertermine (LT) von DC an QSK**	**0%**	**66.3 d**	**Mon 06/06/16**
5		Design Tauchflansch	0%	0 d	Tue 09/08/16
6		Manufacturing Drawings Immersion Tubes	0%	0 d	Tue 30/08/16
7		Design spectrometers, fiber routing, infrastructure	0%	0 d	Mon 06/06/16
8		Manufacturing Drawings infrastructure	0%	0 d	Tue 06/09/16
9		**Meilensteine**	**0%**	**315 d**	**Thu 26/01/17**
10		CXRS ready for OP1.2 measurements (during OP1.2b	0%	0 d	Thu 26/01/17
11		CXRS fully integrated for routine operation (OP2)	0%	0 d	Thu 12/04/18
12		**1-QSK10-CXRS_an_NBI**	**22%**	**661 d?**	**Thu 01/10/15**
13		**R&D**	**80%**	**178.2 d**	**Thu 01/10/15**
14	✓	Start activity on project QSK	100%	1 d	Thu 01/10/15
15	✓	Asses Possible Ports/Views	100%	5.1 mo	Fri 02/10/15
16	✓	Final Decision on Ports/Views	100%	1 d	Tue 23/02/16
17		Concept Immersion Tubes, window and mirror	30%	6 w	Mon 11/04/16
18		Concept optical system (inside immersion tubes)	40%	3 w	Mon 11/04/16
19		Concept fibers, patch panels	80%	1 d	Mon 11/04/16
20		Concept spectrometers	60%	1 w	Mon 11/04/16
21	✓	Concept CoDaC OP1.2 requirements	100%	1 w	Mon 02/05/16
22	✓	Agree use of high-etendue spectrometer with TU/e	100%	1 d	Tue 08/03/16
23		**Design and manufacturing drawings**	**12%**	**473 d?**	**Tue 12/04/16**
24		Design Immersion Tubes	5%	12 w	Mon 02/05/16
25		Fiber routing, infrastructure	70%	1 w	Tue 12/04/16
26		Manufacture drawings Immersion Tubes	0%	3 w	Wed 10/08/16
27		Manufacture drawings infrastructure	0%	1 w	Wed 31/08/16
28		Optical design (ray tracing)	30%	2 w	Mon 16/05/16
29		Design optics holders	0%	3 w	Wed 07/09/16
30		Drawings optics holders	0%	2 w	Wed 28/09/16
31	✓	Concept for CoDaC, Lastenheft OP1.2 requirements	100%	1 w	Mon 02/05/16
32		Concept for CoDaC full integration, Lastenheft OP2	0%	1 d?	Thu 01/02/18
33		**Orders**	**12%**	**282 d**	**Thu 14/04/16**
34		Order other infrastructure	0%	2 d	Thu 11/05/17
35		Order fibers	0%	6 mo	Fri 03/06/16
36		Order optics (lenses etc) (~30k€)	0%	2 mo	Tue 14/06/16
37		Order CCDs (2x, ~30k€ each)	0%	4 w	Tue 07/06/16
38		Order 2 electrical cabinets (1.6k€ each)	50%	3 mo	Thu 14/04/16
39		Transport High Etendue Spectrometer from Garching	0%	2 w	Thu 01/09/16
40		**Manufacturing**	**0%**	**115.8 d**	**Tue 05/07/16**
41		Manufacture Immersion Tubes	0%	15 w	Wed 31/08/16
42		Manufacture infrastructure	0%	6 w	Wed 07/09/16
43		Manufacture optics holder	0%	2 w	Wed 12/10/16
44		Assemble other spectrometers, CCD's	0%	3 w	Tue 05/07/16
45		Assemble High Etendue Spectrometer	0%	2 w	Thu 15/09/16
46		Assemble optics	0%	2 d	Wed 12/10/16
47		**Testing**	**0%**	**20 d**	**Wed 14/12/16**
48		Test Immersion Tubes	0%	4 w	Wed 14/12/16
49		**Installation**	**0%**	**105.8 d**	**Mon 22/08/16**
50		Install Immersion Tubes (Latest OP1.2b)	0%	2 d	Wed 11/01/17
51		Install optics	0%	2 d	Fri 13/01/17
52		Install fibres	0%	3 d	Fri 18/11/16
53		Install infrastructure	0%	3 d	Wed 19/10/16
54		Installation electrical cabinets in spectroscopy room	0%	3 d	Mon 22/08/16
55		Install high etendue Spectrometer	0%	1 w	Thu 29/09/16
56		**Test and calibration**	**0%**	**110.8 d**	**Thu 25/08/16**
57		Test High Etendue Spectrometer	0%	1 w	Thu 06/10/16
58		Test spectrometers, CCD's	0%	3 w	Thu 25/08/16
59		Test optics, fibers links	0%	2 d	Tue 17/01/17
60		In-vessel calibration	0%	1 d	Thu 19/01/17
61		Set-up, final tests and calibration for test operation	0%	1 w	Fri 20/01/17
62		**Integration / CoDaC**	**0%**	**325 d**	**Fri 13/01/17**
63		CODAC integration of shutter control	0%	1 w	Fri 13/01/17
64		Final CODAC integration of spectrometers etc	0%	10 w	Fri 02/02/18
65		Ready for OP1.2 measurements	0%	0 d	Thu 26/01/17
66		Fully integrated operation	0%	0 d	Thu 12/04/18



Critical path

Priority 1: Immersion tubes ready (Early Jan)

Priority 2: Calibration possible (Late Jan)

Immersion tube design

Fibres tender action

Immersion tube manufacturing

Immersion tube Vacuum/heat testing.

