John Adams Institute for Accelerator Science

Imperial College London

Royal Holloway University of London

UNIVERSITY OF OXFORD

Plasma Wakefield Diagnostics in AWAKE

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University of Oxford, UK

PhD Supervisors:
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University of Oxford, UK

AWAKE Meeting,
Geneva, 18 November 2015

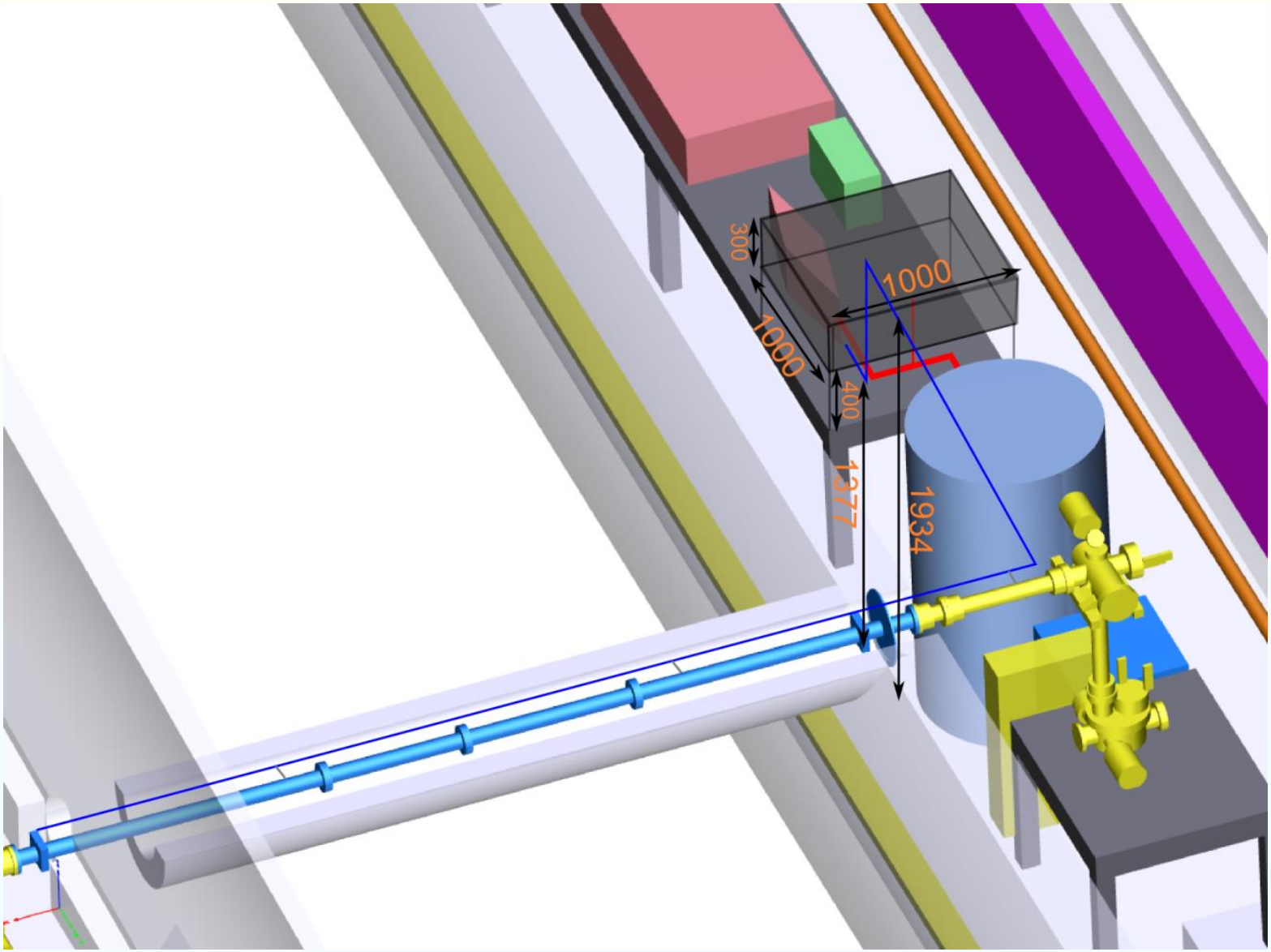
Parameters

- **Pulse parameters on plasma column:**
  - **Pulse duration: 26 ps**
  - **Wavelength: 390 nm**
  - **Bandwidth (FWHM intensity): ~2 nm**
  - **Time separation: 17 ps (0.5 cm delay path)**
  - **Diameter: 10 mm**
- **Picked pulse parameters:**
  - **Pulse duration: 160 ps**
  - **Bandwidth ($1/e^2$): 20 nm → FWHM: 11.8 nm**
  - **Energy: ~50 mJ**

Parameters

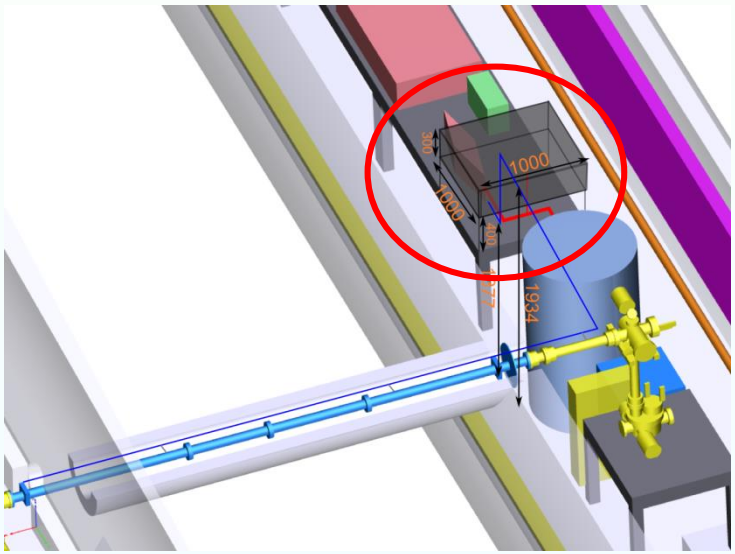
- **Spectrograph on the shelf:**
  - Supplier: Princeton Instruments
  - Type: Czerny-Turner
  - Focal length: 75 cm (SP-2750)
  - Gratings: 2400 g/mm
- **Detector on the shelf:**
  - Supplier: Thorlabs
  - CCD pixel size: 7.4
  - CCD resolution: 2048 x 2048
- **Detector parameters:**
  - Central wavelength: 390 nm
  - Wavelength range: ~ 8.3 nm
  - Wavelength resolution: ~ 0.01 nm
  - Pixel resolution: ~0.003 nm

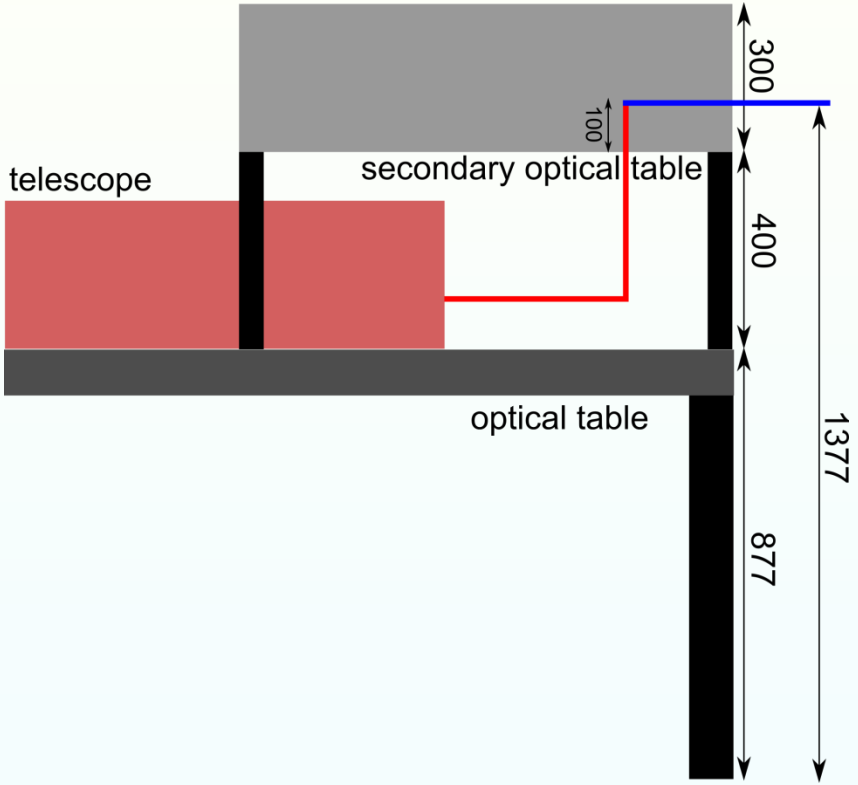
Laser room



Laser room

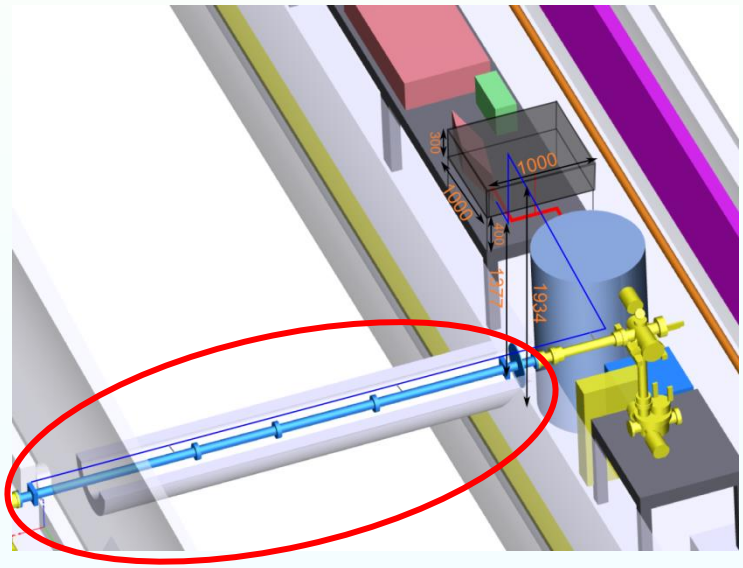
- **Beam height:**

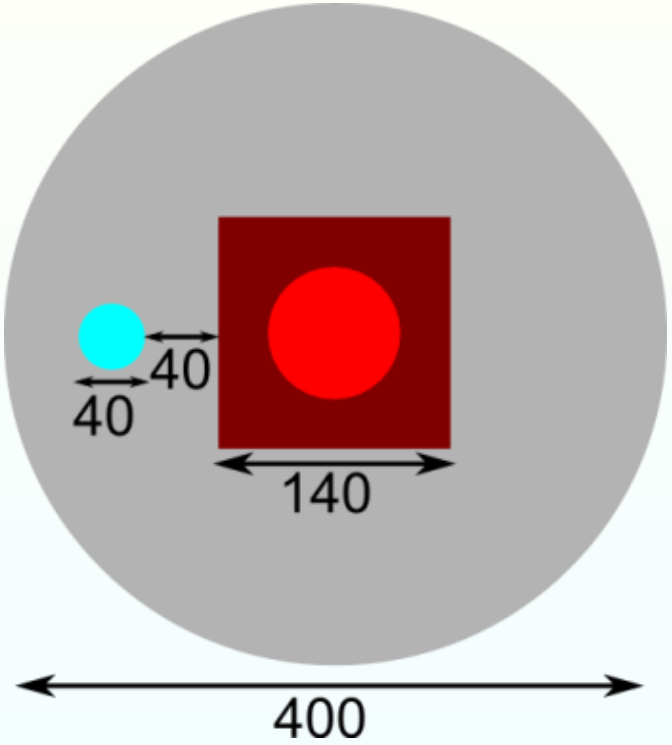




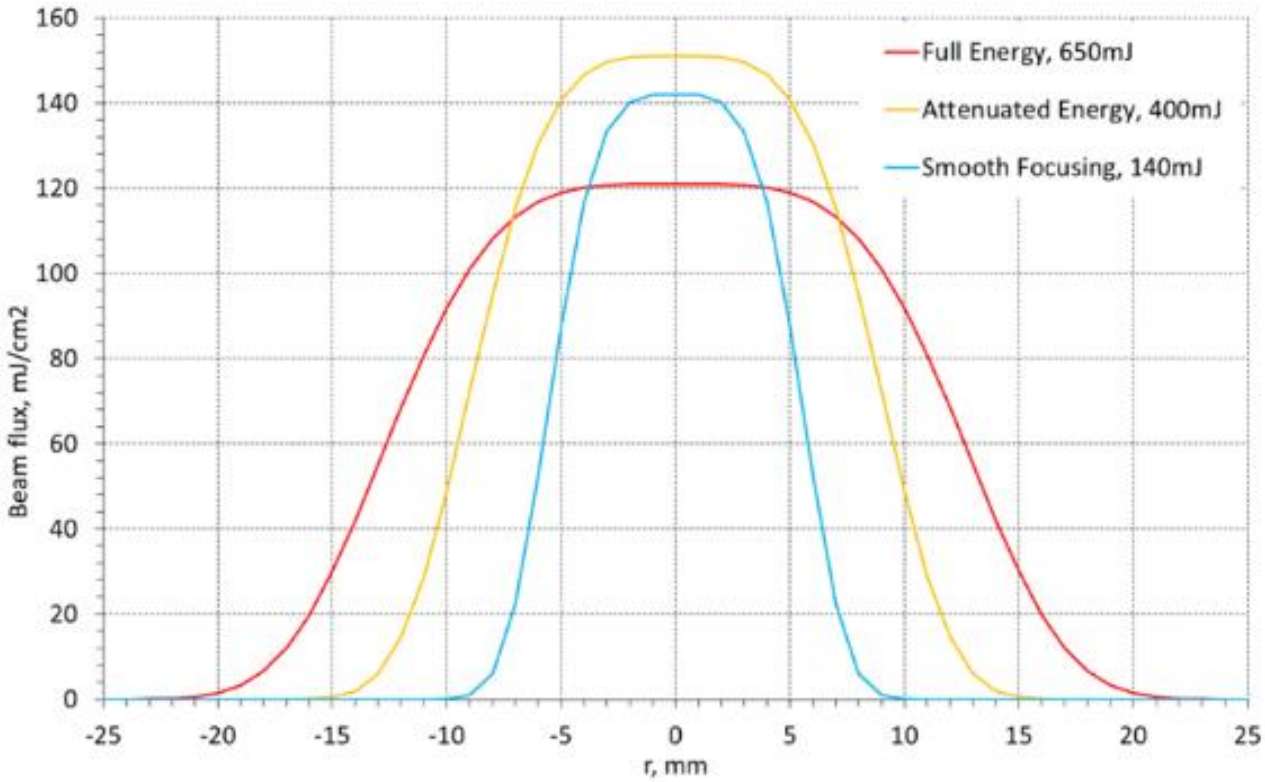
Laser room

- **Laser pipe transport in the tunnel:**





Laser pick-off



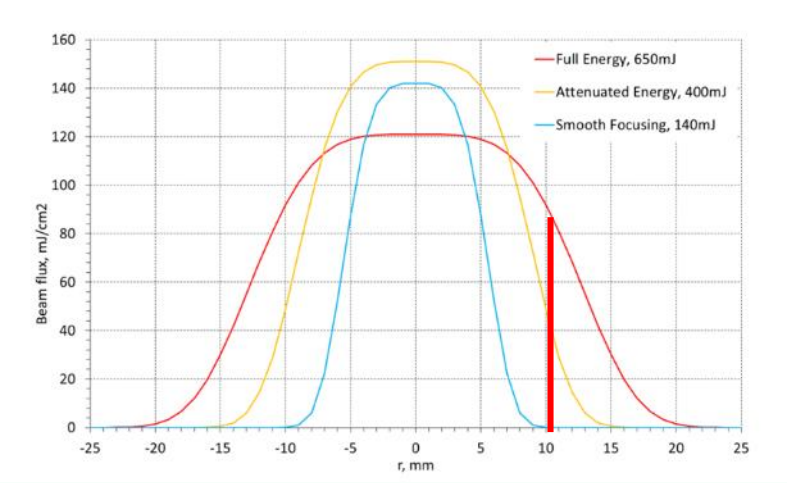
$$\phi_1 \approx (120)\ 2^{-r^4/(12.5)^4}$$

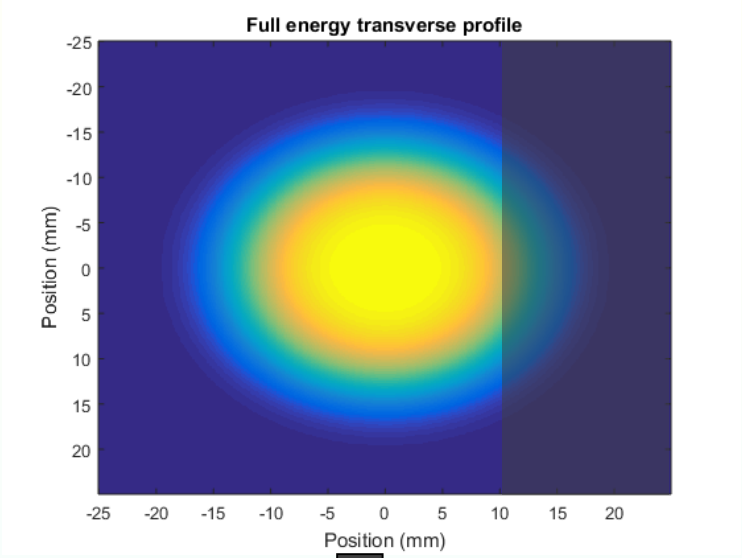
$$\phi_2 \approx (150)\ 2^{-r^4/(9)^4}$$