Open Questions

Urgent design decisions:

- AEM21: Vacuum window - CF Flange or copy AEM41?
- Shutter/mirror drive and cooling mechanism for both AEM21 and AEA21.
- How much of OP2 requirements to satisfy now.

Time critical orders:

- Fibres, >100k€, requires tender action - start generic requests immediately.
- CCDs, 60k€, requires tender action.
- Windows and seals,
- Mirrors
- Vacuum feed throughs

(Windows and seals, Mirrors, Vacuum feed throughs: required for port tube installation.)

Non-urgent open questions:

- Space allocation in laboratory.
- Finalise fibre layout in optical heads.
- Integration of installation/calibration procedure in AEA21 concept.
- More precise financial plan including mechanical components.
- Water cooling and power supplies for lab electrical racks.
- Initial fibre-spectrometer configuration.

Procedural/Documentation:

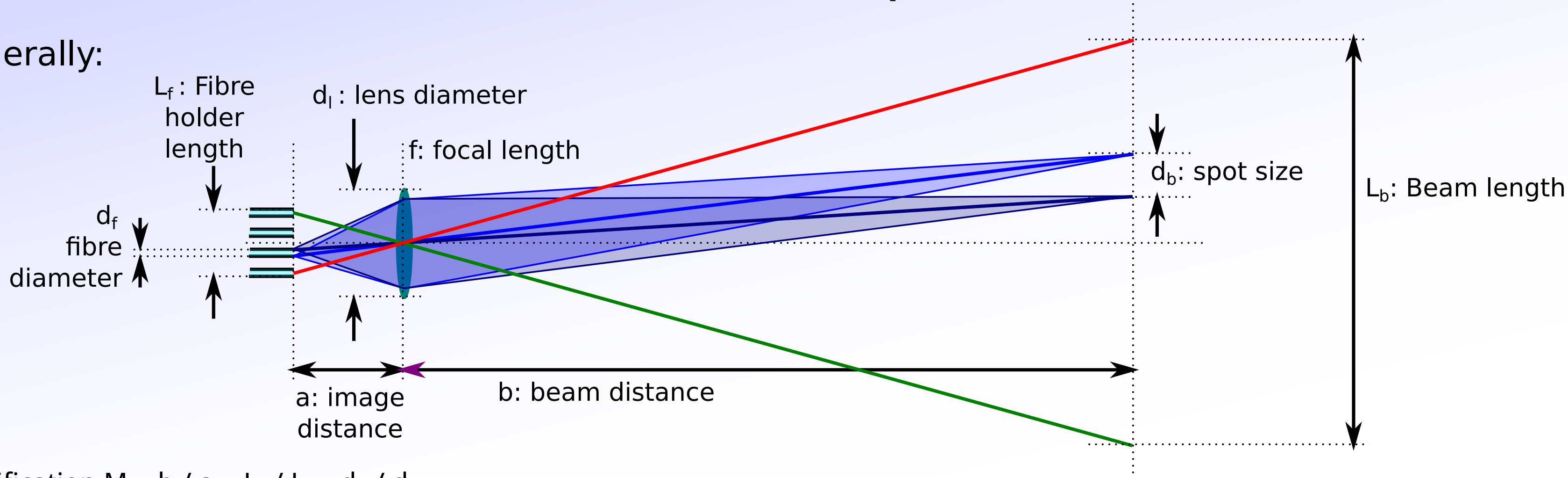
- Change Note for AEM21 port.
- Change of maintenance space for patch panels at AEM21, AET21.

Safety:

- No significant safety risks to machine or people.
- Passive components: No lasers, high voltage, high temperature, high pressure etc (except shutter drive)

[Additional] Optics Basic

Generally:

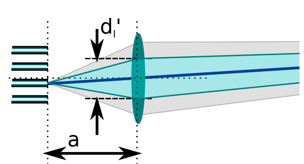


Fixed things:
Lb = 60cm
AEM21: b = 1300mm
AEA21: b = 2200mm
(including lens-mirror)

Magnification $M = b / a = L_b / L_f = d_b / d_f$
$d_b = d_f\, b / a$

Étendue of optics:
$G_o = \pi^2/4\, d_b^2\, d_l^2 / b^2 = \pi^2/4\, d_f^2\, d_l^2 / a^2$

So collected light G goes as $d_f^2\, d_l^2 / f^2$ until it overfills the fibre.
After that, effective lens size d_l' is determined by fibre NA:
$d_l' = 2\, a\, NA$
and the étendue is fixed at $é_f = \pi^2/4\, d_f^2\, NA^2$

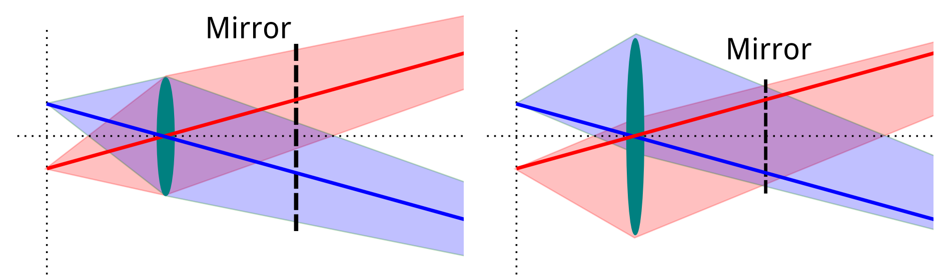


Increasing f then makes lens bigger and spot size smaller and é remains at the max. Minimum lens size to just fill the fibre is:
$d_l^2 = 4\, b^2\, d_f^2\, NA^2 / d_b^2$

So we can choose d_l or d_b. Bigger spot size = smaller lens.

Biggest possible dl just gives smaller db, which only helps if we want > 200 spatial positions per port. If we want more fibres for more light, we can stack vertically.
Set d_b to match 1/2 geometric resolution from flux surfaces.

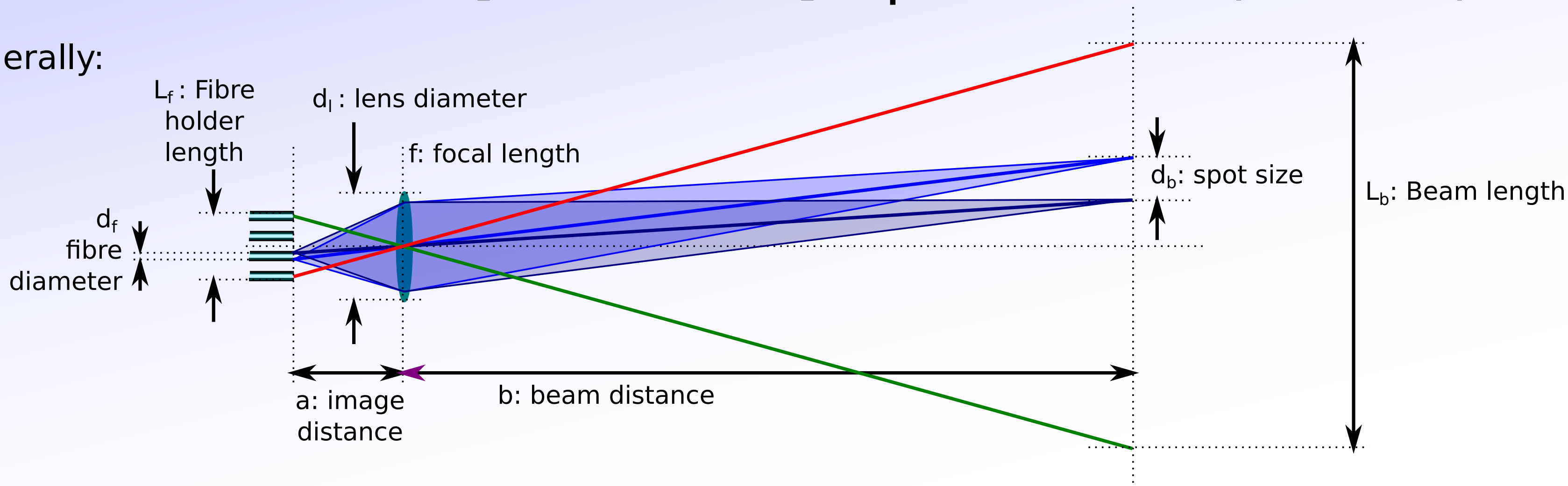
For the detailed optical design we can trade between window and mirror sizes, for the same aperture:



This also adjusts the virtual obs position and can fine-tune the geometric resolution.

[Additional] Optics Basic (AEM21)

Generally:



Fixed things:
Lb = 60cm
AEM21: b = 1300mm
AEA21: b = 2200mm
(including lens-mirror)

AEM21:
Min geom resolution in r_{Eff} (std/Q7, ρ=0.7) = 17mm
dR_{eff}/dR_{local} = 1.4, so requried local resolution = 17/1.4 = 12mm

Optical resolution of 5mm is more than good enough.