$$\phi_3 \approx (142)\ 2^{-r^4/(5.5)^4}$$

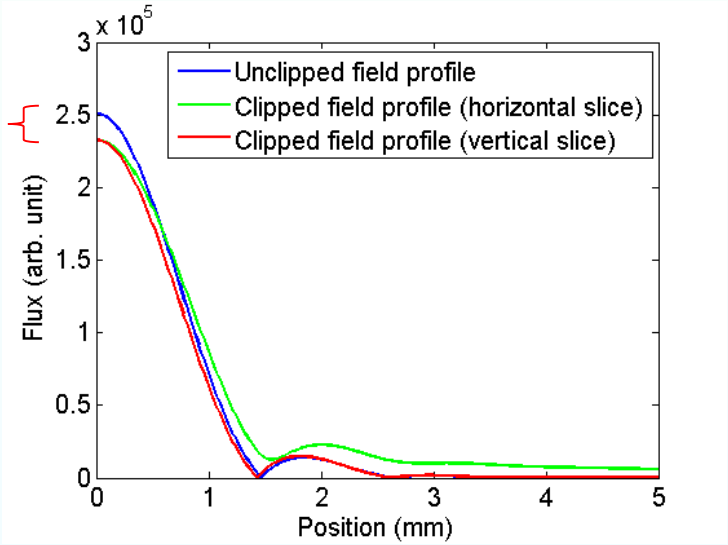
Laser pick-off

- **One side pick-off**

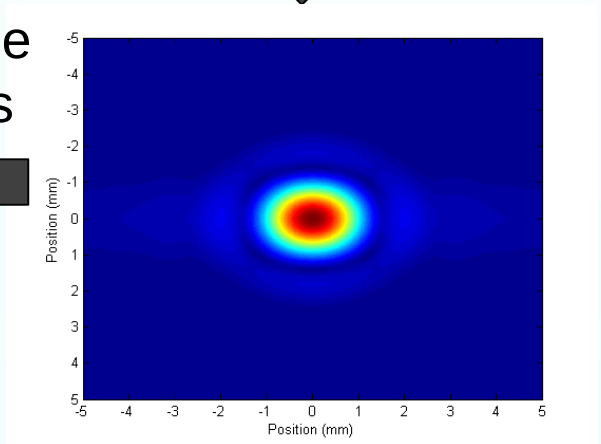




Focused field

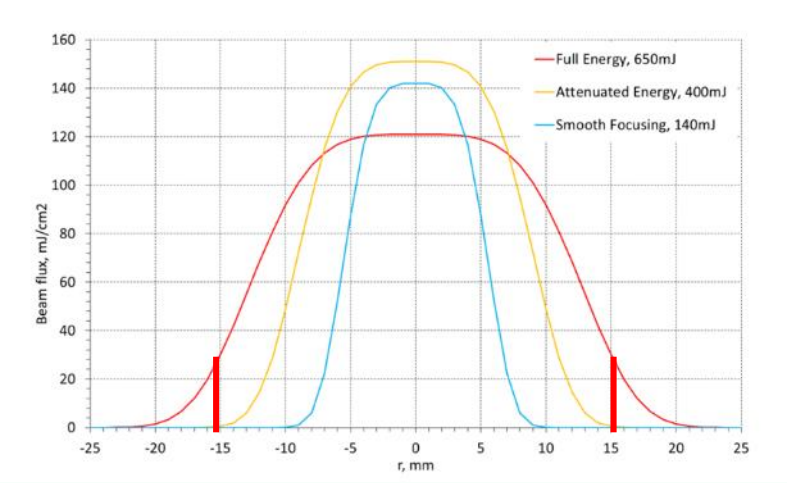


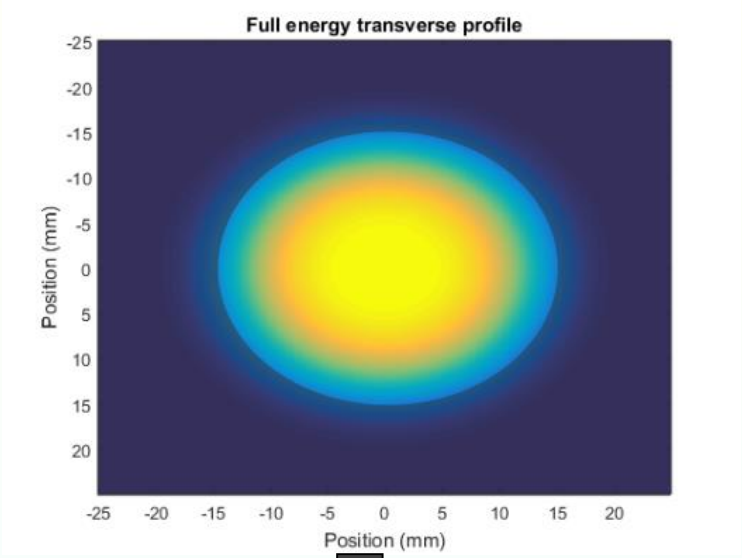
1D slice profiles



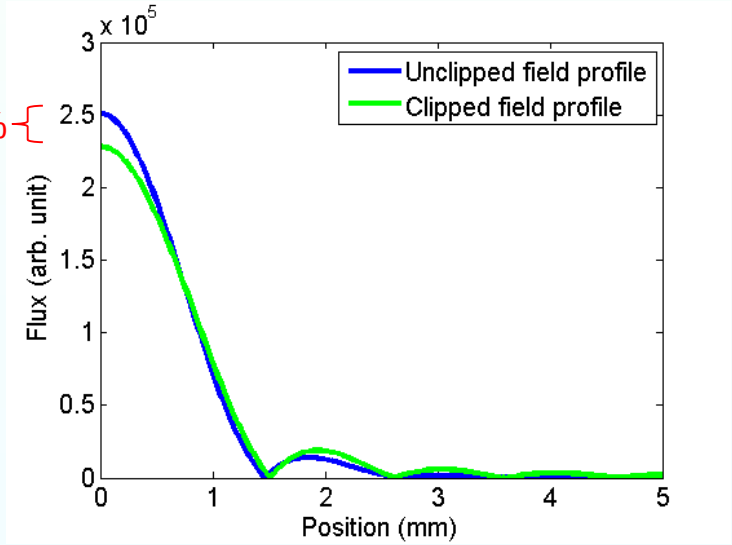
Laser pick-off

- **Round pick-off**





Focused field



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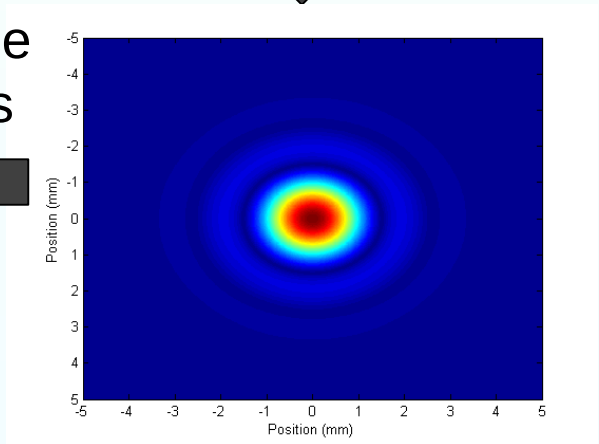
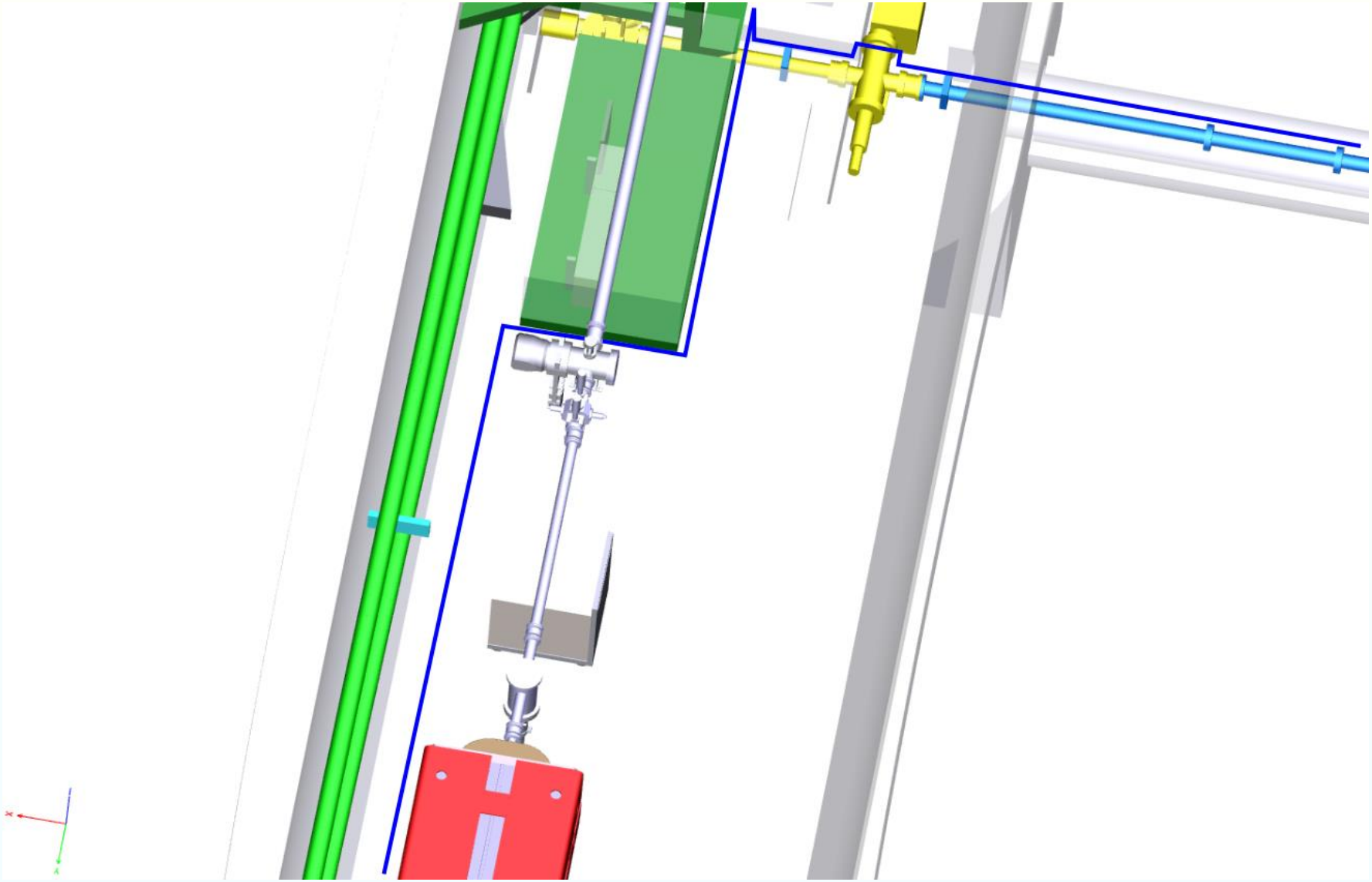


Laser transport (upstream)



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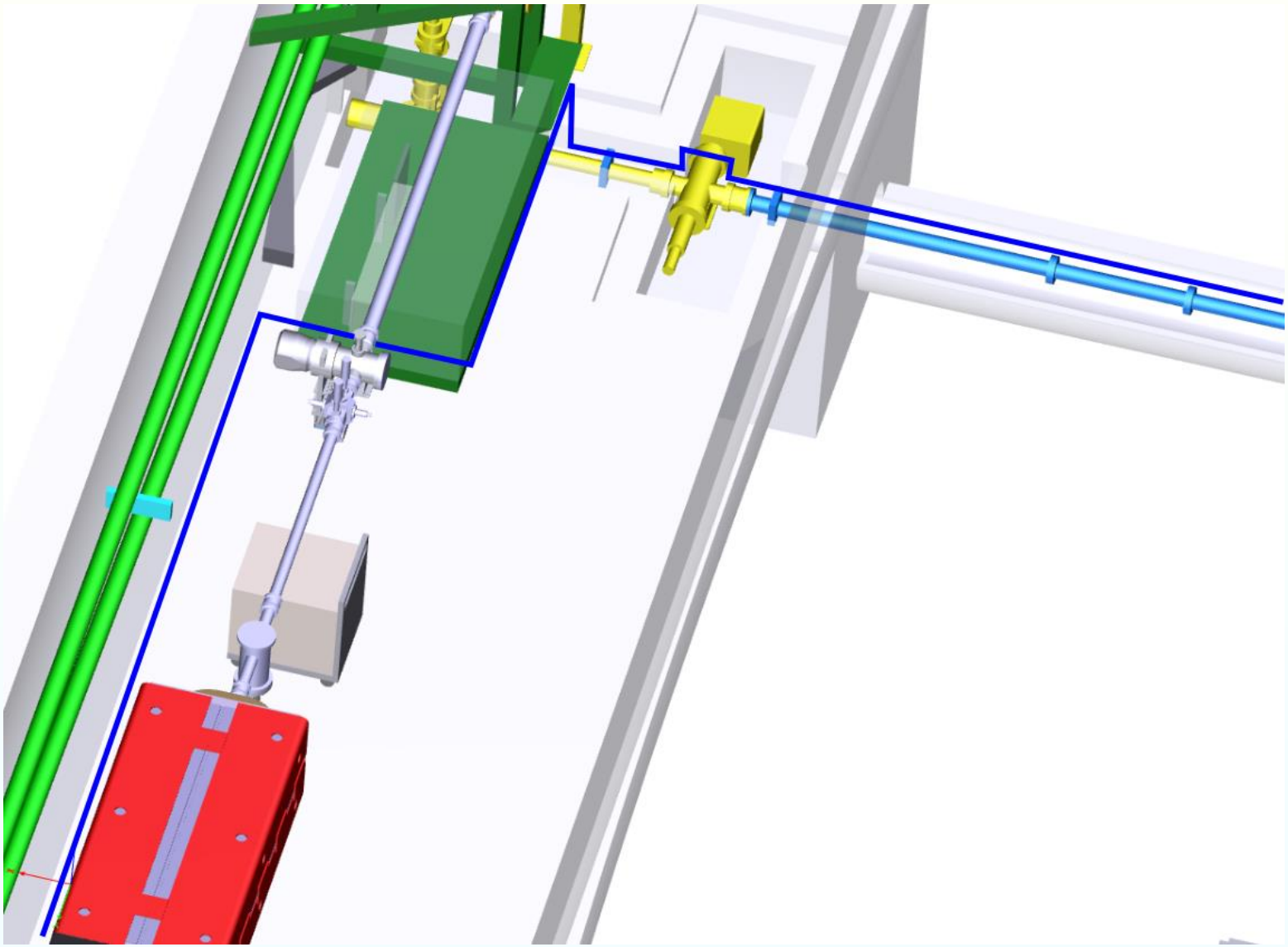

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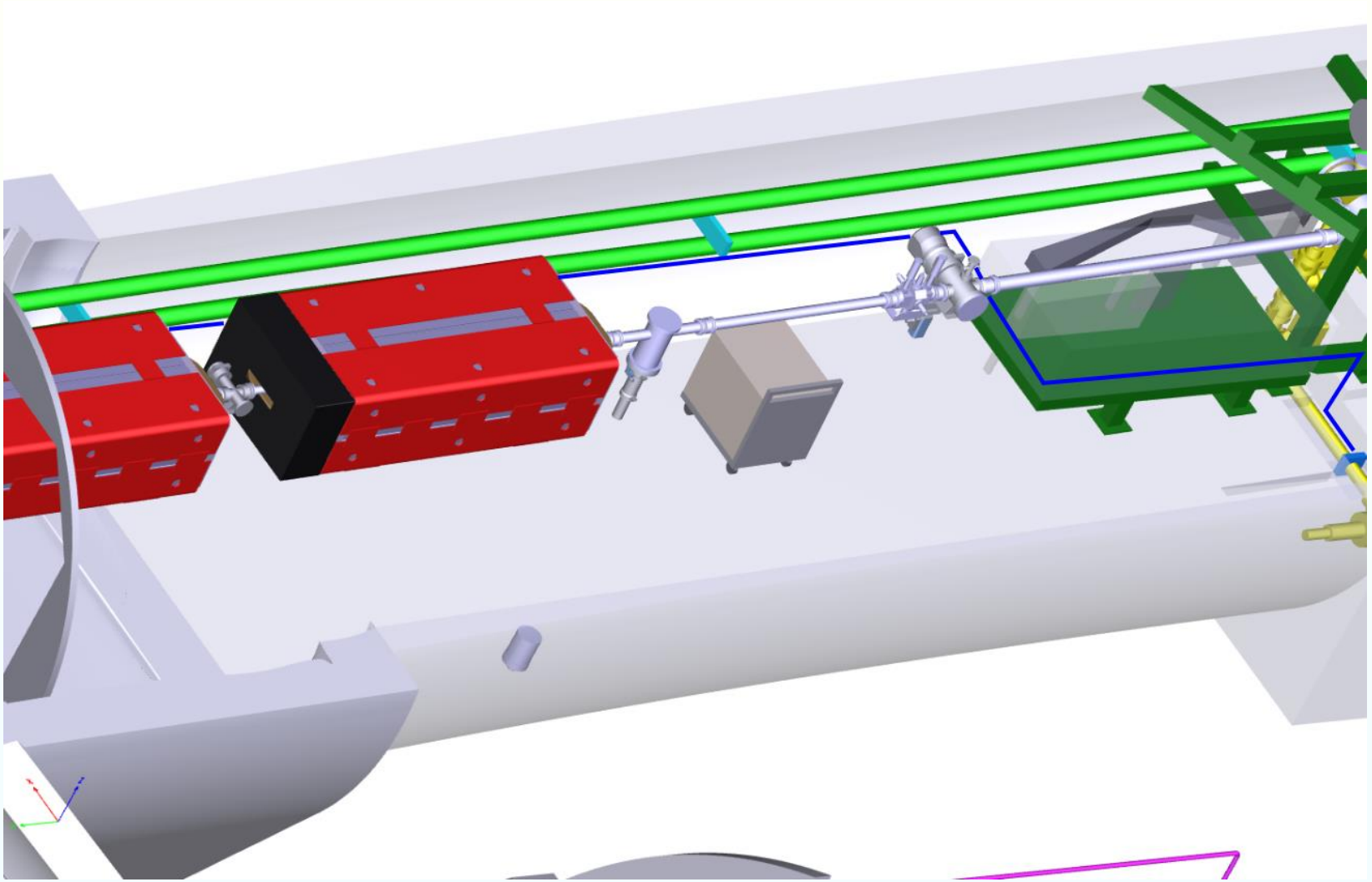
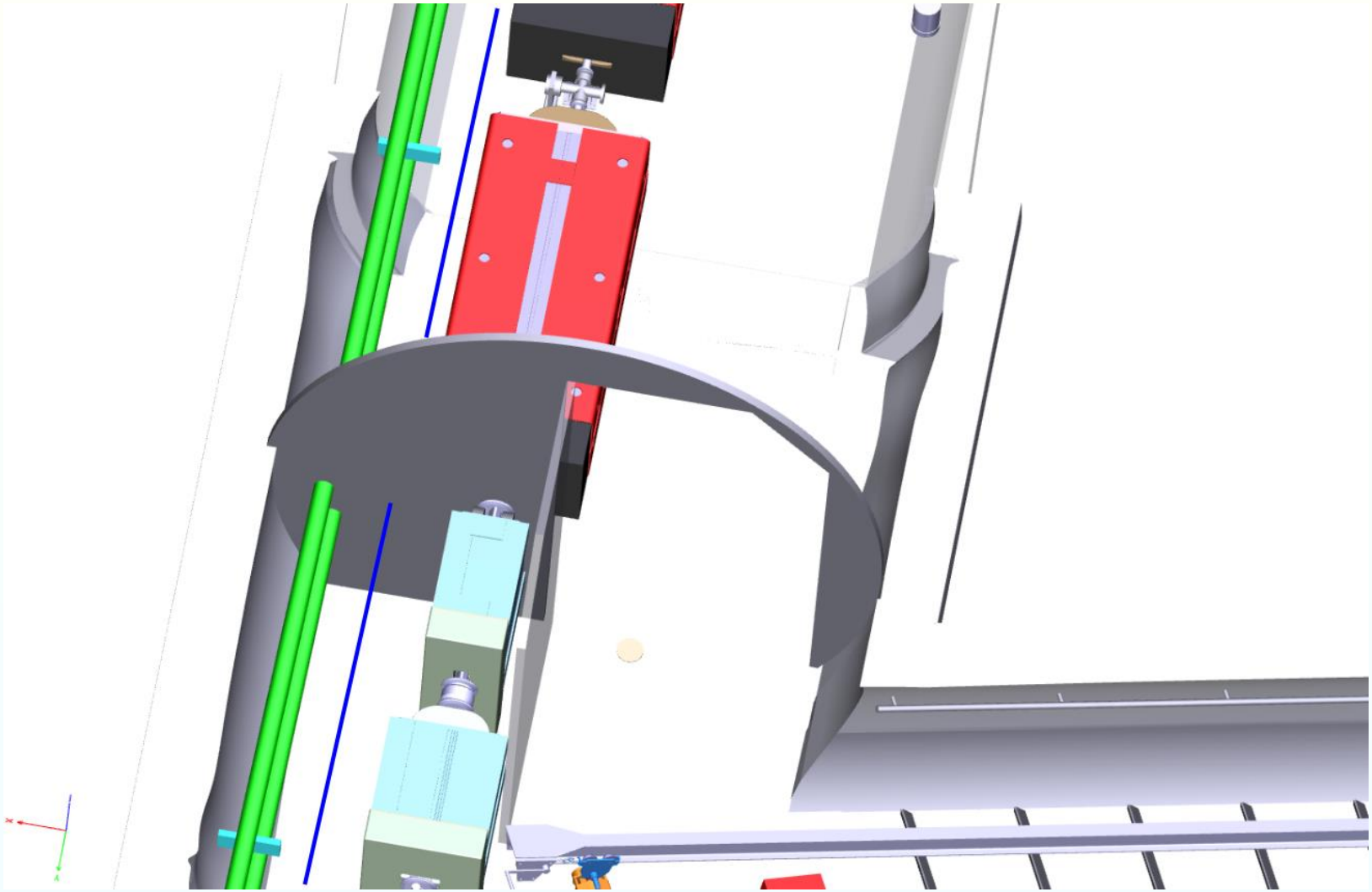
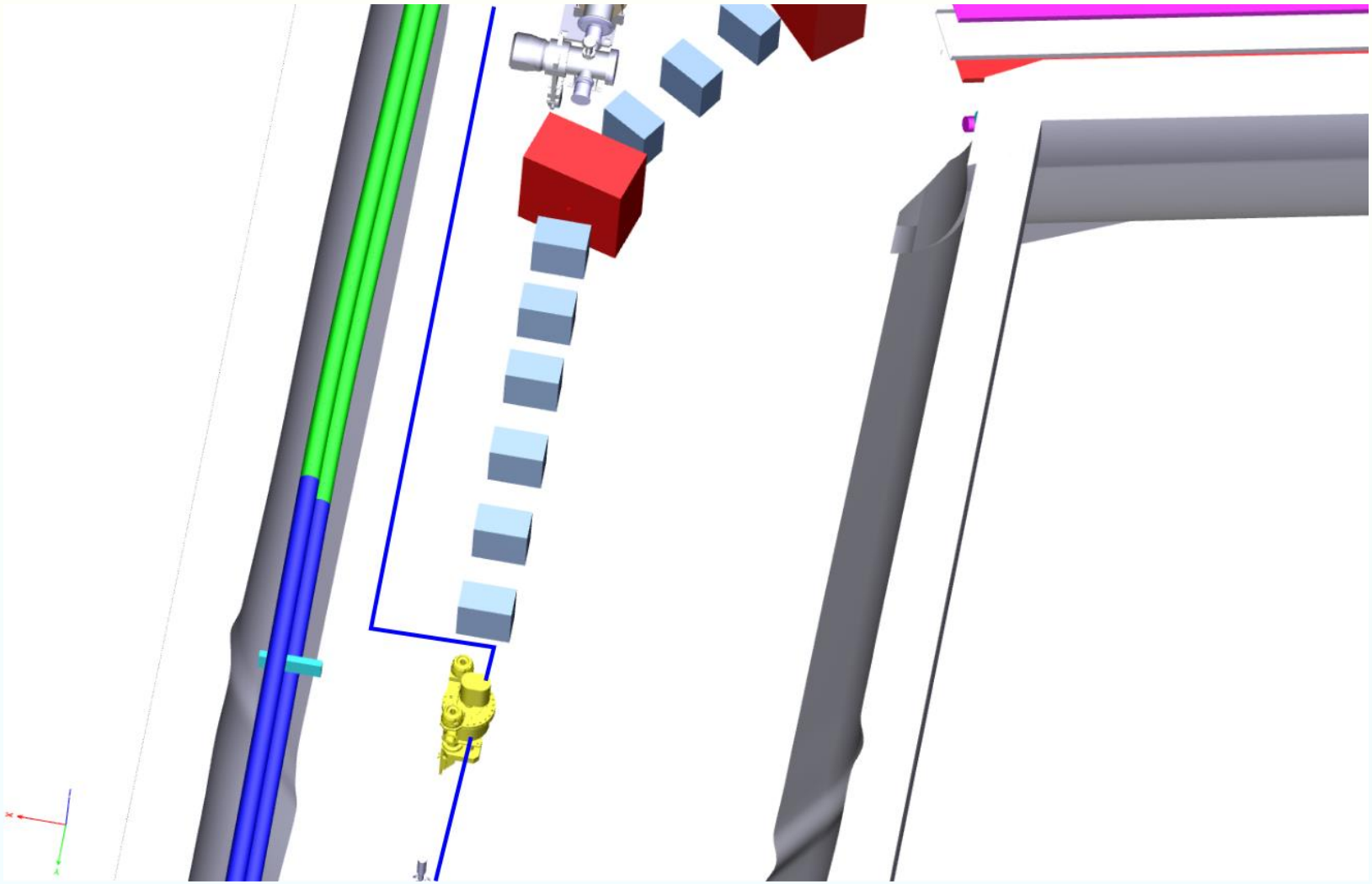


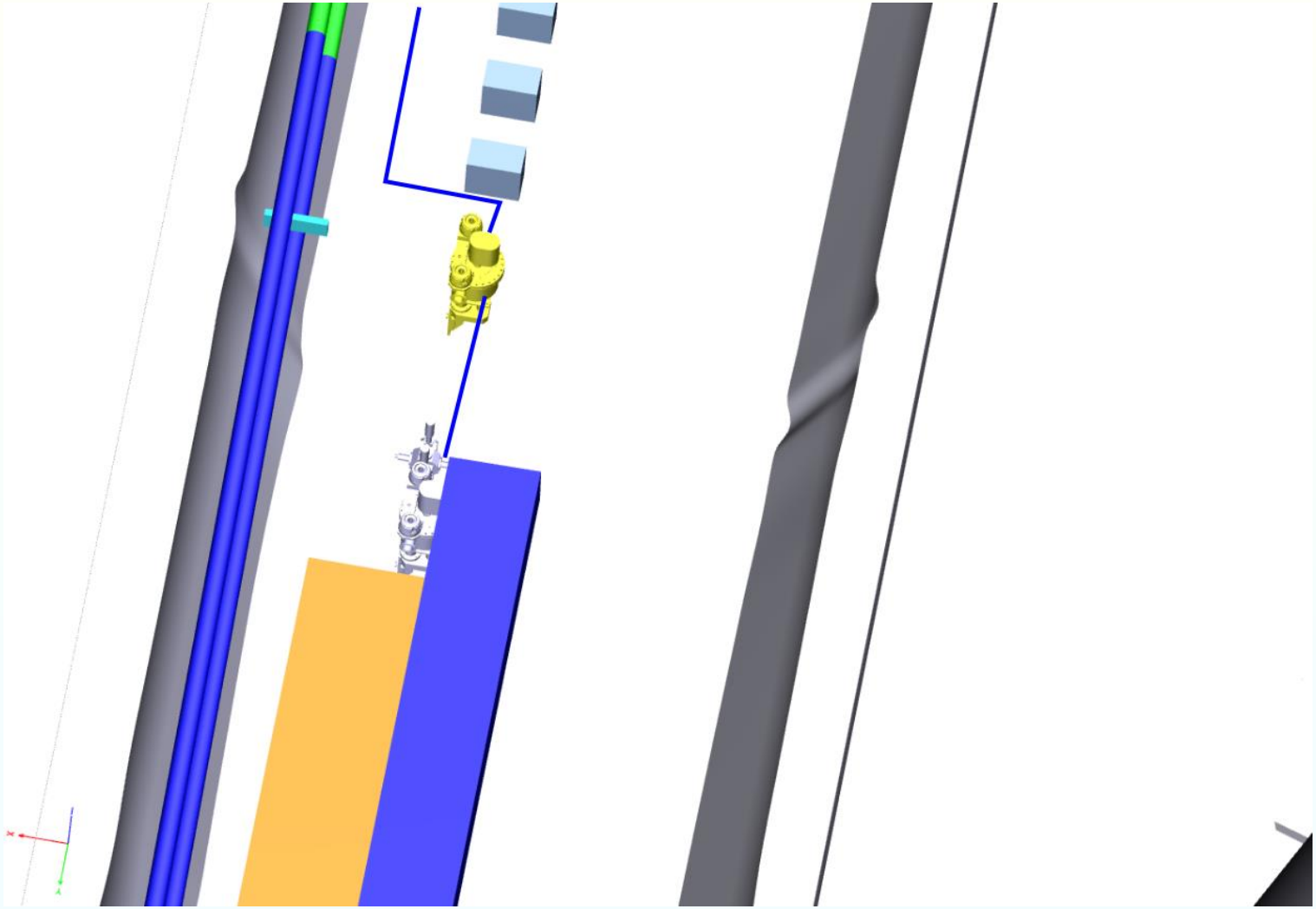
Laser transport (upstream)



Laser transport (upstream)

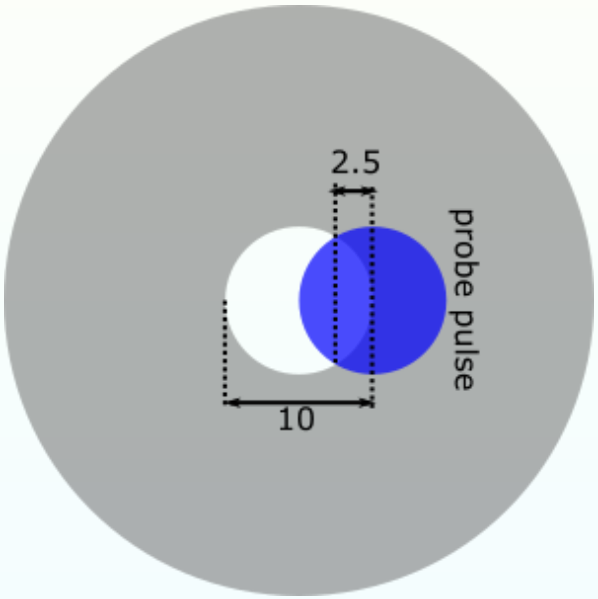


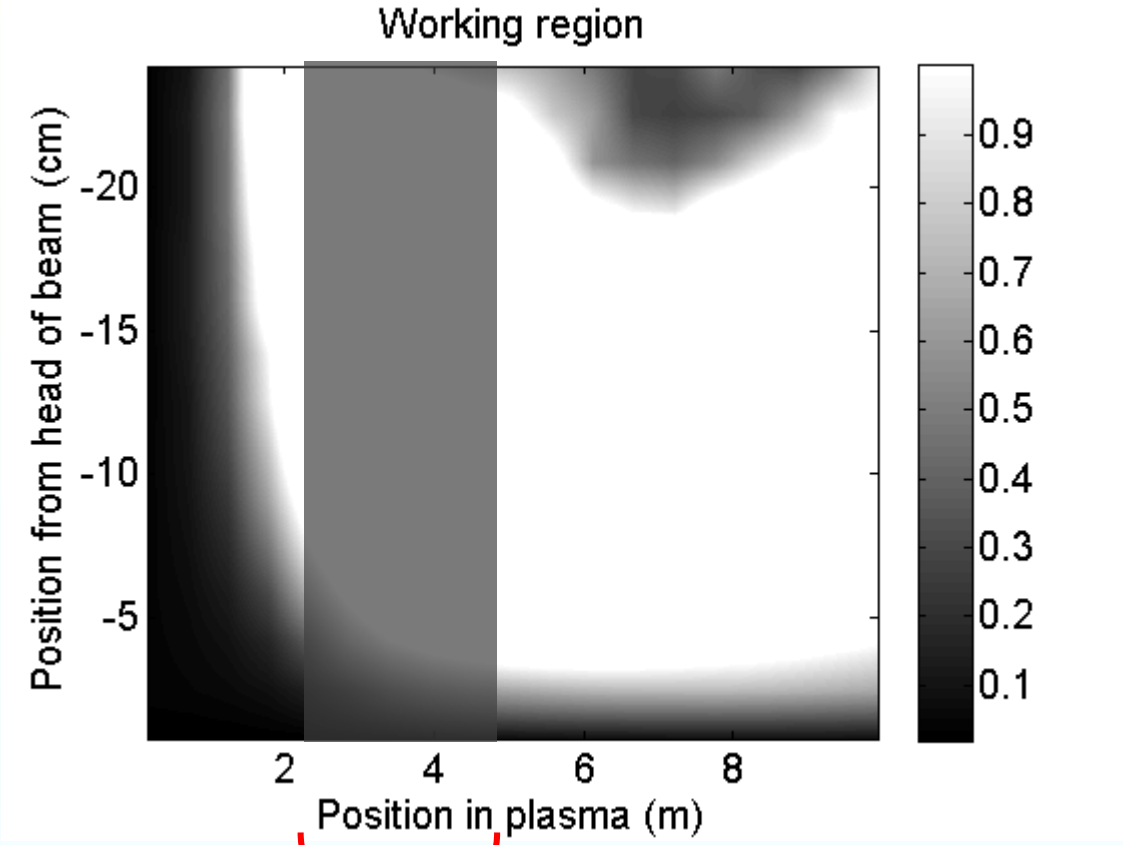
Laser transport (upstream)



AWAKE Working Region

- **Plasma wakefield diagnostics working region (including some blockings due to geometry):**

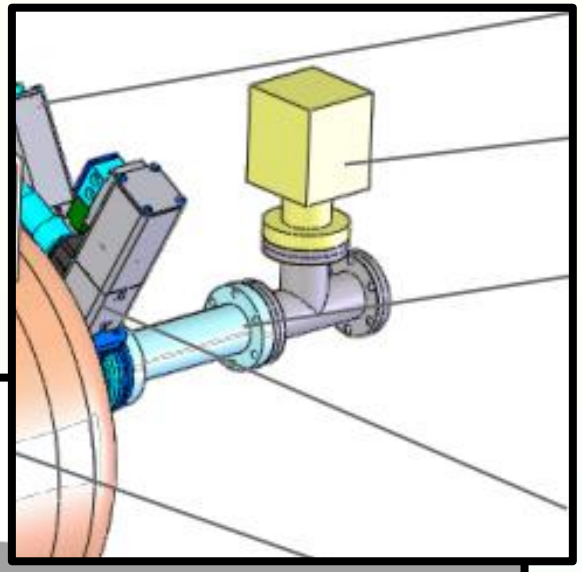


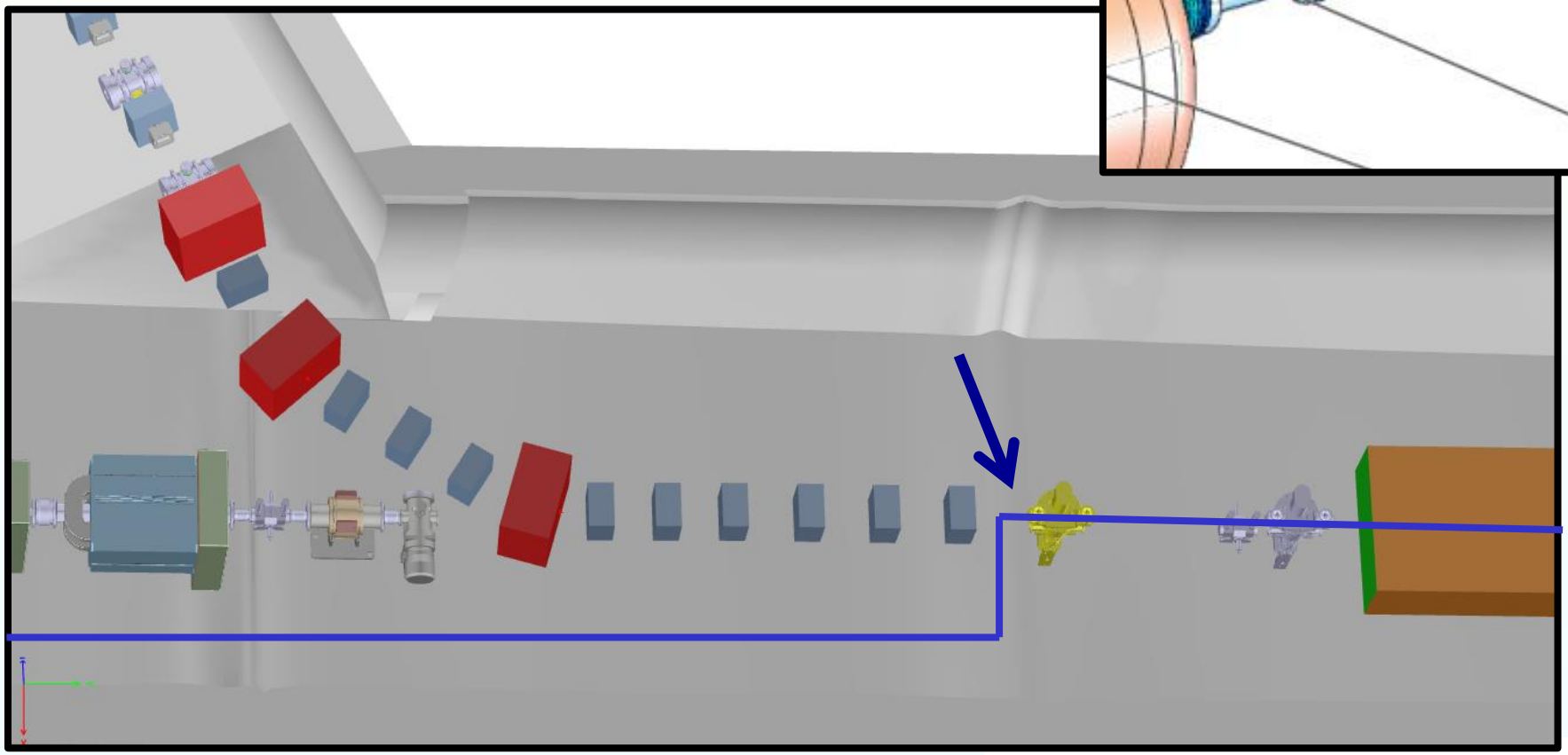


(2.5 – 5) m

Proposed merge point: A

- Require 15 cm long box with window in which to mount a 1 inch mirror





3D model courtesy of Ans Pardons

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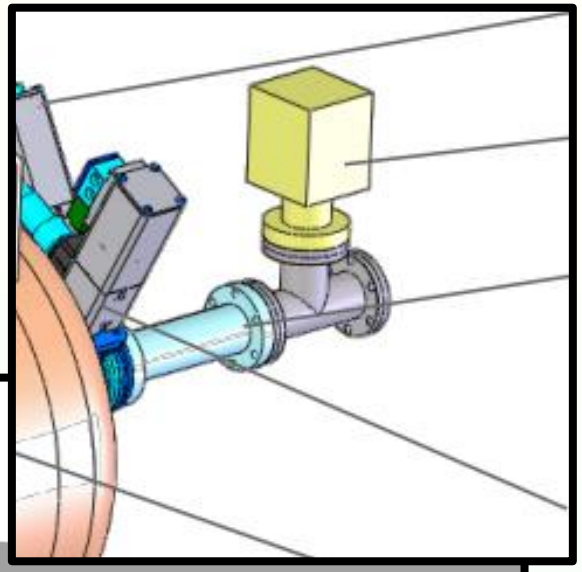
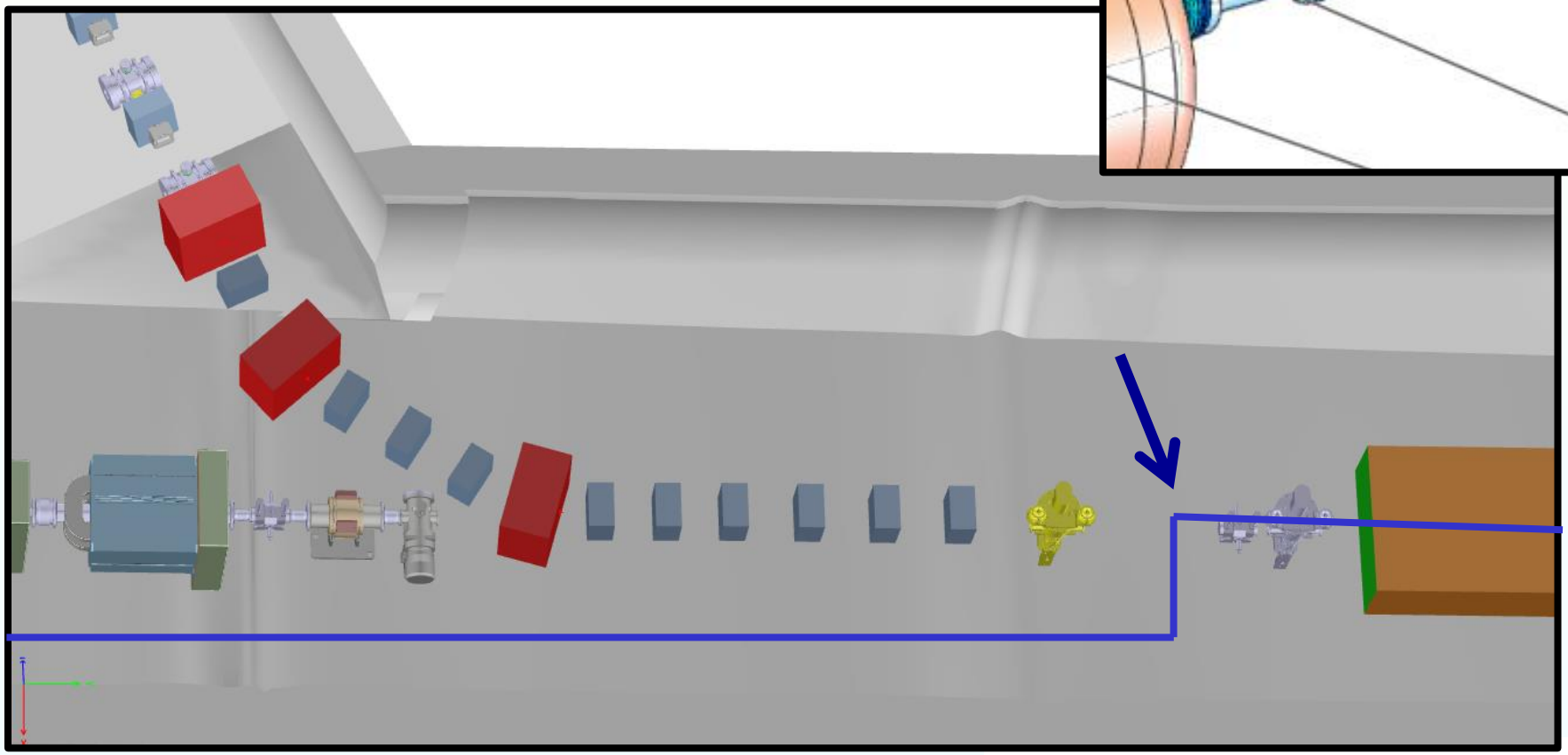
Proposed merge point: B

- Require 15 cm long box with window in which to mount a 1 inch mirror





3D model courtesy of Ans Pardons

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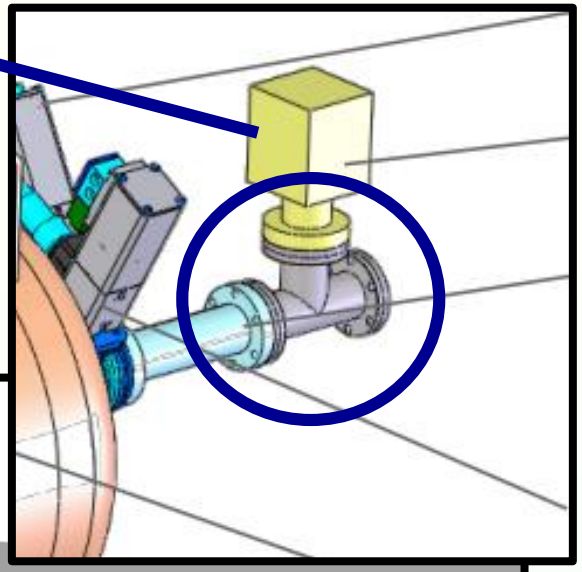
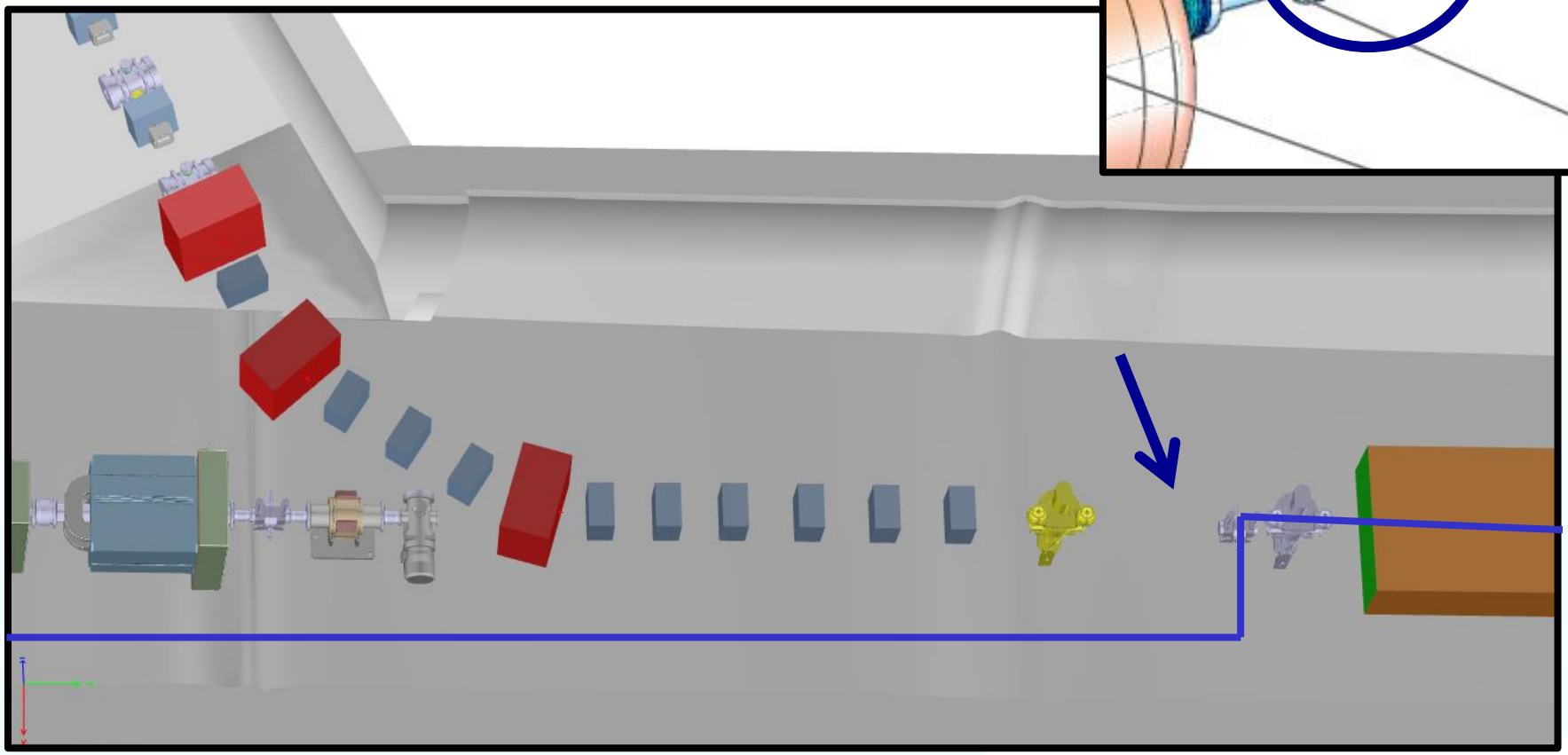
Proposed merge point: C

- Require 15 cm long box with window in which to mount a 1 inch mirror
- Incorporate probe merge point and vacuum gauge?

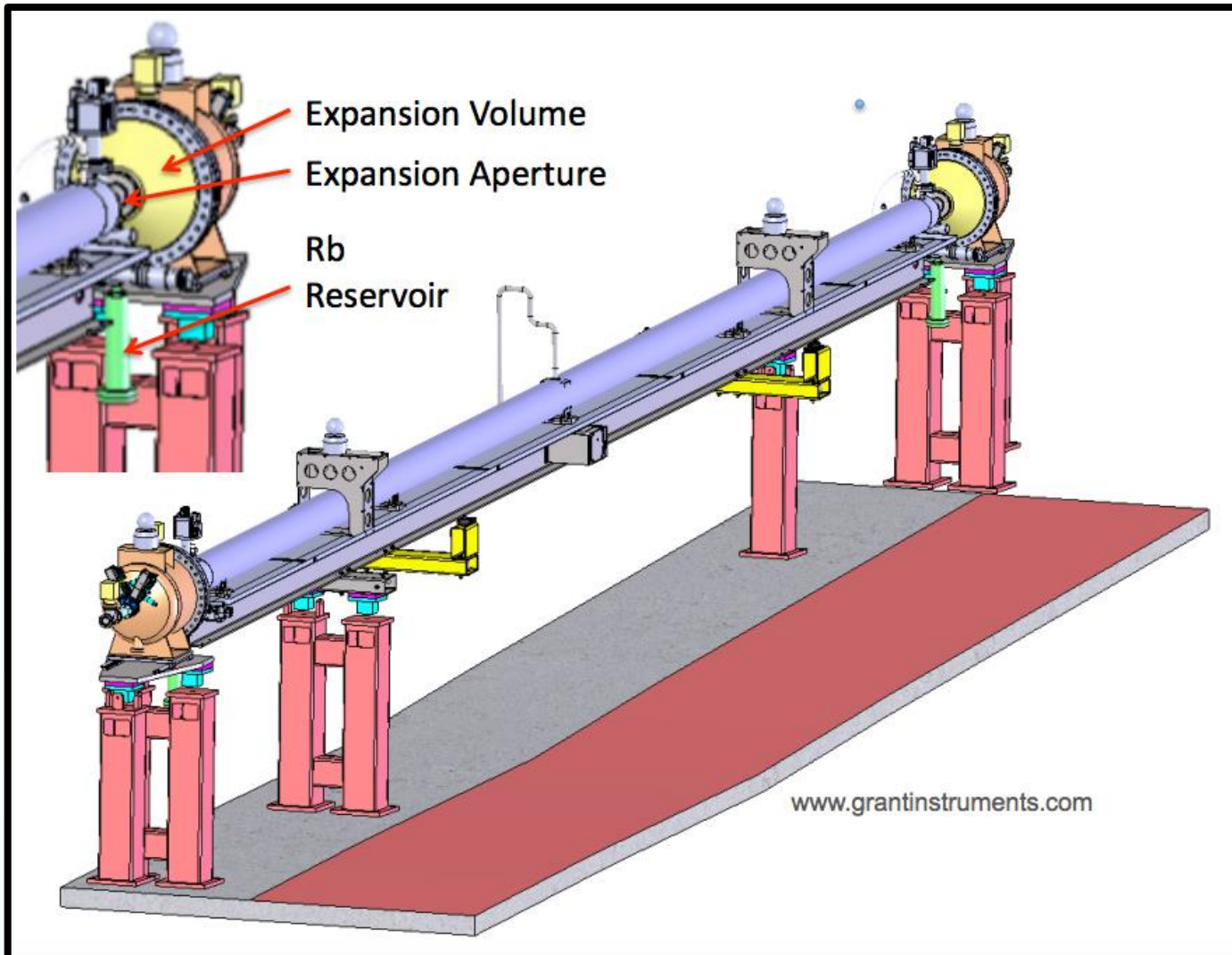




3D model courtesy of Ans Pardons

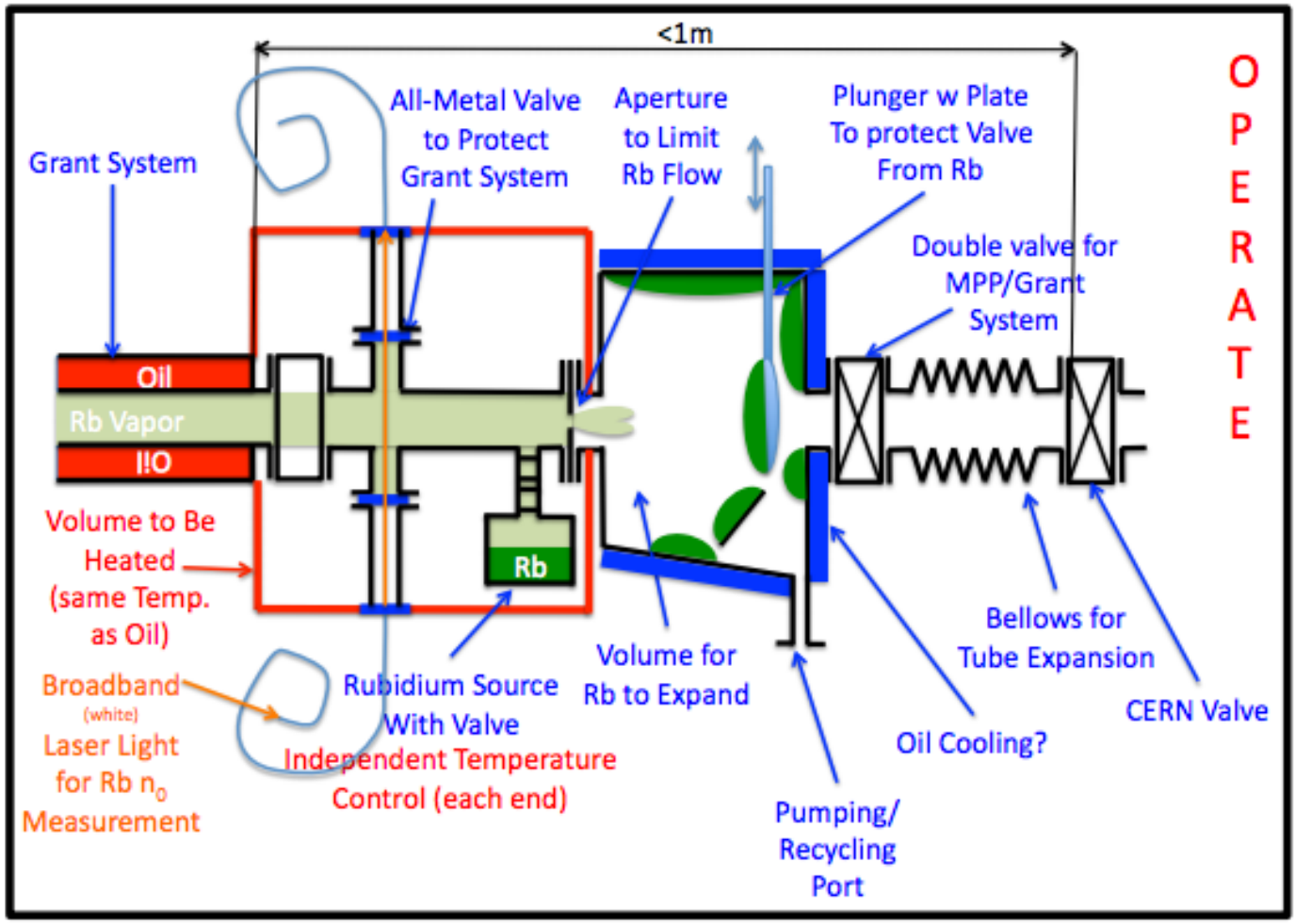
ADL abandoned. Now have expansion volume