AUG fibres: d_f=400μm, NA=0.22,

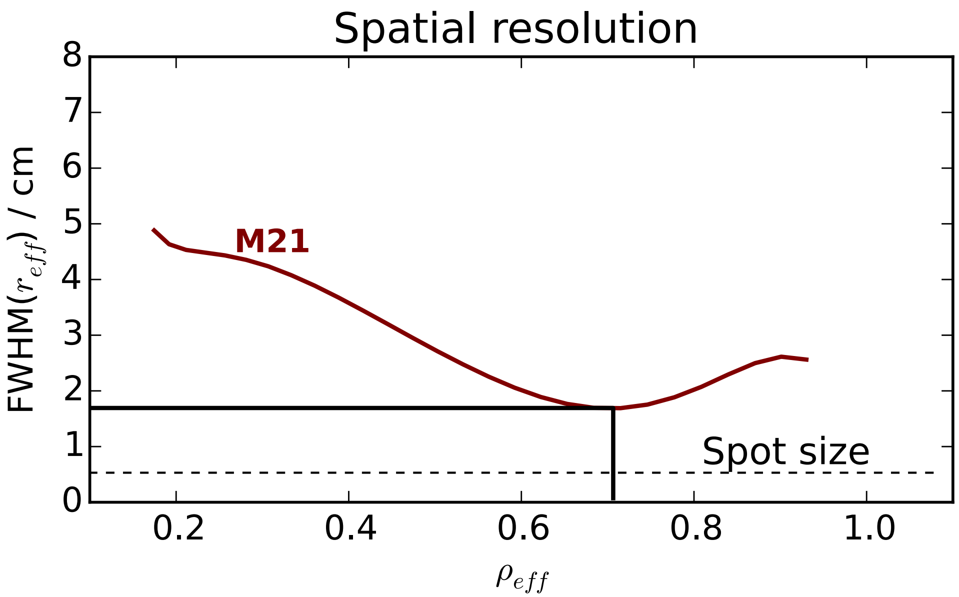
db = 5mm, M=5: **dl = 45mm**
a=88mm, f=82mm

Higher NA fibres: NA=0.28 (F/1.8), d_b = 5mm: **dl = 60mm**
(but NA=0.22 already fills the spectrometers)

Larger core fibres: df=1000μm, db = 5mm: **dl = 115mm**
Larger core fibres: df=1000μm, db = 10mm: **dl = 60mm**

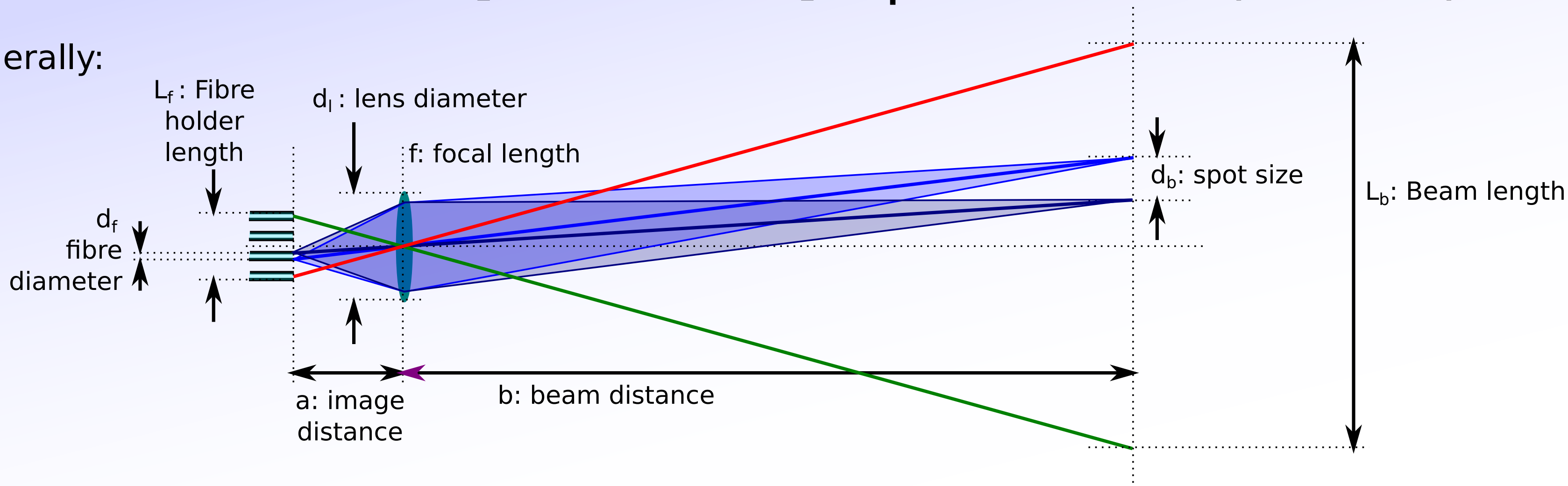
Bigger spot sizes:
OK: db = 10mm: **dl = 20mm**, f=25mm
LowRes: db = 30mm: **dl = 7mm**, f=17mm
Short focal lengths become difficult to get good focus.

Desired window: 50mm < dl < 90mm



[Additional] Optics Basic (AEA21)

Generally:



Fixed things:
Lb = 60cm
AEM21: b = 1300mm
AEA21: b = 2200mm
(including lens-mirror)

AEA21:
Min geom resolution in r_{Eff} (std/Q7, ρ=0.0) = 8mm
dR_{eff}/dR_{local} = 1.4, so requried local resolution = 8/1.4 = 5mm

Optical resolution should be 2.5mm (means 200 fibres!!)