- **Adds 50 cm to each end.**



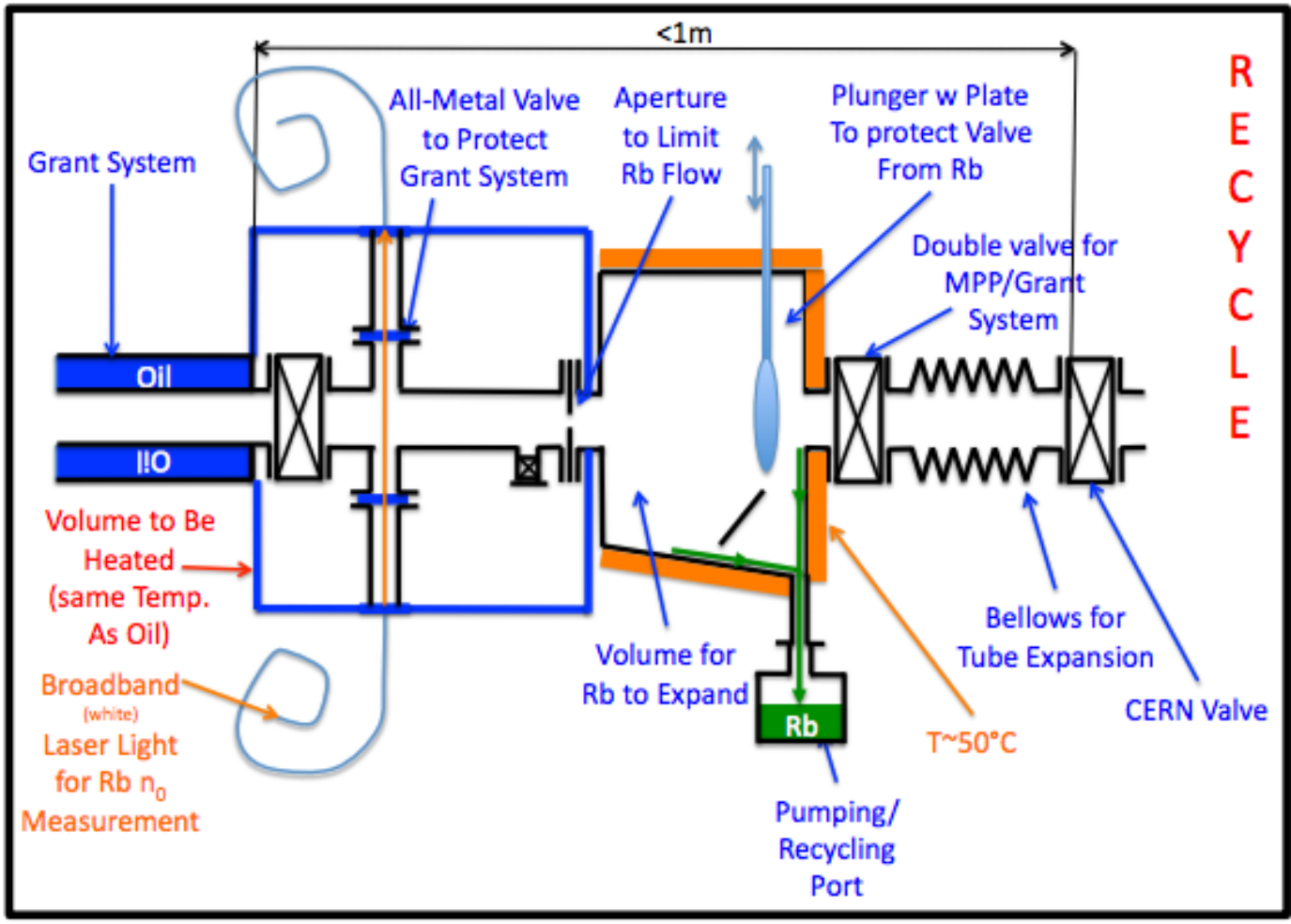
ADL abandoned. Now have expansion volume

- Adds 50 cm to each end.
- Expansion volume has 2 mm of rubidium build up every two weeks



ADL abandoned. Now have expansion volume

- Adds 50 cm to each end.
- Expansion volume has 2 mm of rubidium build up every two weeks
- Cannot put components inside



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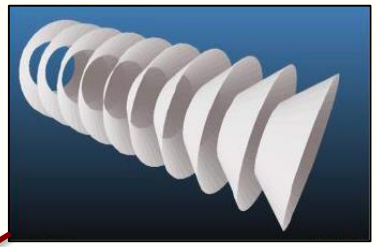
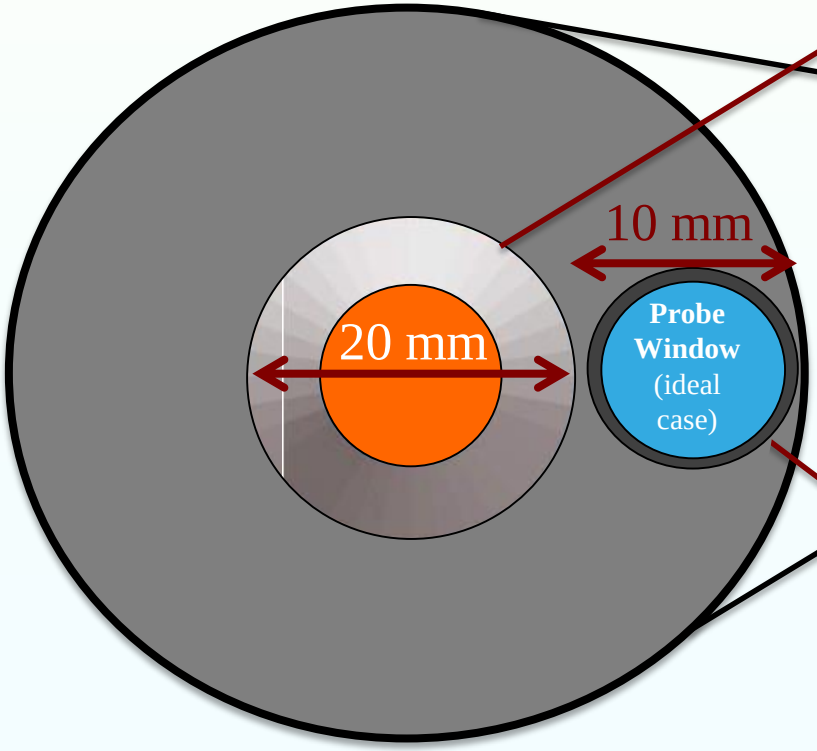
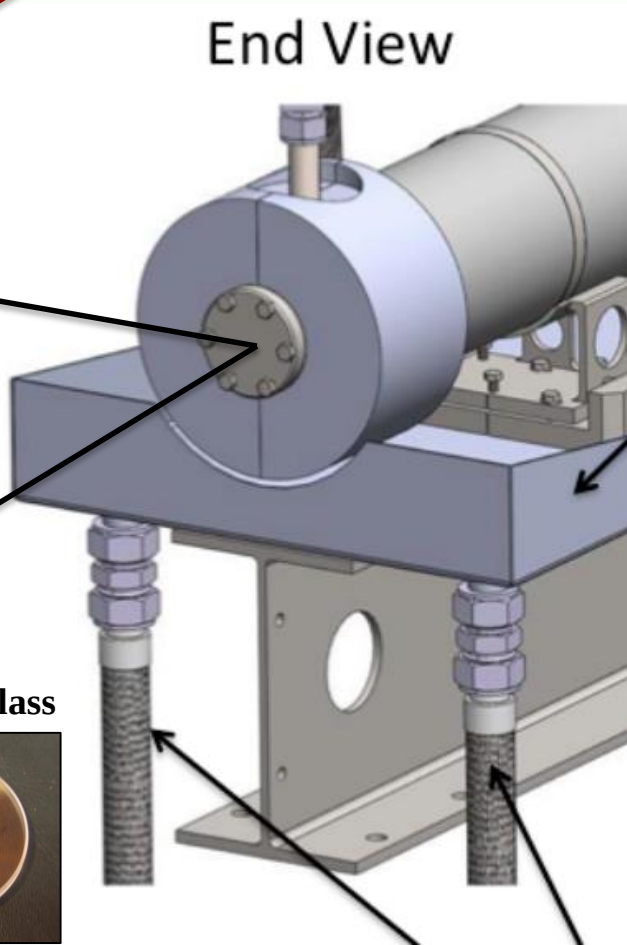
Into the plasma cell OUTDATED

- **Acoustic Delay Line restricted space for probe laser pulse**
- **Probe beam is 10 mm, entrance and exit window was to be 10 mm**
- **No room for manover**

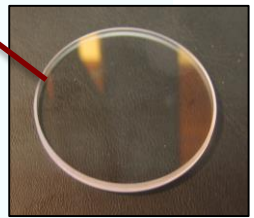


Acoustis delay line



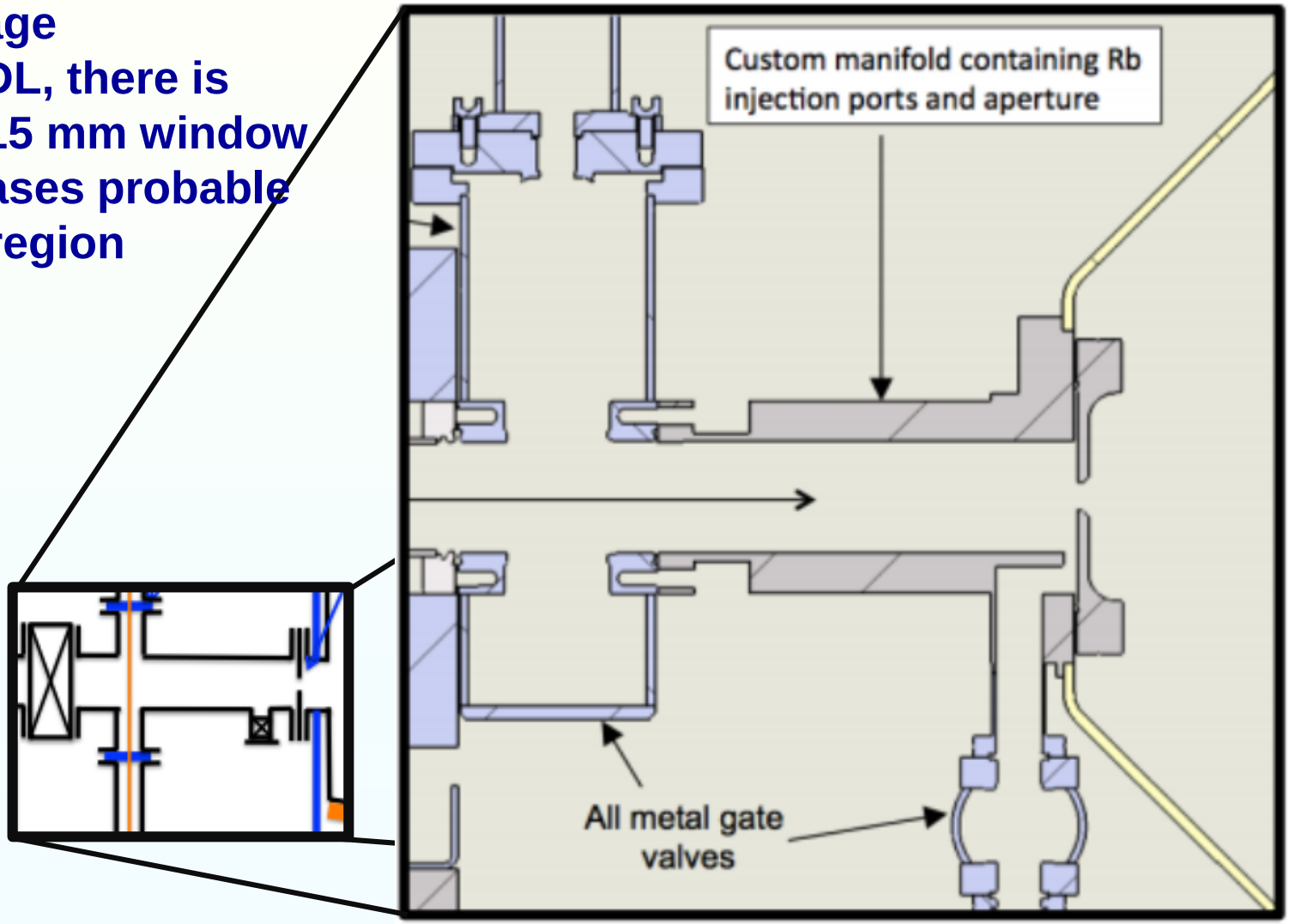


Sapphire glass



Sapphire window

- Need to pass probe into plasma stage
- Without ADL, there is space for 15 mm window
- This increases probable wakefield region



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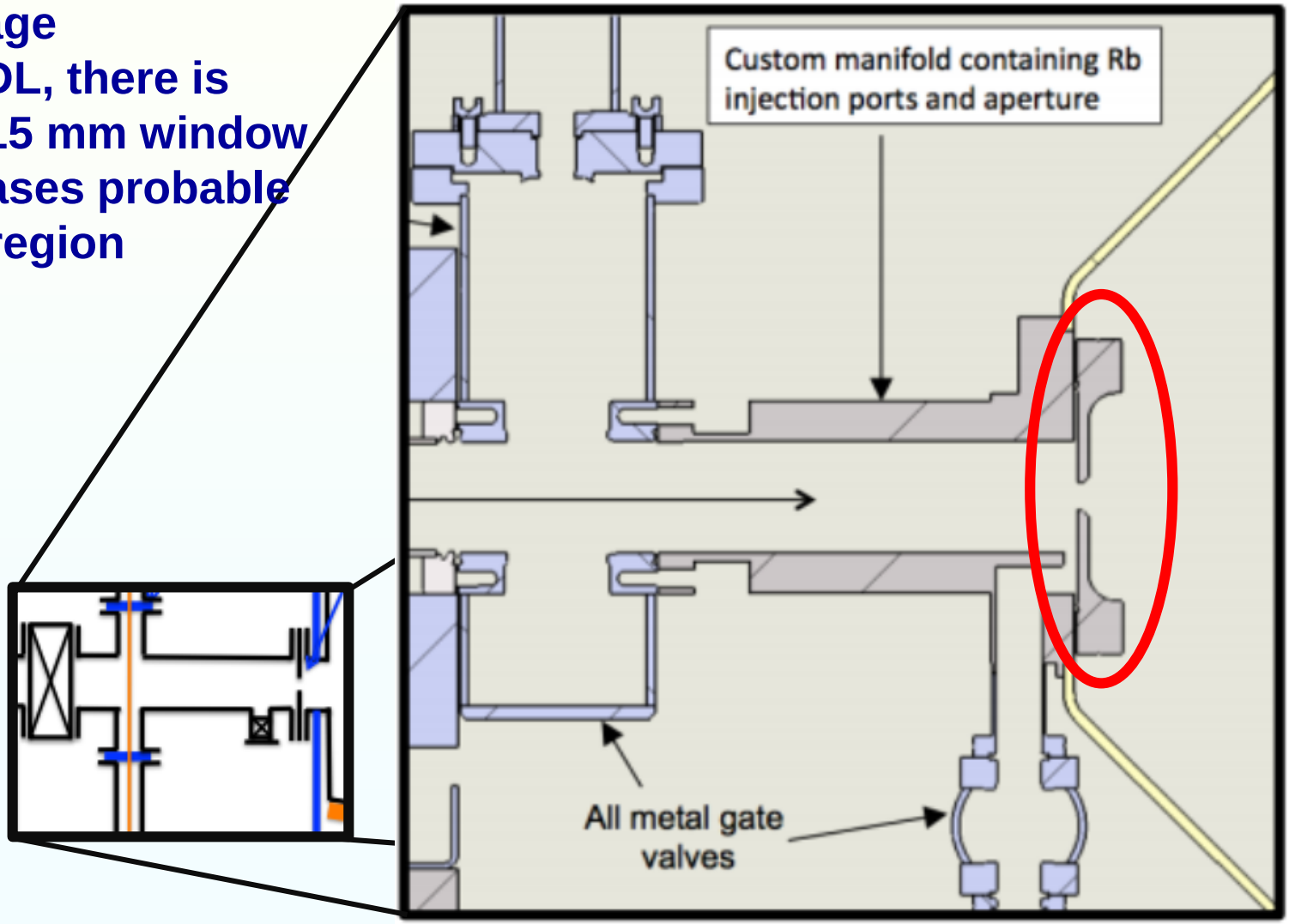

Sapphire window – port

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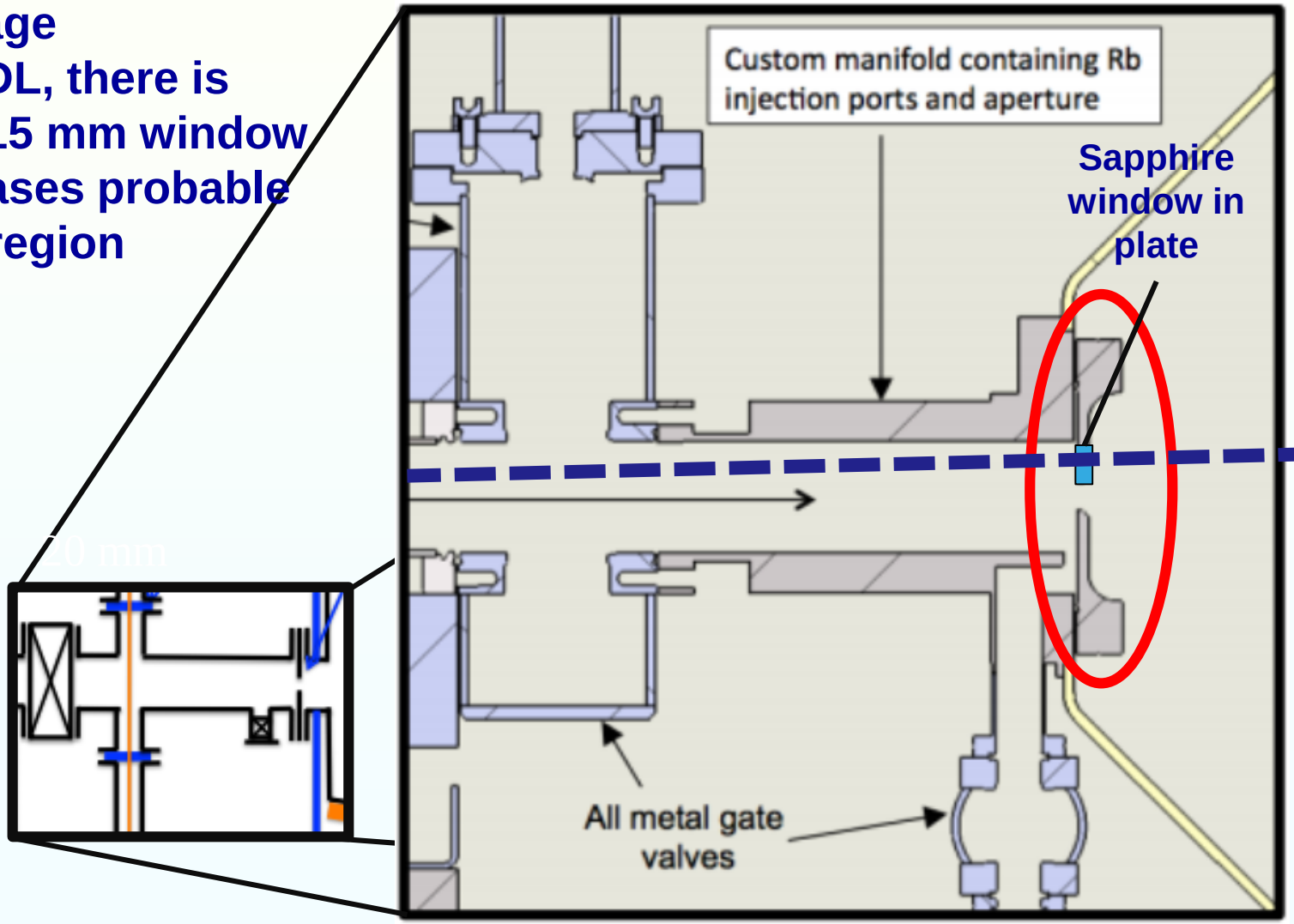

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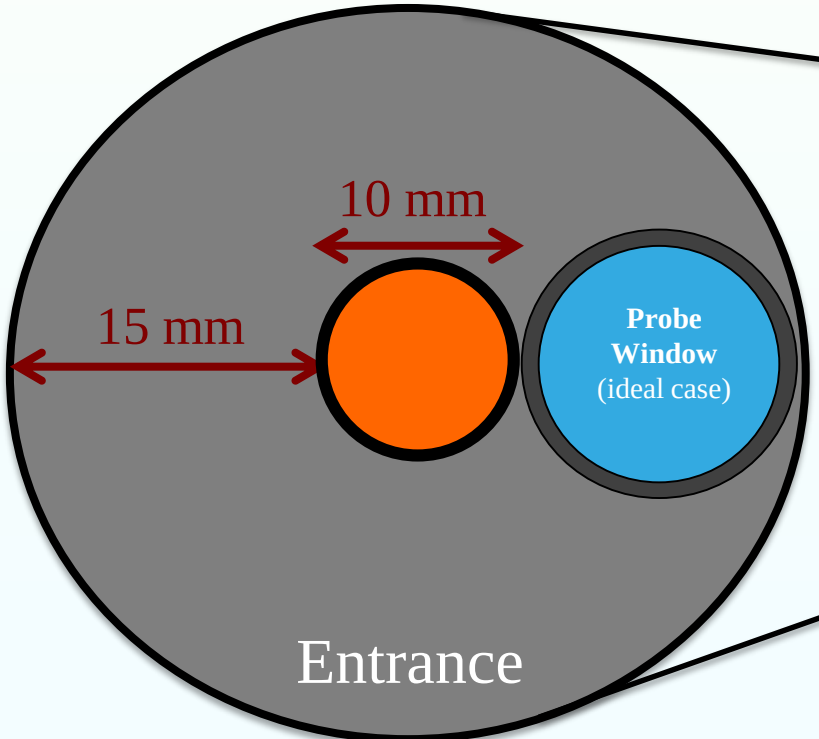
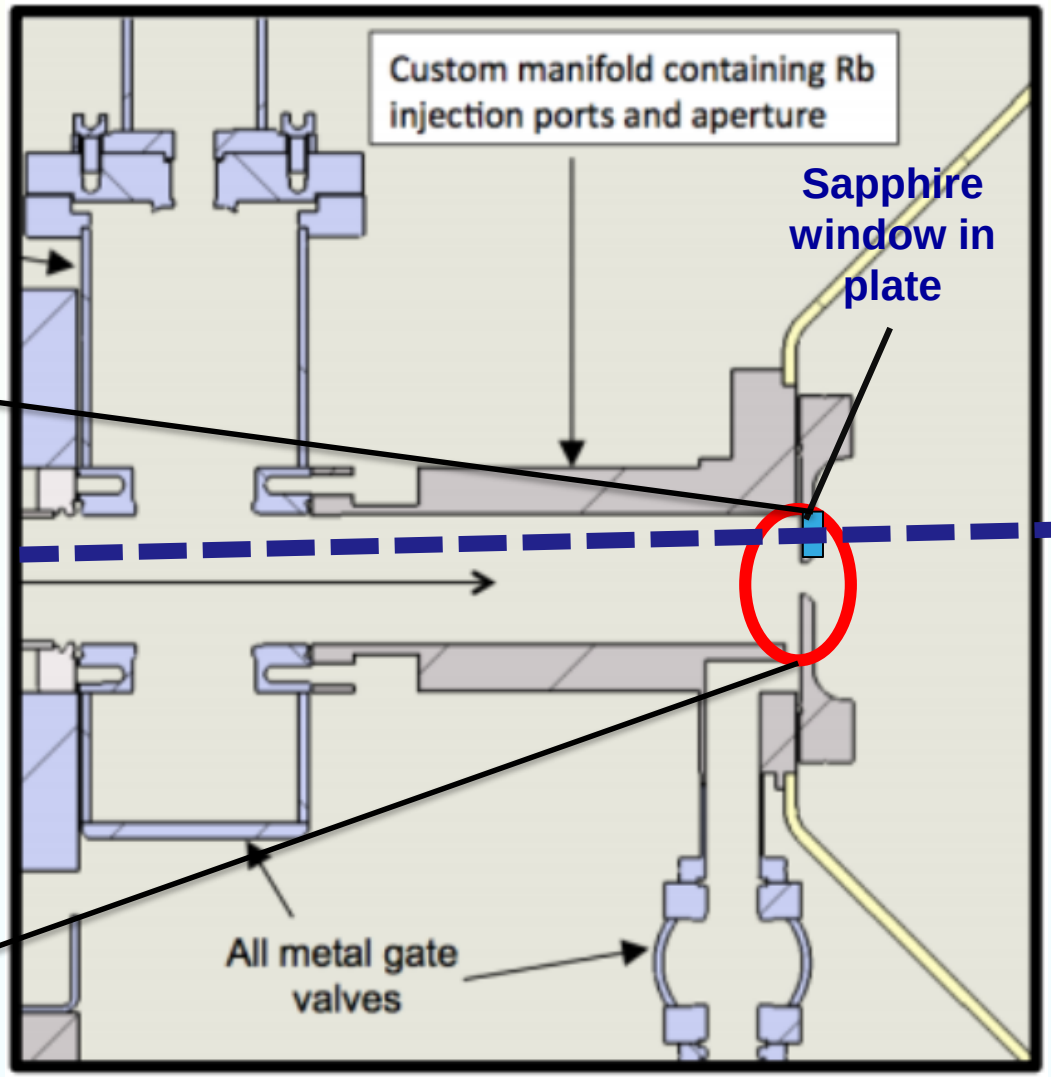
Note, no rubidium deposit on window because sapphire is above condensation temperature (~ 23 C)

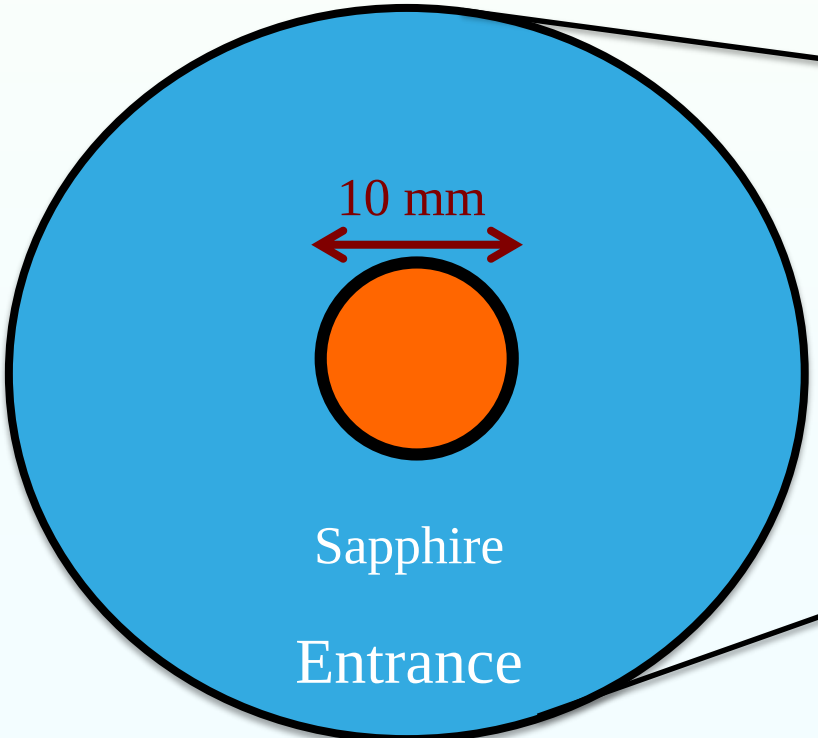


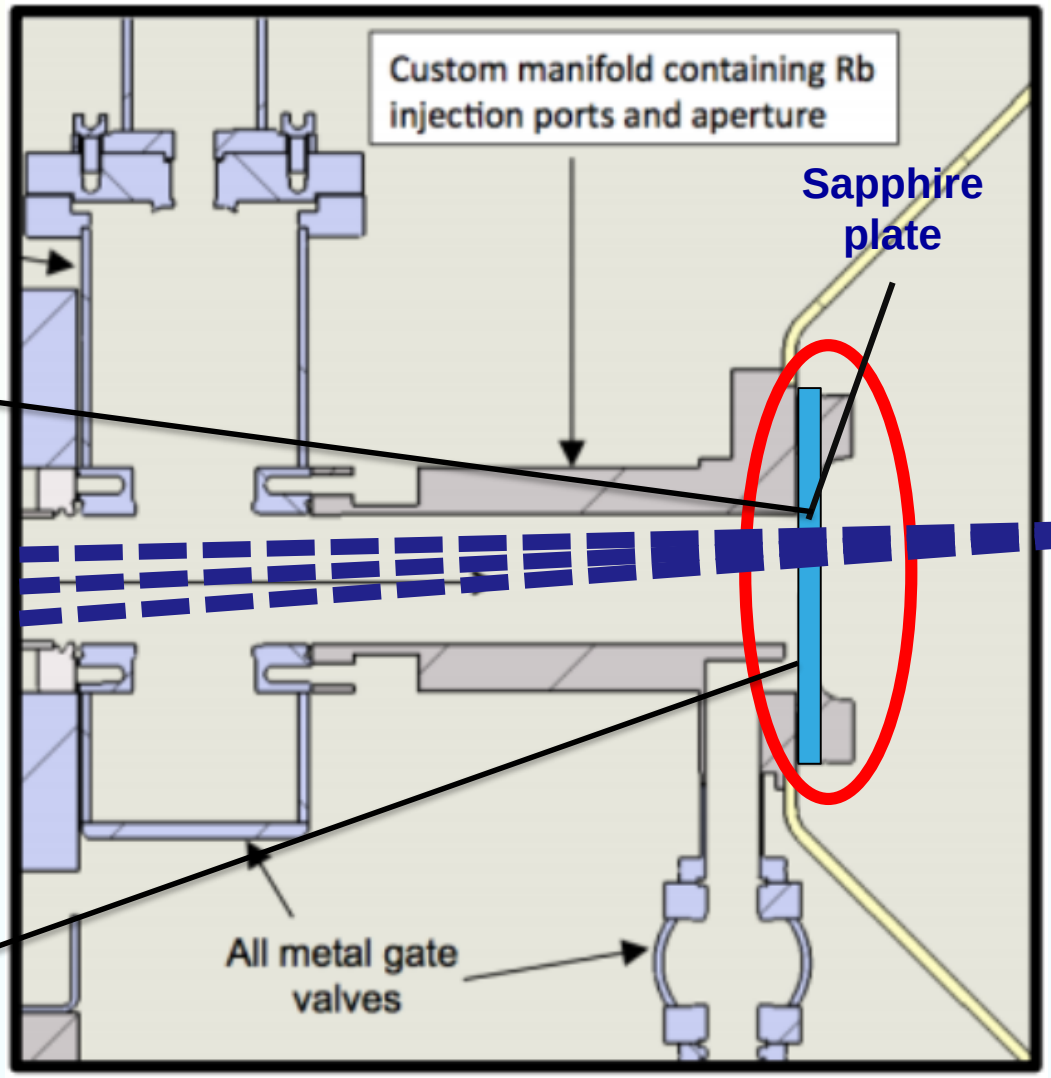


Sapphire window – plate

- Whole face of plasma cell is sapphire window
- Provides maximum flexibility for probing regions of plasma
- Angle and translation

Note, no rubidium deposit on window because sapphire is above condensation temperature (~ 23 C)





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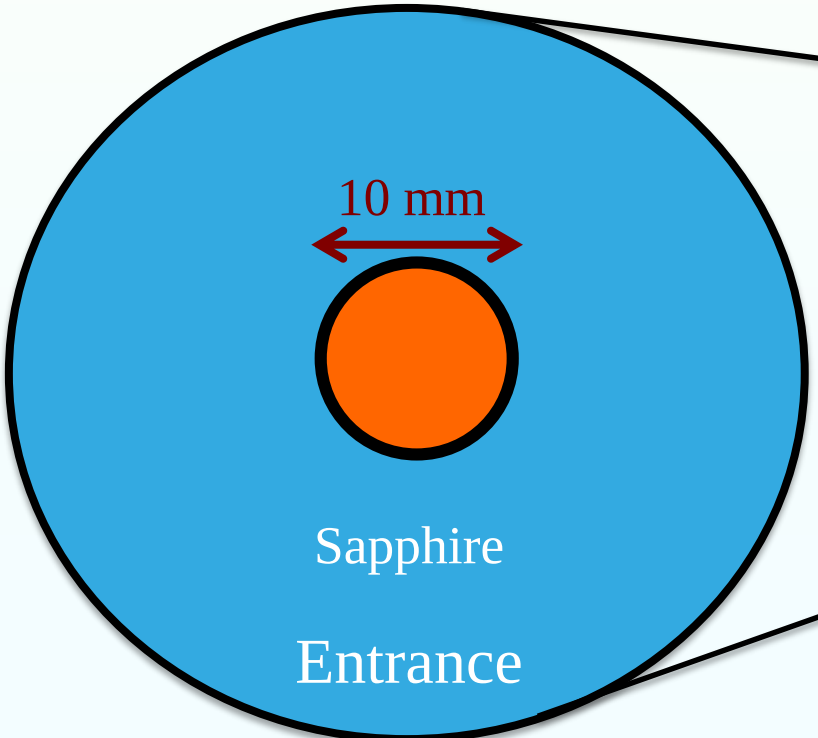
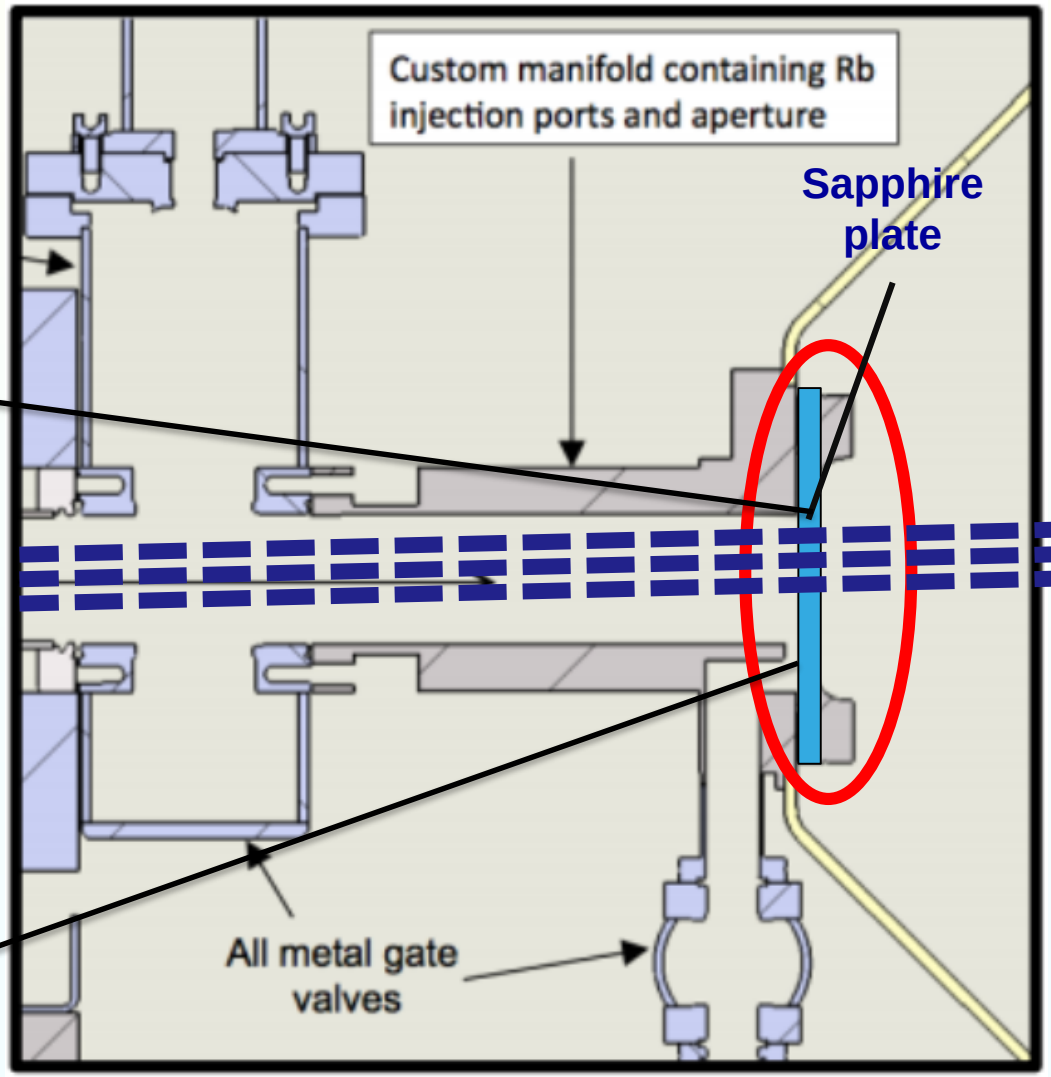
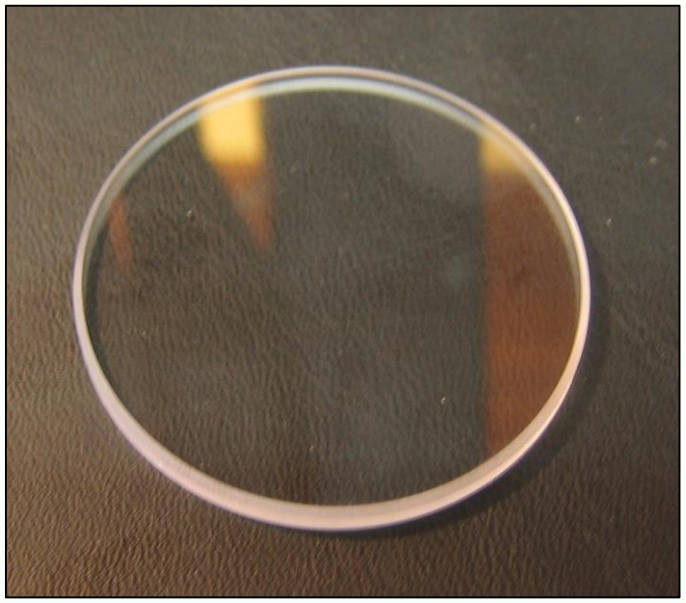




Sapphire properties

- **Melting point ~ 2,000 C**
- It will have to width stand ~ 200 C



- **Strong**
- Approximate pressure of plasma on window will be 1 Pa (10^{-5} bar)
- This gives a force of one newton for a window of O(10 mm^2) this

- **Inert**
- From our findings so far it should not react with the rubidium

- Commonly used well known and existing manufacturers produce to optical standards
- Can test on ‘dirty’ plasma stage

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3D model courtesy of Ans Pardons

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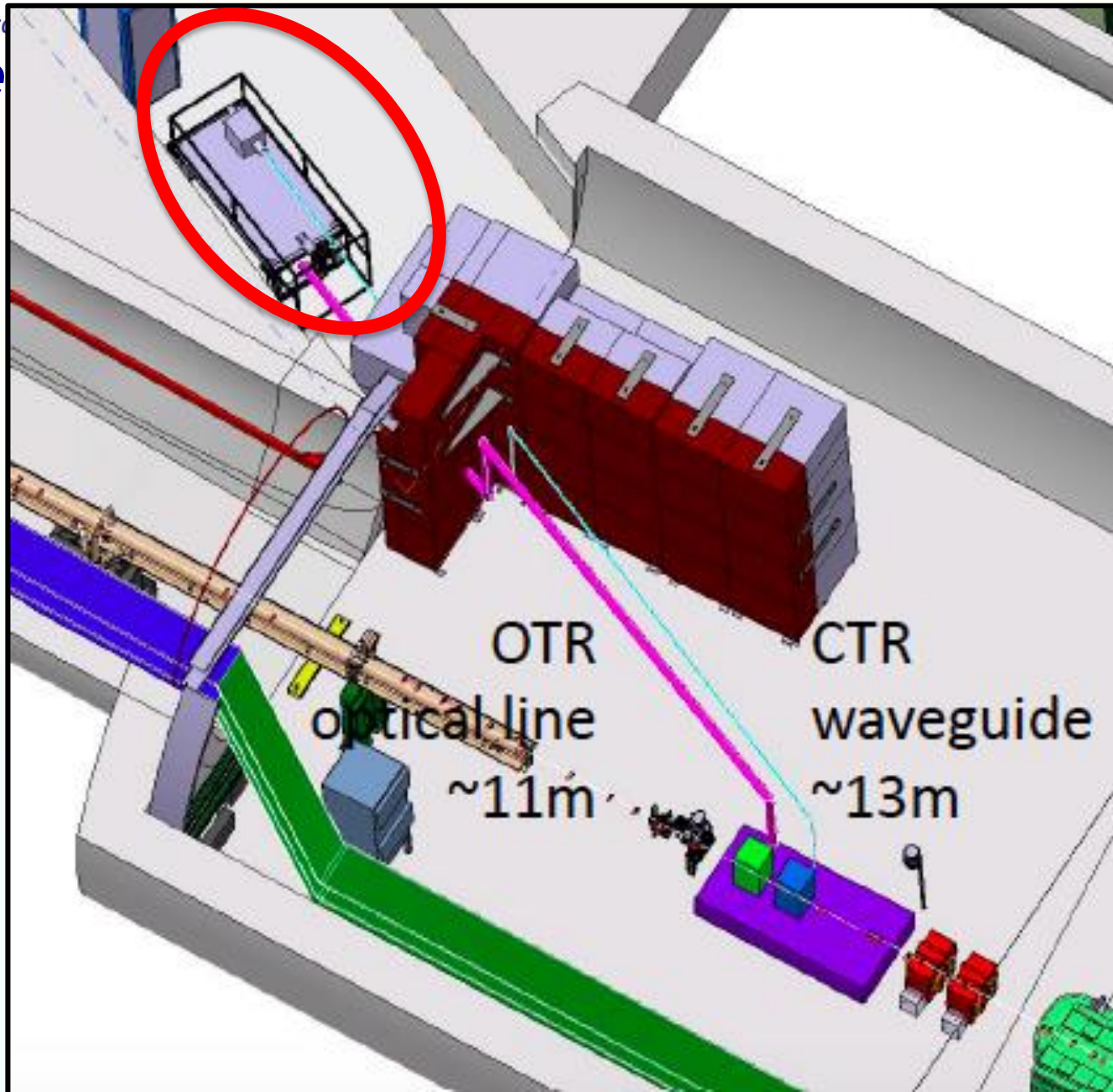
Diagnostic table

- Interested in this area
- Need ~1 m^2 for spectrometer and accompanying optics
- Optical fibre not possible
- Ideally add an additional optical line!
- Alternatively use mirrors to pass onto diagnostic table the long way



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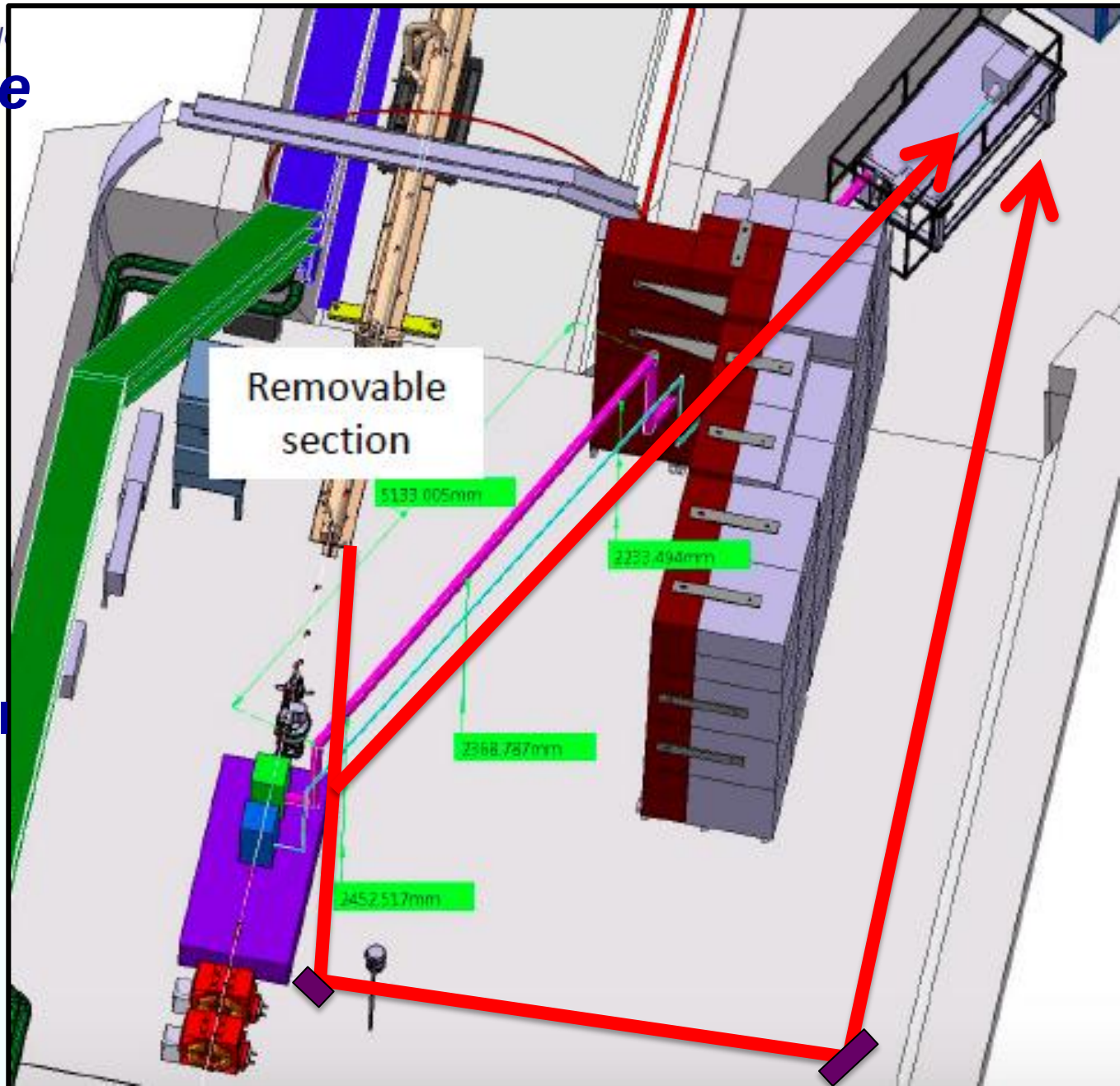

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Data Acquisition

- Acquiring optics on each shot:
- Two Auto alignment cameras
- One transverse beam profile
- One Andor 2048 x 2048

- Approximately 20 mb for each shot. 40 mb after backing up.

- For a run of 1000 shots that is very little (40 gb).

- Data recorded in one of two ways:
- Locally on machines in the experimental area and copied across to control room
- Or straight to control room.

- Gigabit ethernet interface will suffice.

- Intend to have a machine in the experimental area for Auto alignment system

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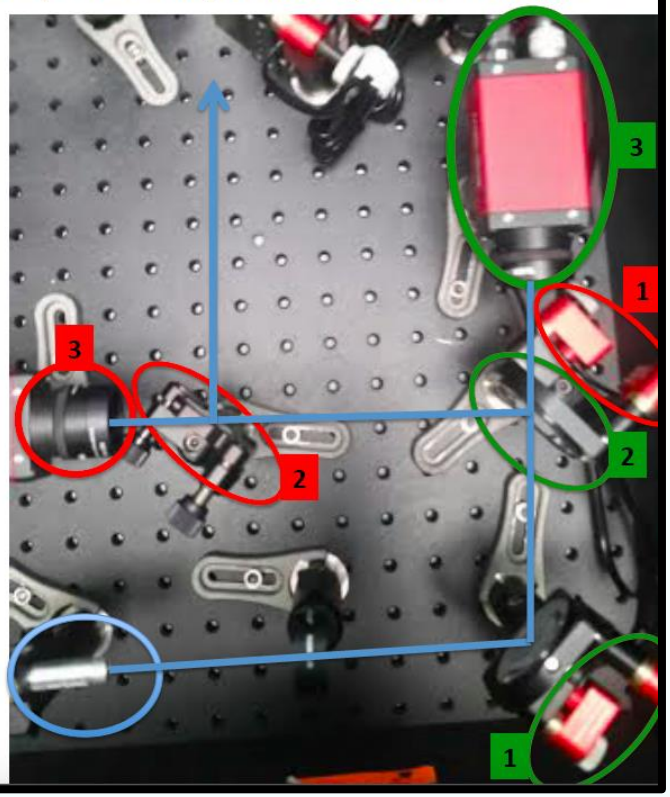
Auto alignment system

- AA system components purchased
- Implementing on Muhammad's 3D spectrometer to test in situ
- Alleviates concerns about pointing of our probe pulse (need sub 1 mrad precision)

Rutherford Appleton Laboratory: Auto-Alignment System Example

A demonstration of a auto-alignment system produced by RAL.