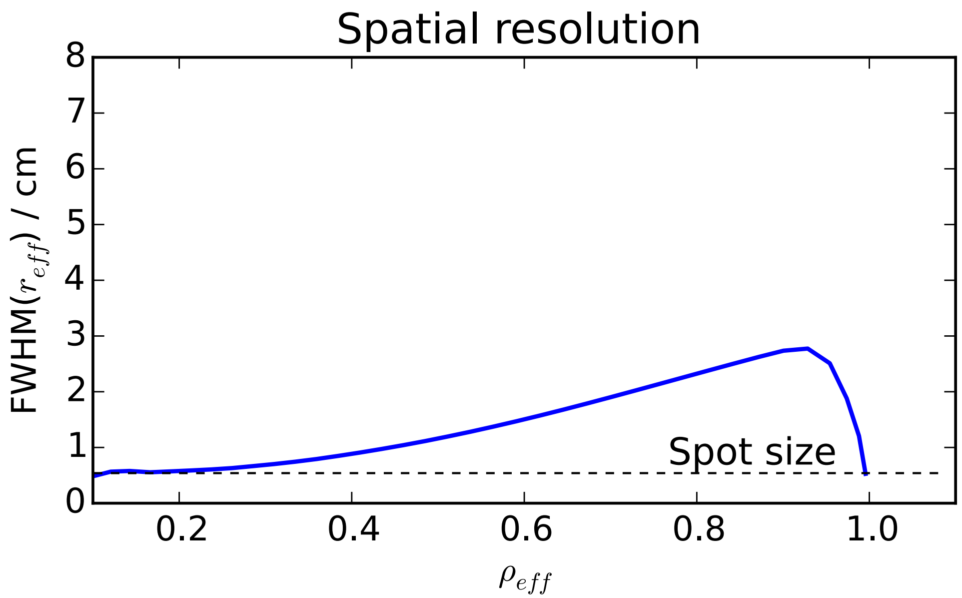
AUG fibres: d_f=400μm, NA=0.22,

db = 2.5mm, M=6: **dl = 150mm** (too big) f=300mm
db = 5mm, M=13: **dl = 80mm** (good) f=160mm

Higher NA fibres: NA=0.28 (F/1.4), d_b = 5mm: **dl = 100mm**
(but NA=0.22 already fills the spectrometers)

With reasonable 100mm window, 1000μm fibres here would drop us to 10mm resolution. So for A-port stick with the 400μm fibres.

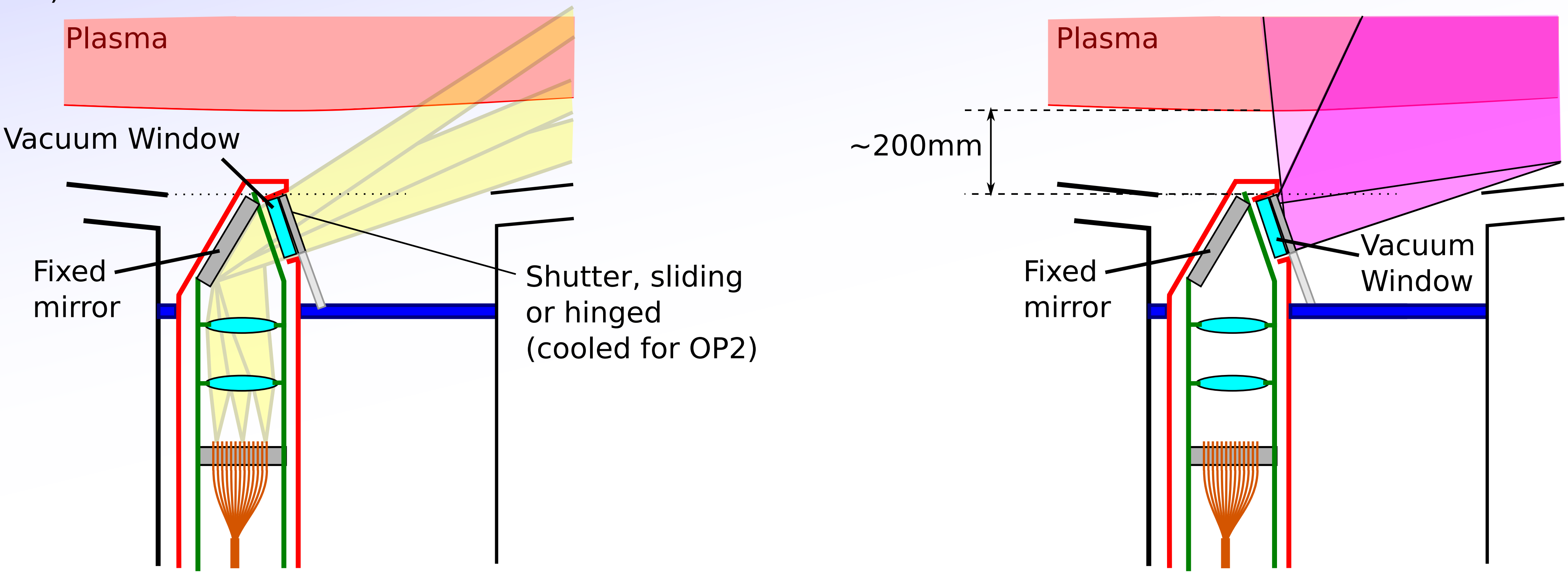
Desired window: 80mm < d_l < 100mm



K1 (AEA21): Optics and Protection (b)