- Actuators **(1)** control the pitch and yaw of the first mirror.
- The mirror **(2)** leaks light on to camera **(3)**
- Actuators **(1)** are adjusted by computer program to bring the beam onto the centre of camera **(3)** and therefore the centre of mirror **(2)**
- The same process brings the beam onto the centre of mirror **(2)** for the optics highlighted in red.
- This pair of components (red and green) will align the beam. Many such pairs may be needed over the entire beamline



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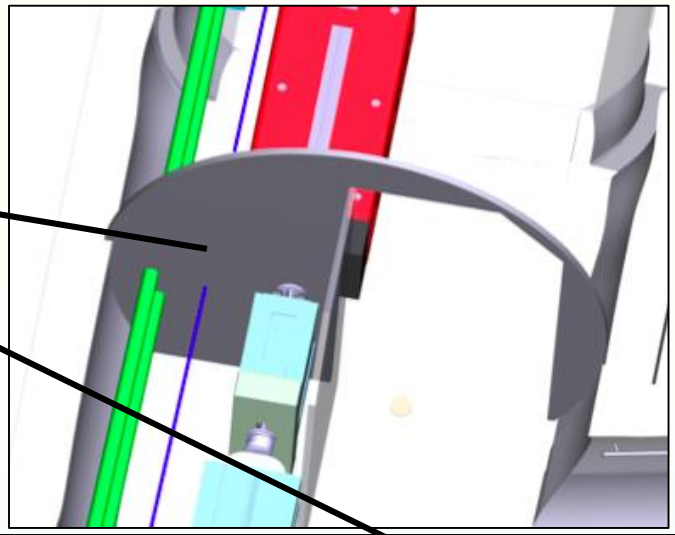
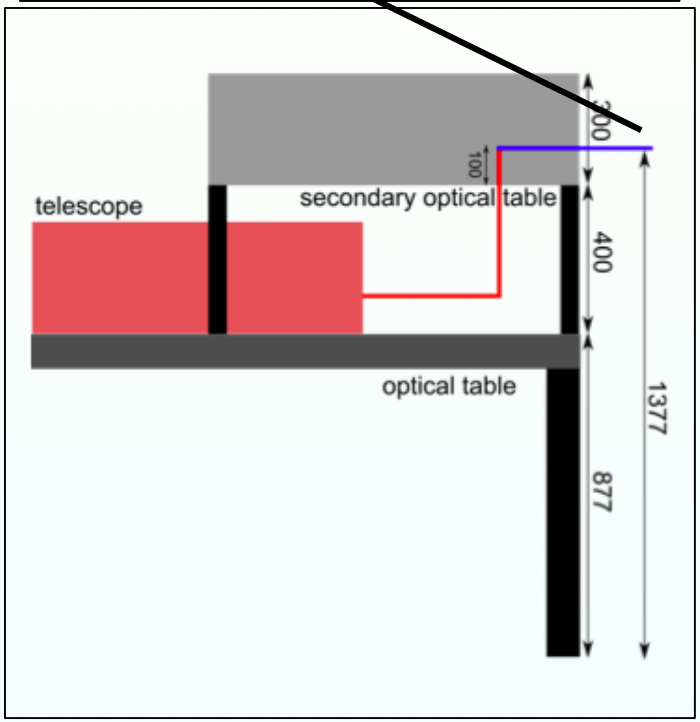
Safety

- Going through a fire door?
- Height of probe pulse in laser room
- Working with 800nm and 400nm lasers in same area (opaque goggles)
- Shielding of probe pulse beam line (so far considered simple beam block)
- Safety issues from your side?





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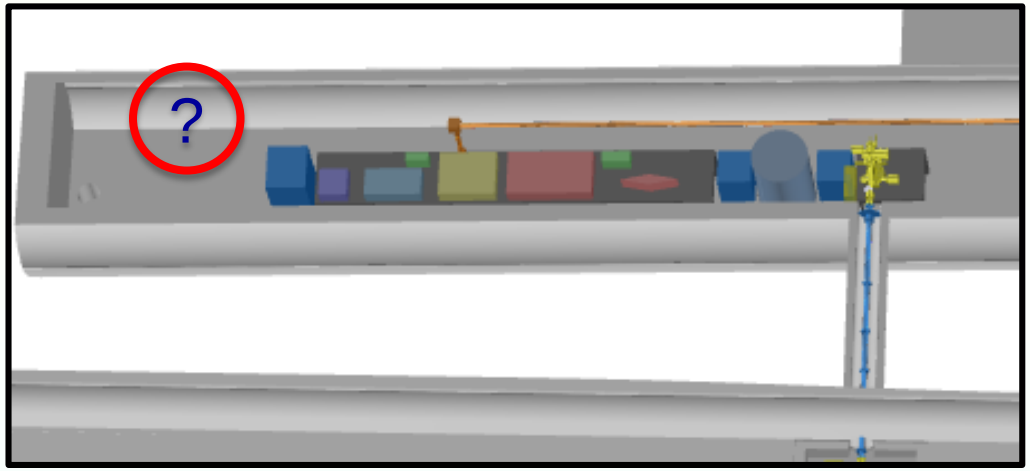
Summary

- Probe pulse can be generated from 50 mJ pick off of ionisation beam
- Merging requires space!
- (Sapphire) window is mission critical for the diagnostic
- Need large space for forward diagnostic table
- DAQ system is simple
- Racks / cabling needs to be discussed in future
- Safety concerns are not major but need to be addressed

Generating The Probe Beam

3D model courtesy of Ans Pardons

- Pick off (a small piece!) from ionisation laser before compression
- Frequency double



Issues

- No space in laser room
- Minimal spare energy in ionisation laser pulse

Solution

- **Small bread board (dimensions) above** will have beam X cm below head height.
- **If zero energy spare – run diagnostic when photo injector not running (phase I when most useful)**
- **If little energy spare – no problem!** 50 TW cm^{-2} for ionising pulse. Need 2 TWcm^{-2} ionize.

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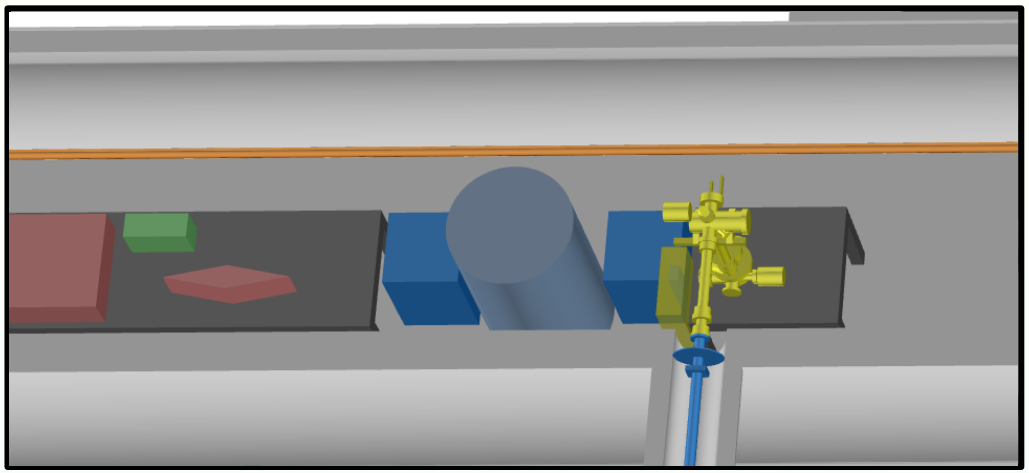

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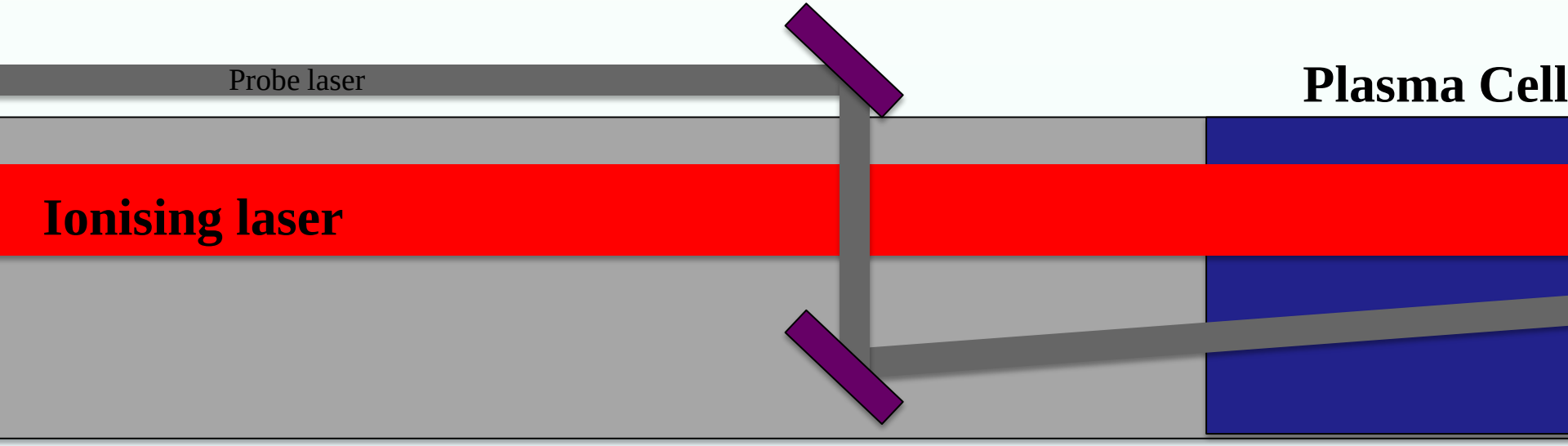
Probe beam: From Laser room to plasma cell

- **Probe uses same transport mirrors as ionisation laser – probe beam offset**
- **The probe pulse is 'caught' by a small mirror before entering the plasma cell**



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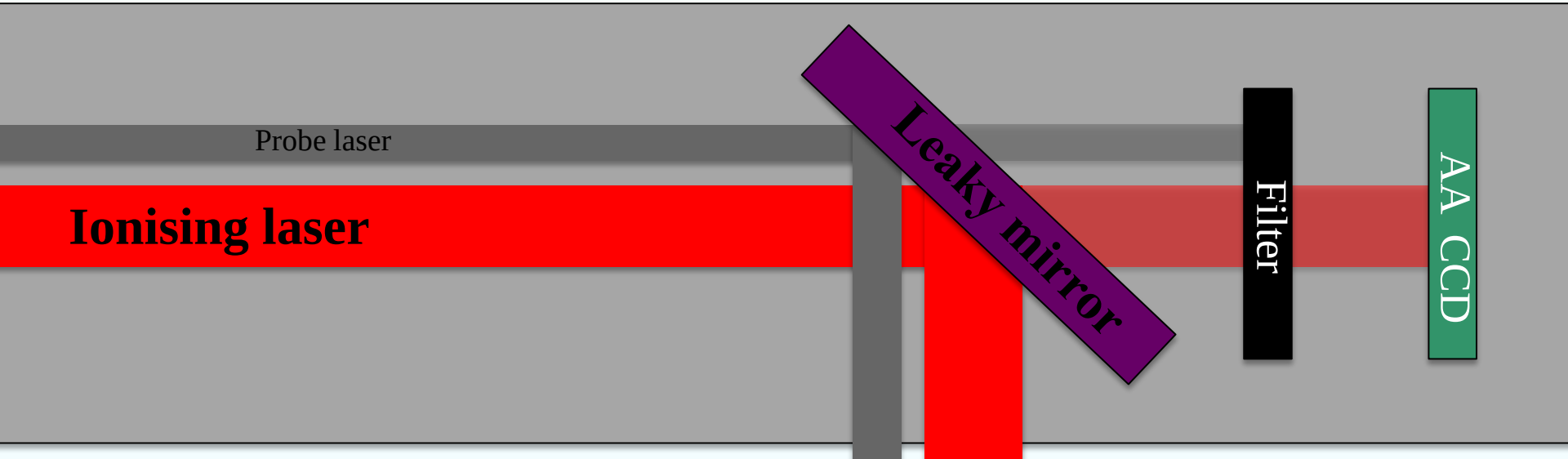
Probe beam: From Laser room to plasma cell

Issues

- **Auto alignment system** (if implemented?)
- **Clipping**

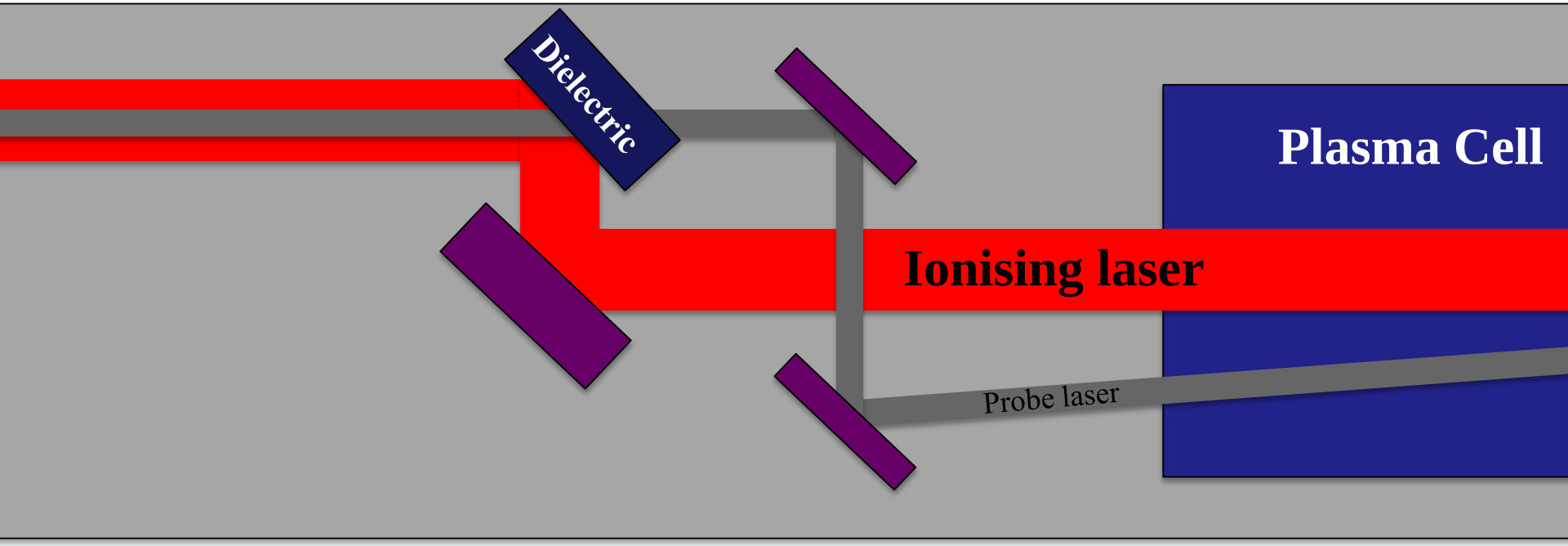
Solution

- **Frequency doubled leaked probe pulse can be discriminated against with filters / dielectric mirrors etc**



Probe beam: From Laser room to plasma cell

- **Probe uses same transport mirrors as ionisation laser – probe beam *overlaid***



Issues

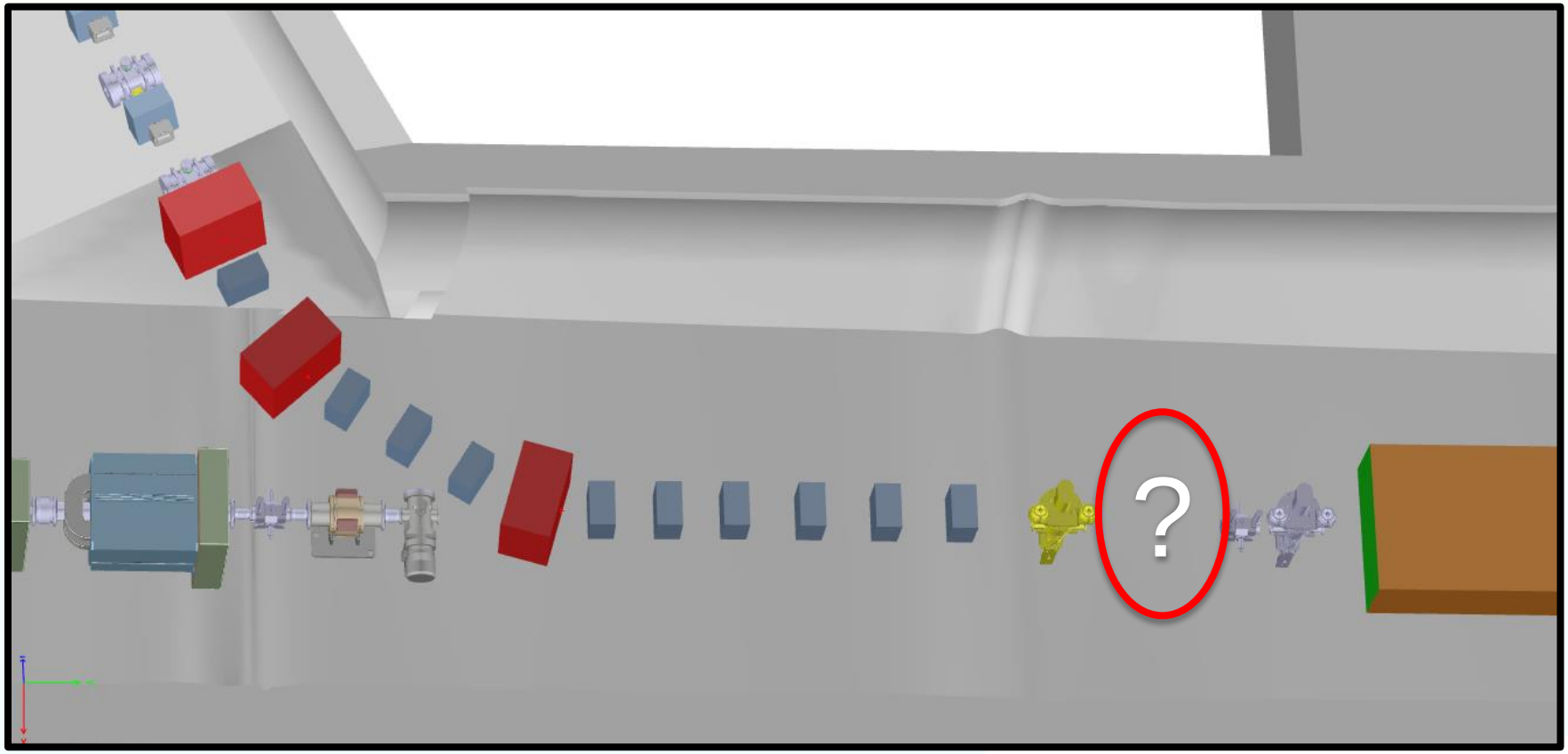
- **Ionisation pulse has two additional reflections (one dielectric mirror)**
- **More space required**

Problem

Probe beam: From Laser room to plasma cell

- **Finalized design: crowed!**

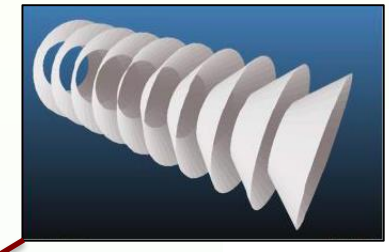
Solution: ***work with technical board and beg a shoebox of volume***



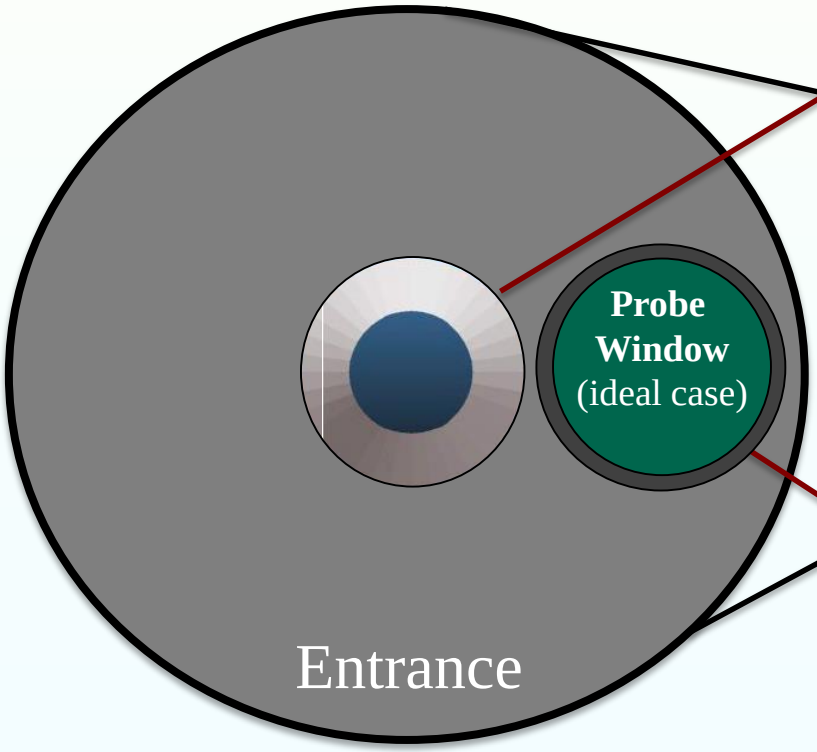
3D model courtesy of Ans Pardons

The plasma cell

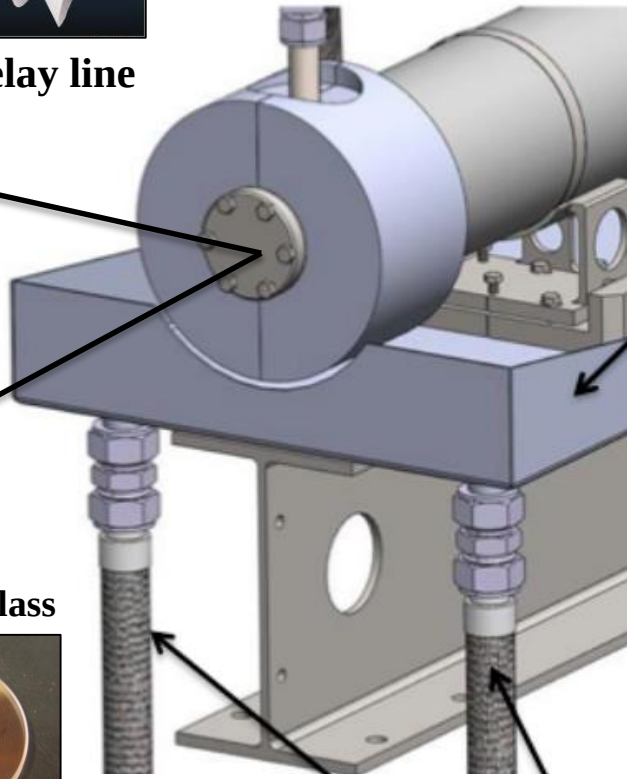
- Propagate probe pulse at a small angle (1 mrad) to proton beam axis
- Plasma cell has no window access
- Plasma cell has Ø = 40 mm
- Probe pulse has Ø = 10 mm