Solutions for protection/cooling of components:

b)



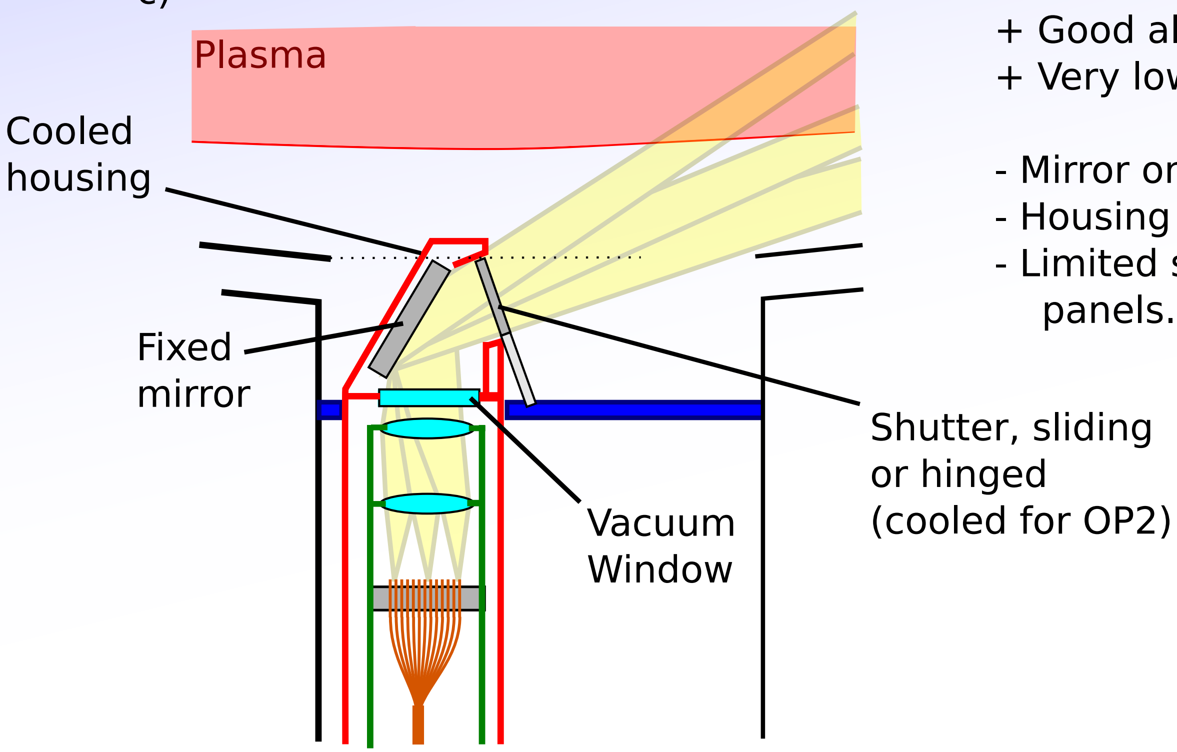
+ Good alignment stability (fixed mirror)
+ Mirror on air side in optics frame, but still difficult to adjust during campaign.

- High window exposure - much closer to plasma, although solid angle still limited.
- Housing and shutter require cooling.
- Limited space for housing - may need to protrude past panels.

K1 (AEA21): Optics and Protection (c)

Solutions for protection/cooling of components:

c)