Acoutis delay line



End View



Sapphire glass

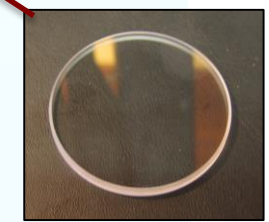


Image pilfered from P. Muggli

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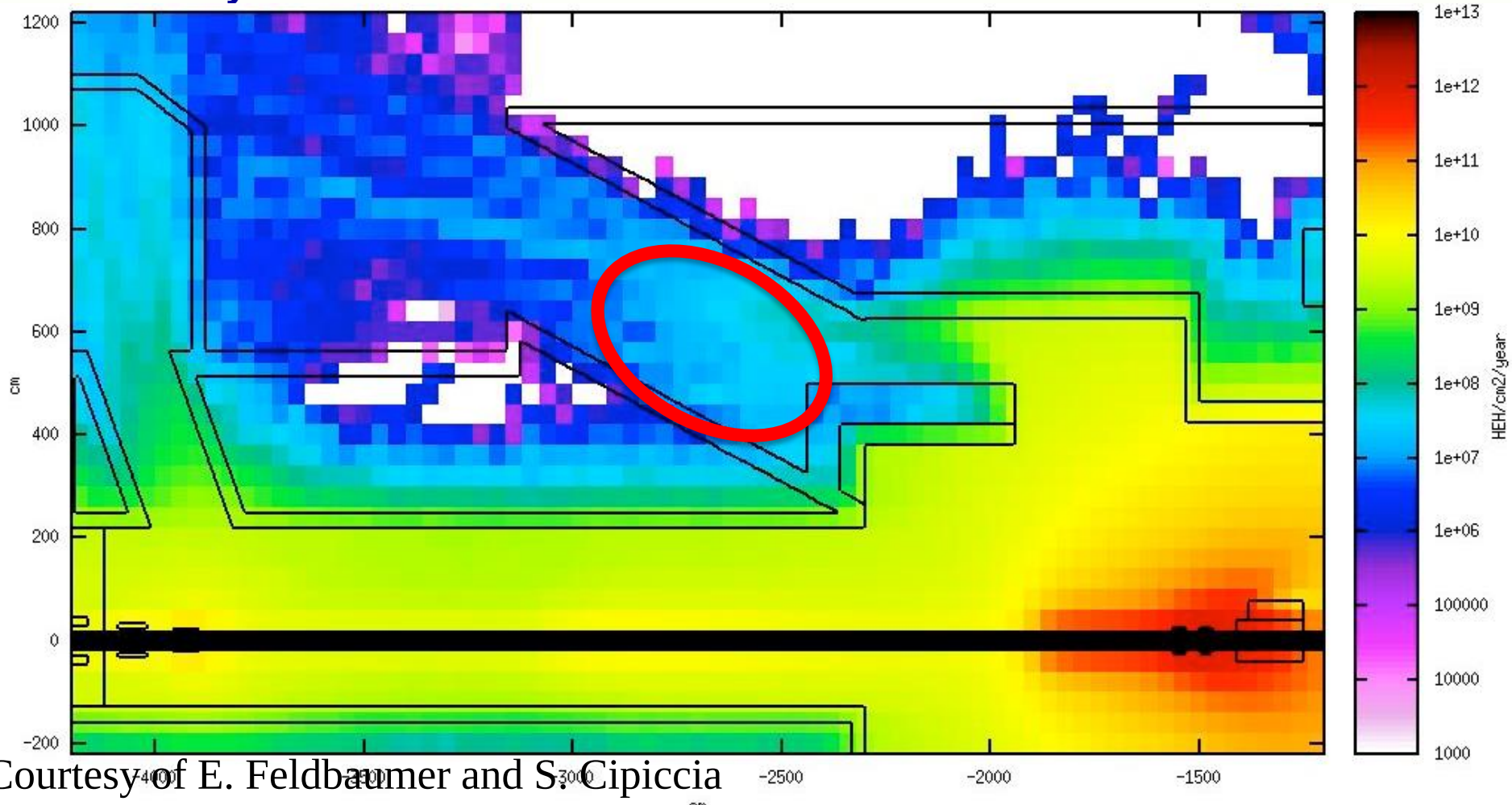
From plasma cell to diagnostic table

- **There is not much space**
- **Radiation is an issue**
- **COTS systems limit: 1e+8 HEHcm^{-2}**



Courtesy of E. Feldbaumer and S. Cipiccia

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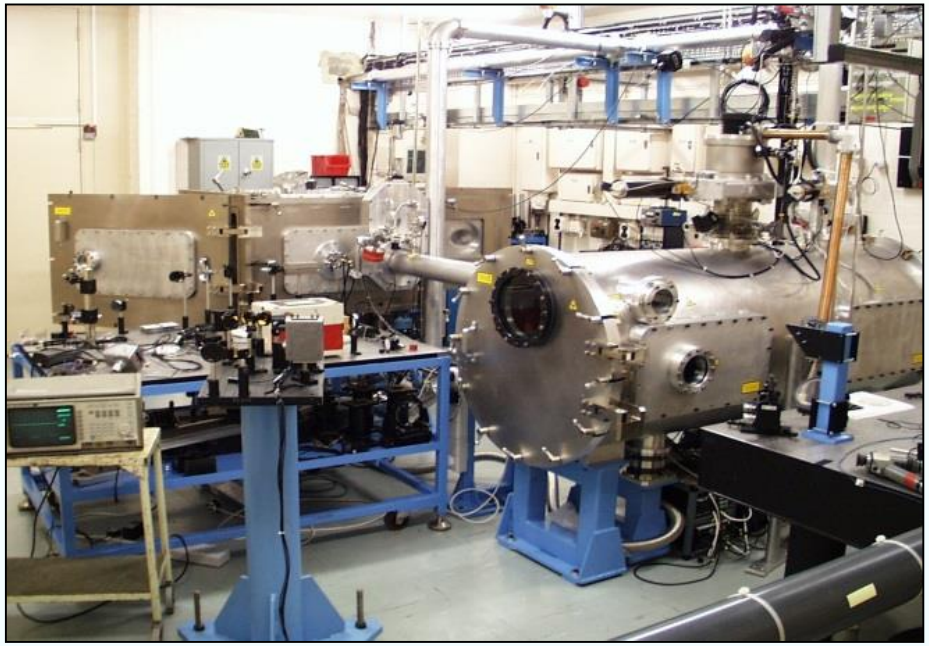
Astra Experiment

- **A 12 week experiment using the** E = 500 mJ, T = 40 fs **Astra laser pulse to drive a wakefield**
- **Test the diagnostic in situ**
- **Develop software to analyse data on the fly – real time plasma diagnostic**
- **Begins in May 2016**



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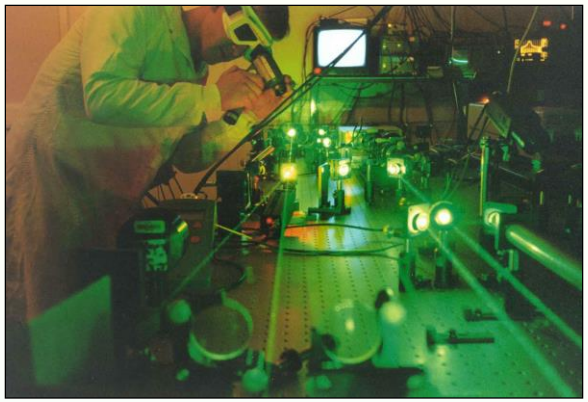
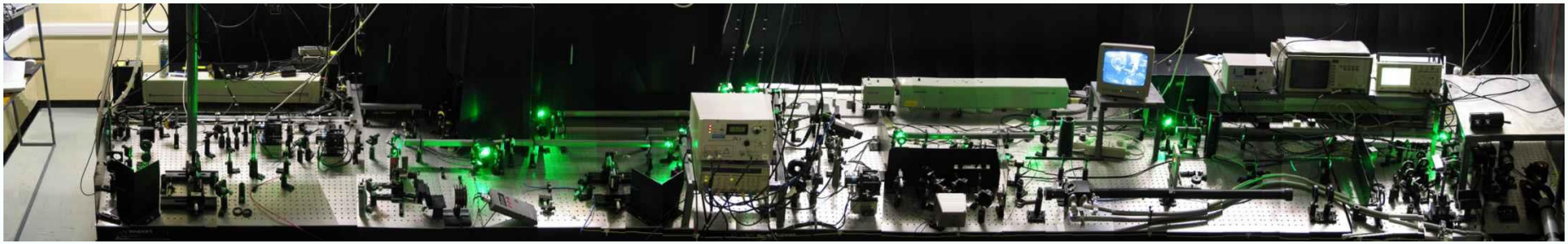
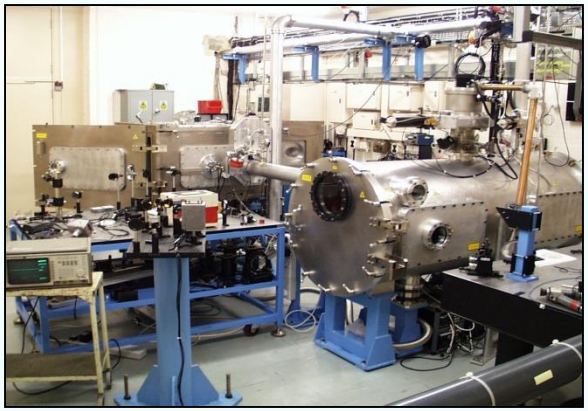
Thank you for listening

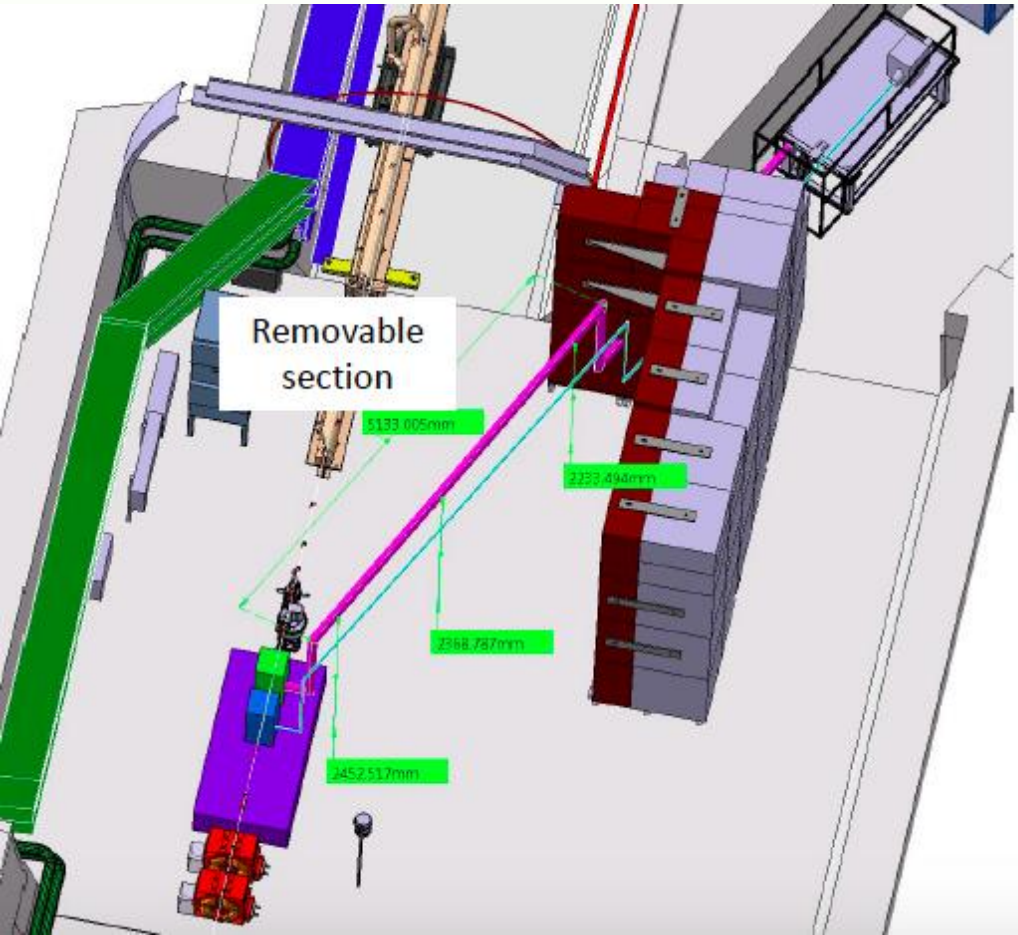
Astra laser

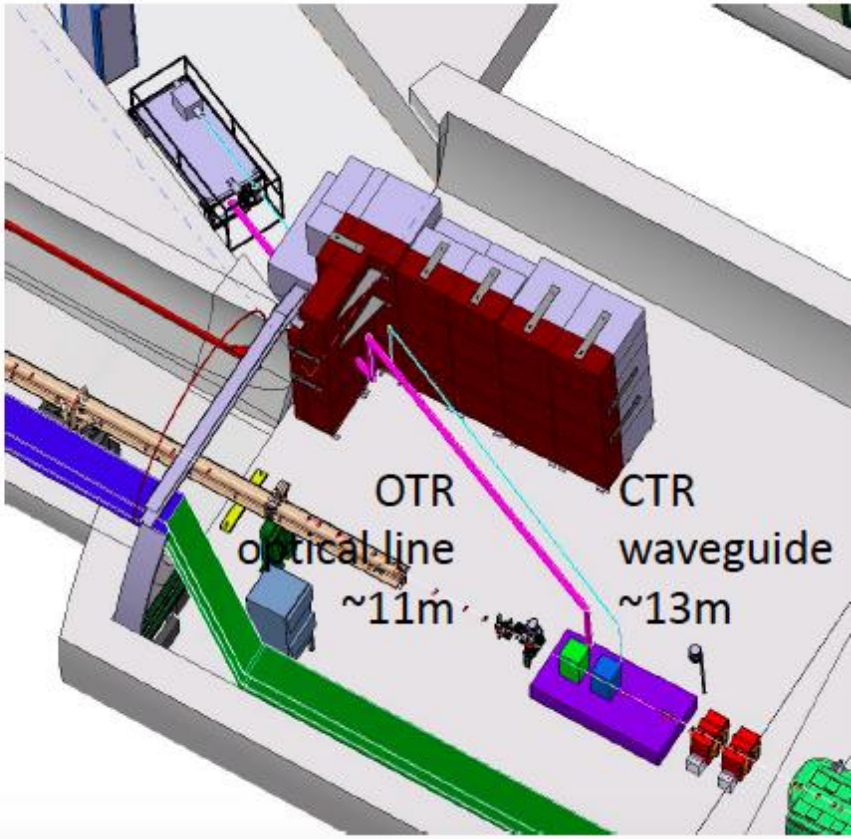


- Single Beam Titanium Sapphire laser system
- 10 TW optical pulse at 10Hz / 25TW at 1Hz
- Experiments in Laser-Plasma Physics






Removable section
5133.005mm
2233.494mm
2368.787mm
2452.517mm


OTR optical line ~11m
CTR waveguide ~13m

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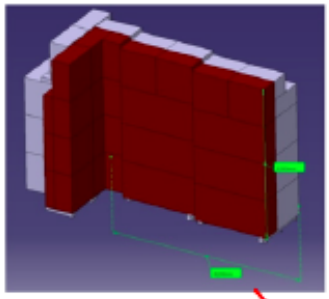
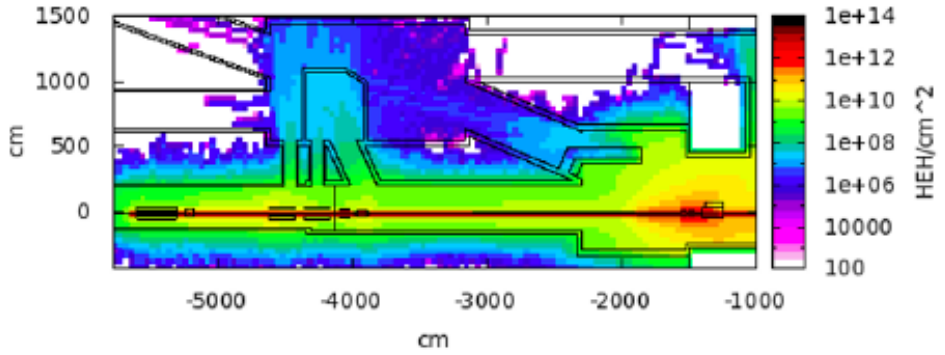
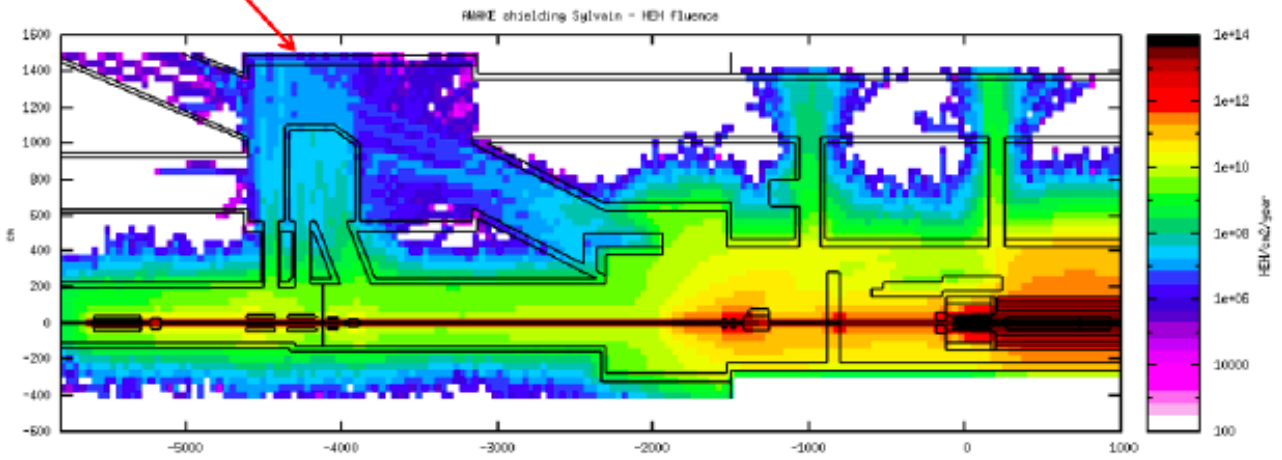
HEH - proposed shielding

AWAKE



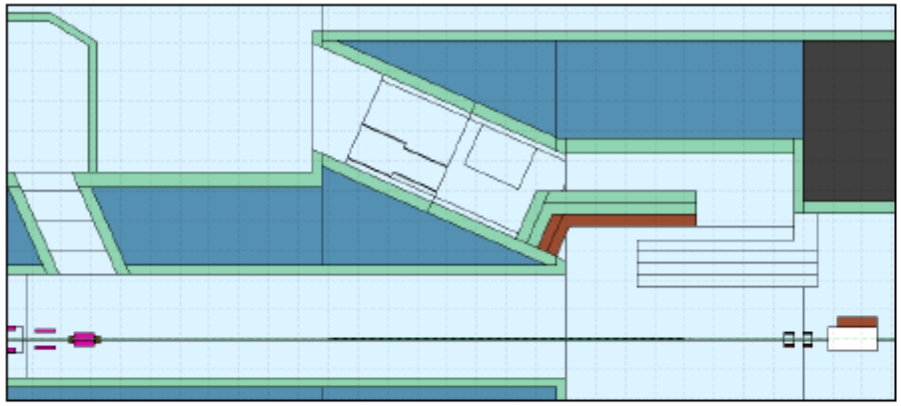


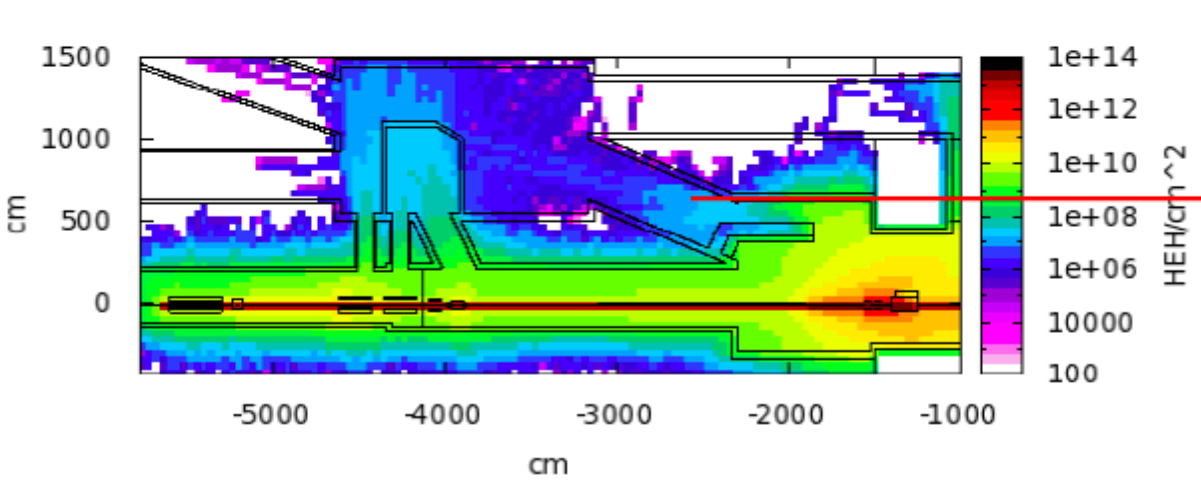


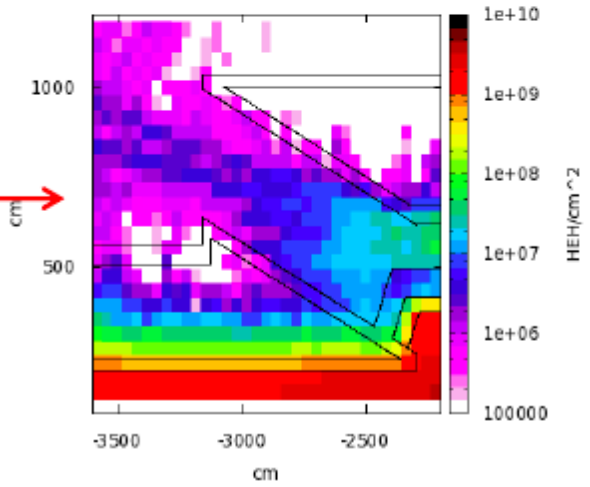
- TSG41 shielding designed
- Alcove idea abandoned as not sufficiently shielded

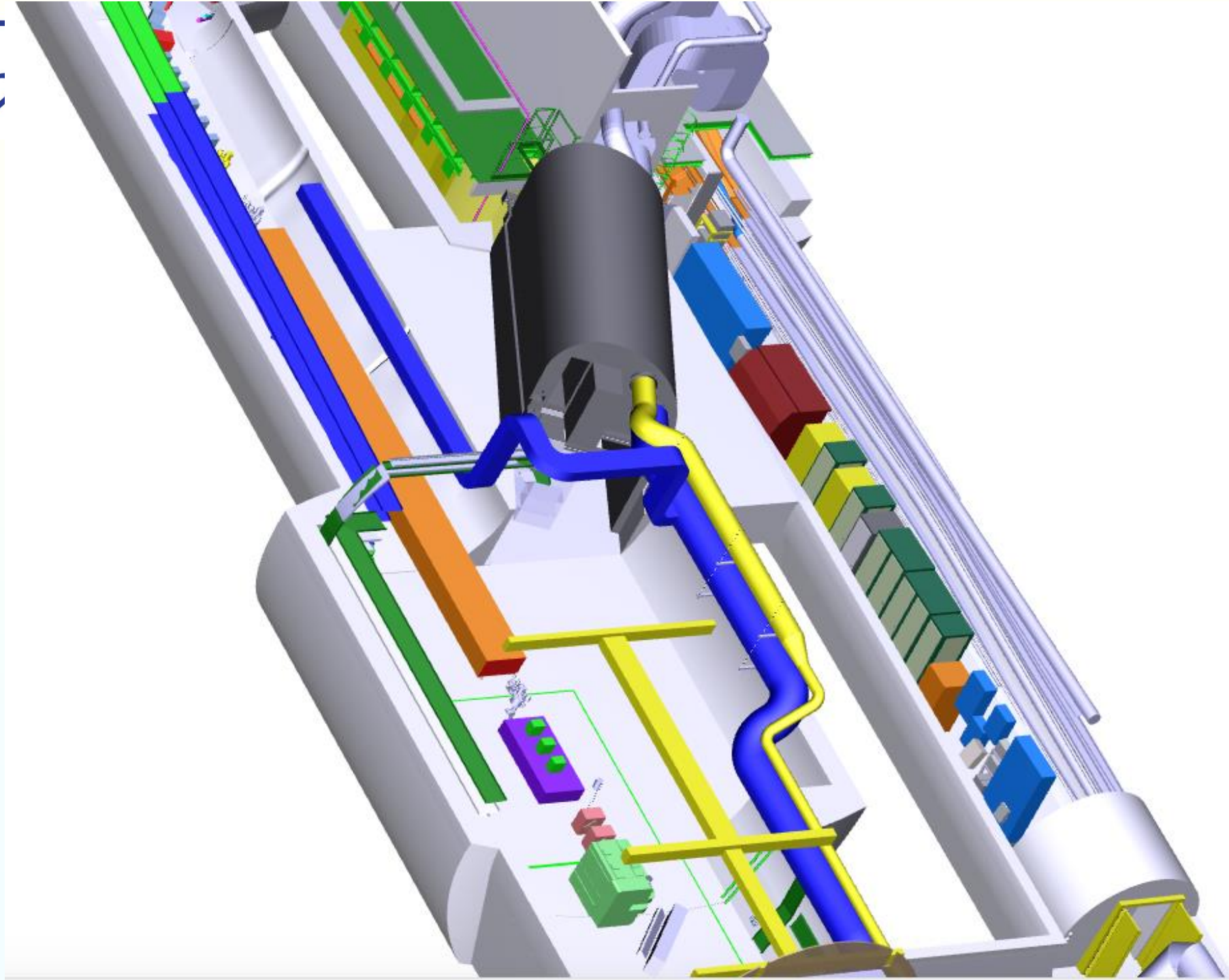
Courtesy of E. Feldbaumer & S. Cipiccia

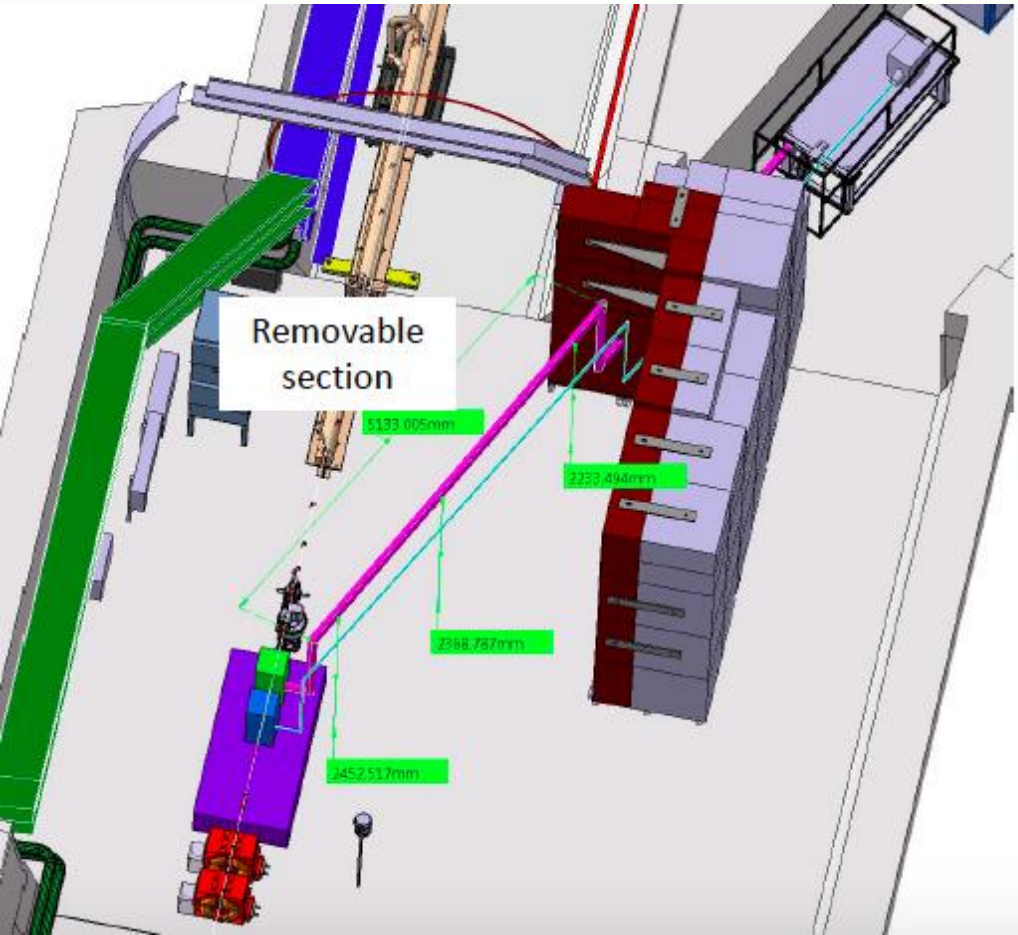
- Short section:
  - Iron: from 40 cm -> 60 cm
  - Concrete 80 cm
- Long section:
  - Iron 40 cm
  - Concrete 80 cm
  - Length: 4.4 m
- Height: from 2.1 m -> 3.9 m










Removable section
5133.005mm
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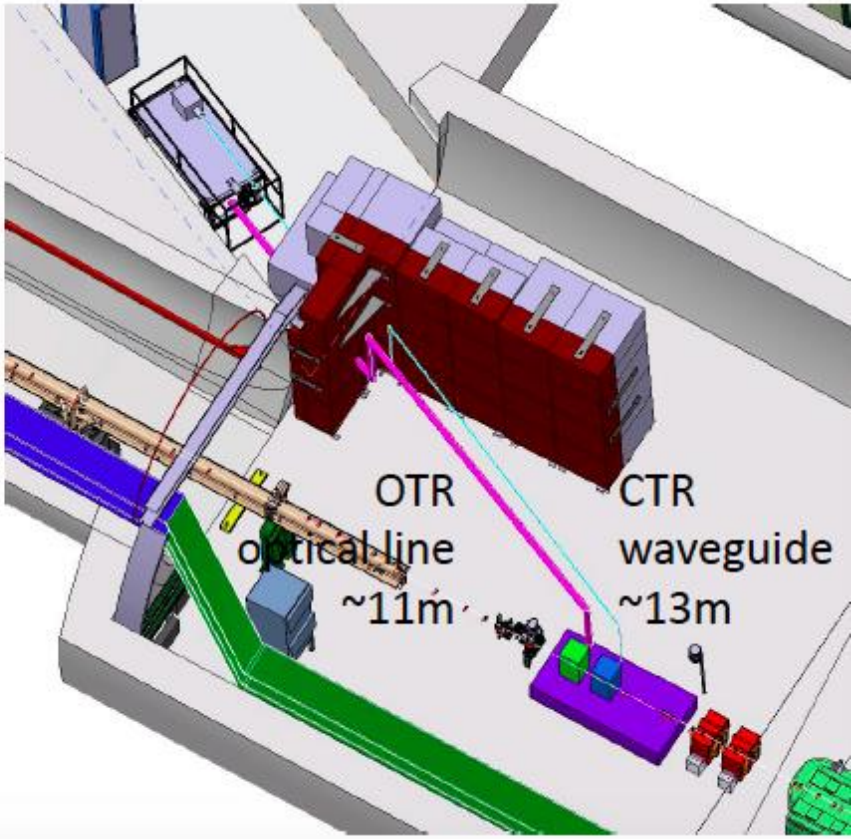
OTR optical line ~11m
CTR waveguide ~13m

Shielding option 2:

- Short section:
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  - Concrete 80 cm
- Long section:
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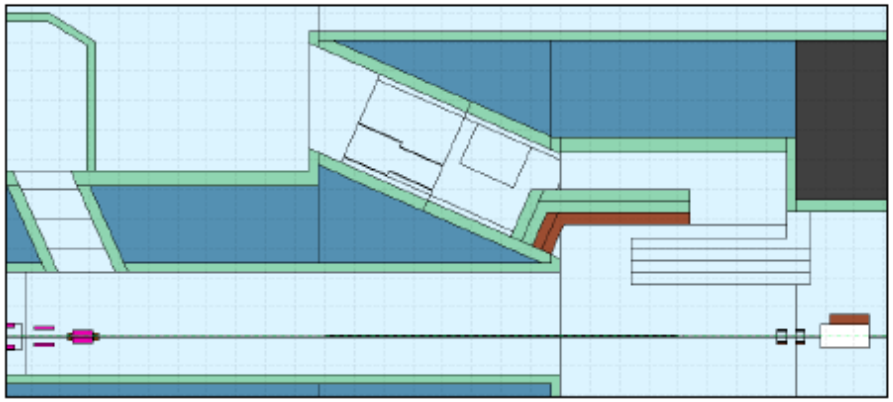
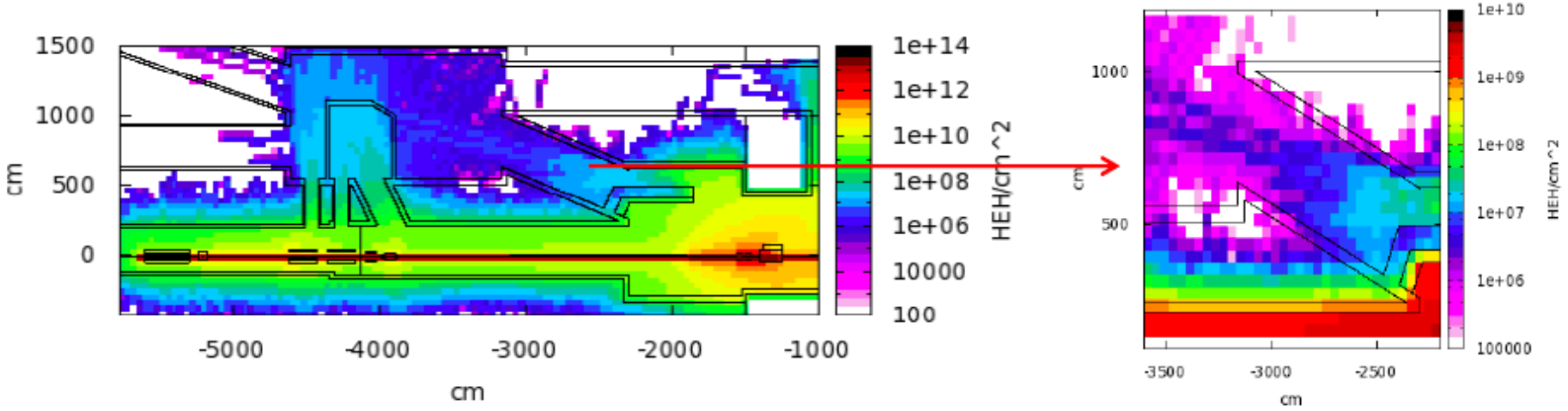
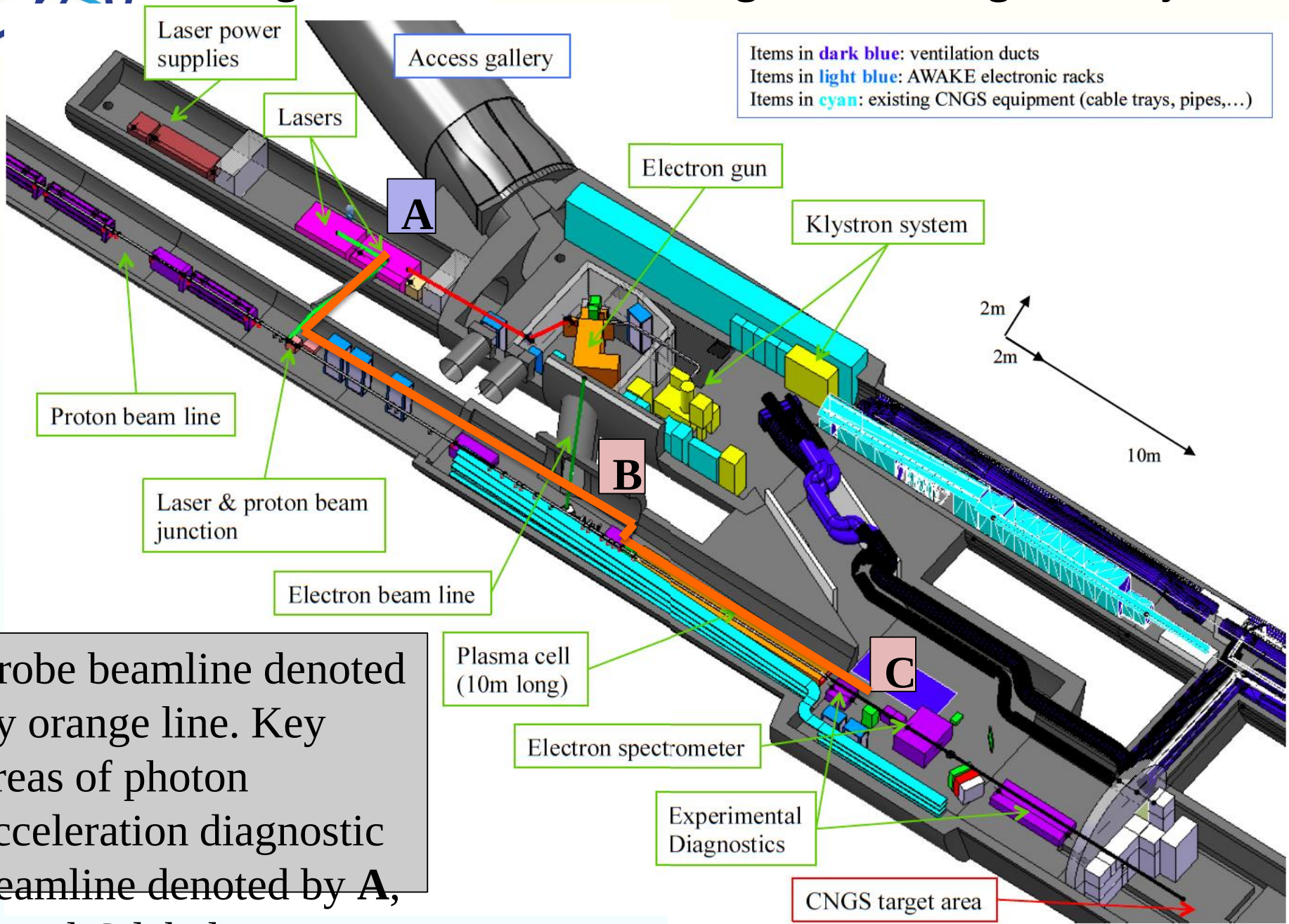
  - Concrete 80 cm
  - Length: 4.4 m
- Height: from 2.1 m -> 3.9 m





Probe beam diagnostic beamline: costing the auto-alignment system.

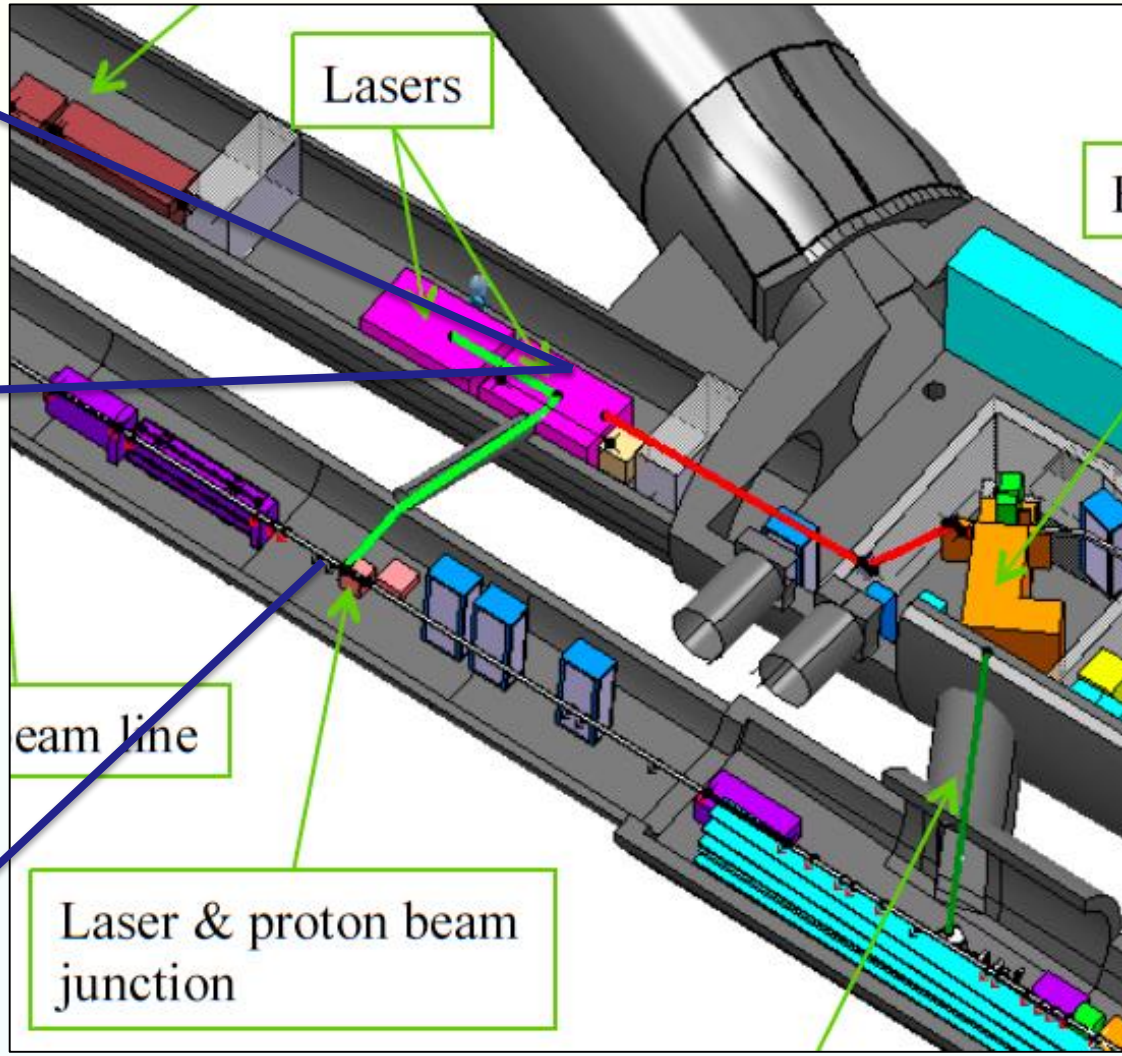


Probe beamline denoted by orange line. Key areas of photon acceleration diagnostic beamline denoted by **A**,

A: Laser Room.

1) Probe laser picked off from ionising laser before final compression. Probe laser is T = 160 ps, 20 nm bandwidth NIR at this point.

2) Probe laser telescoped up to 10 mm diameter and frequency doubled using SHG crystal. Bandpass filter used to resulting in a 390 nm, 3 nm bandwidth, 26 ps duration probe laser pulse. Both 1) and 2) can be achieved on additional breadboard in



B: Proton Tunnel.

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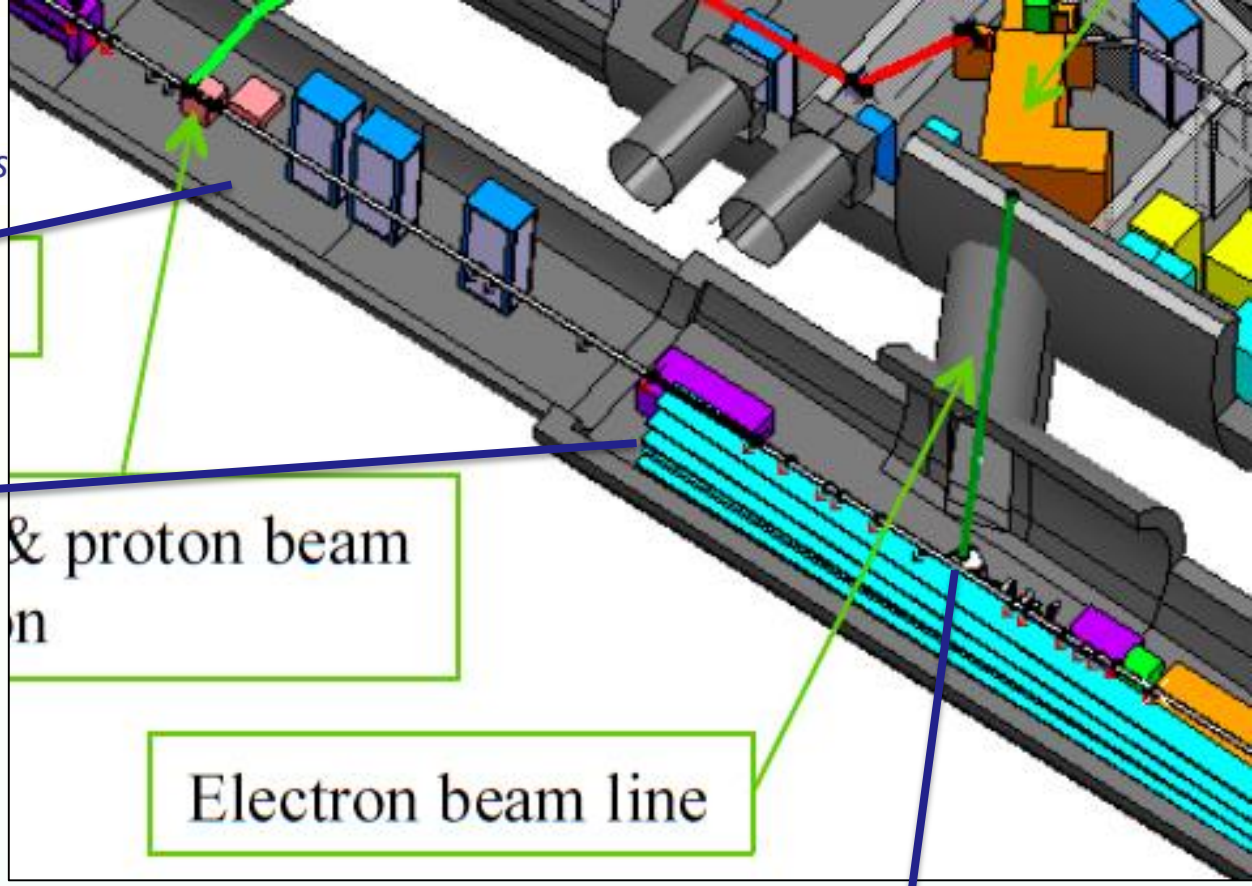
Probe laser steered in air down proton tunnel

Dog-leg used to pass through junction (non-critical).



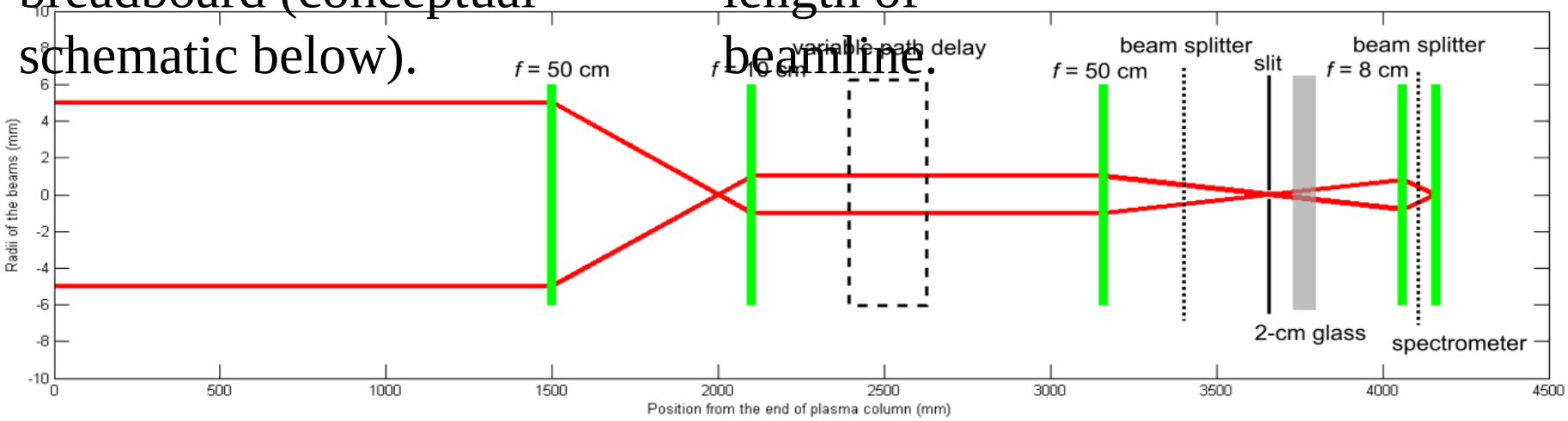
Probe laser merged with proton and ionising laser pulse 2 m from plasma cell. Pointing stability from the last mirror before plasma stage needs to be a maximum of 0.2 mrad, ideally 0.1 mrad.

Probe laser merged with proton and ionising laser pulse 2 m from plasma cell.

C: After Plasma

Probe pulse has 1.5 m of propagation after plasma cell before entering diagnostic table breadboard (conceptual schematic below).

'Variable path delay' not significant compared to length of beamline.



Note: The angle between the probe pulse and the proton beam is important to know on a shot-by-shot basis for analysis later.

Would an auto alignment system have a feature where it could record such

ADL abandoned. Now have expansion volume

- Adds 50 cm to each end.
- Expansion volume has 2 mm of rubidium build up every two weeks
- Cannot put components inside
- Expansion vol