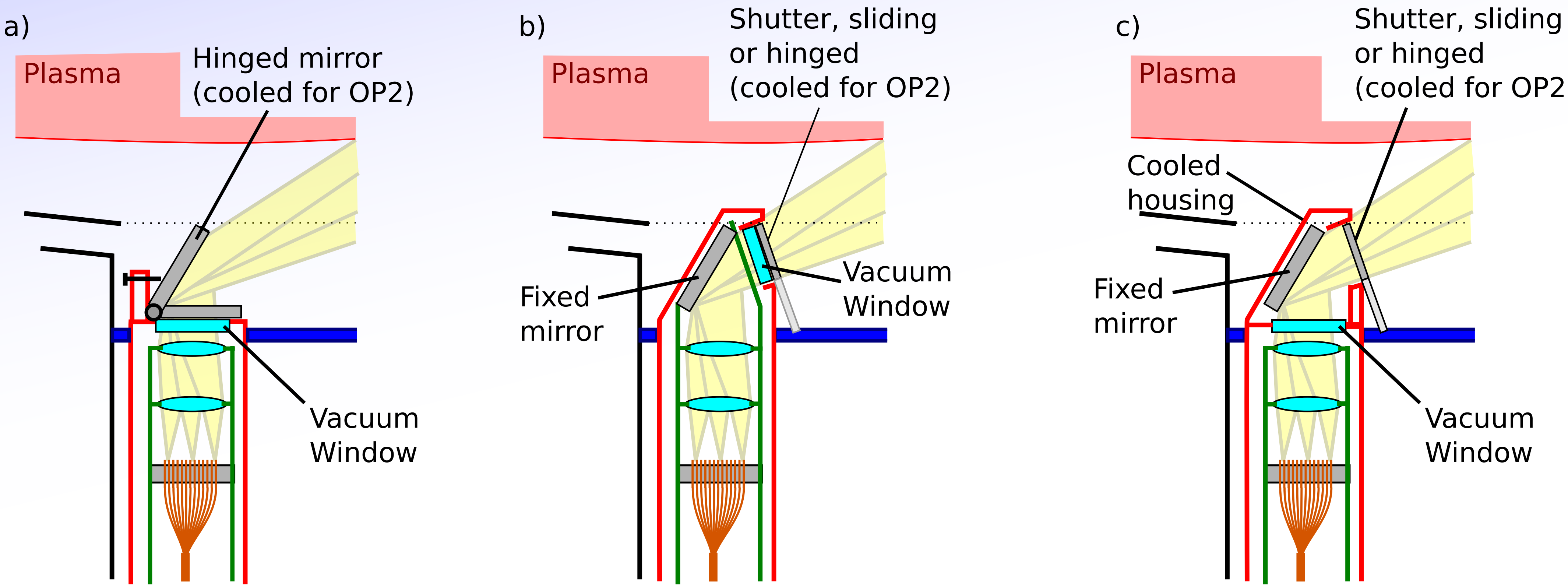


+ Good alignment stability (fixed mirror)
+ Very low exposure of window to plasma radiation.

- Mirror on vacuum side (no adjustment during campaign)
- Housing and shutter need to be cooled.
- Limited space for housing - may need to protrude past panels.

K1 (AEA21): Optics and Protection

Solutions for protection/cooling of components:



a)

+ Less cooled components.
+ Reduced window exposure.

- Poor alignment stability.
- Mirror on vacuum side.
  (no adjustment)

b)

+ Good alignment stability.
+ Mirror on air side in optics frame.

- High window exposure.
- Housing + shutter cooling.
- May not be space for housing - probably needs to protrude past panels.

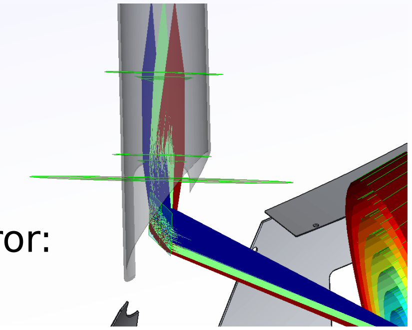
c)

+ Good alignment stability.
+ Low window exposure.

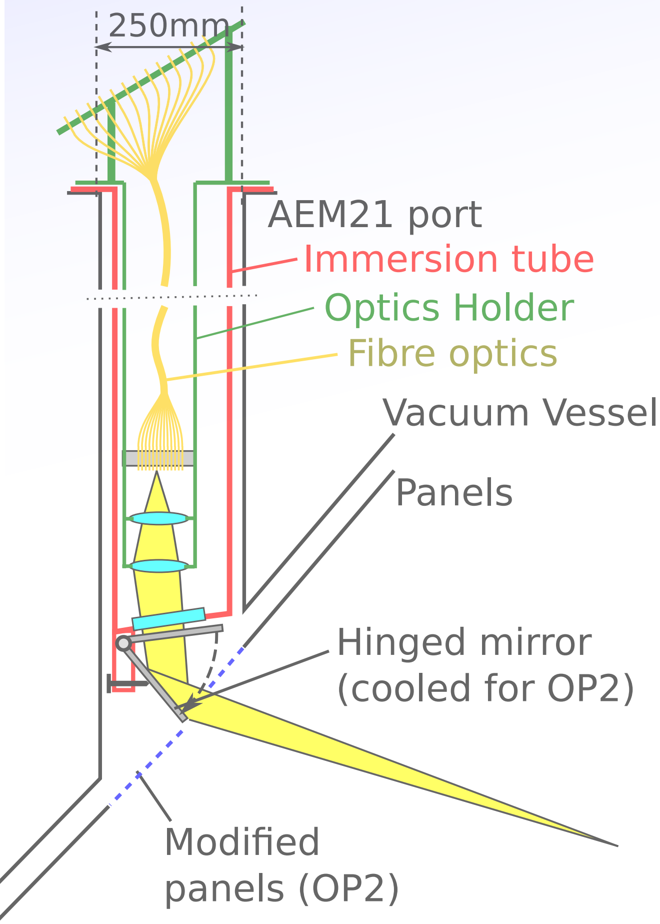
- Mirror on vacuum side (no adjustment)
- Housing + shutter cooling.
- May not be space for housing - probably needs to protrude past panels.

[Additional] K2 (AEM21): Optics Alternatives

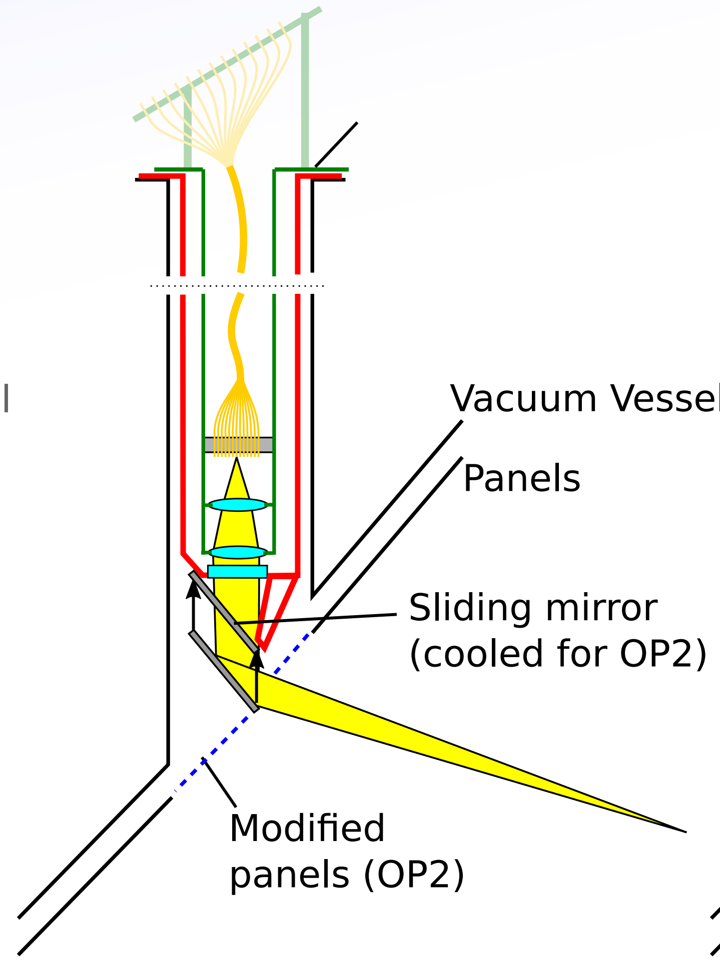
Mirror must protrude to within 10mm of the panel level, so air-side mirror not possible.
Collection area is long but narrow, so most of the port opening can be enclosed with a cooling plate for OP2, so window cooling not required.



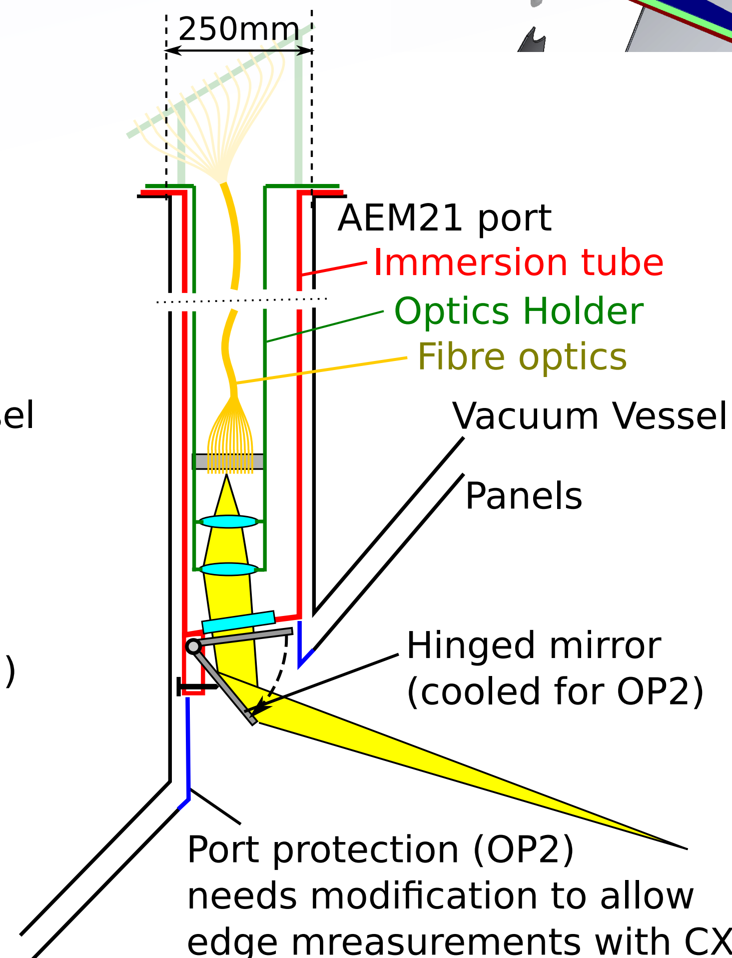
a) Hinged Mirror:



b) Sliding Mirror:



c) Sliding Mirror:



Mirror could be hinged or sliding. Folding is less technically demanding.
Both give relatively poor alignment reproducibility - needs BES for spatial calibration.