Vacuum Systems for Diamond-II

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(On behalf of Diamond-II Vacuum and Engineering Teams)

Diamond-II: challenges and novel solutions for upgrading the national synchrotron light facility

Rutherford Appleton Laboratory

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Topics

- Requirements
- Challenges
- Solutions and Technologies

Diamond-II upgrade

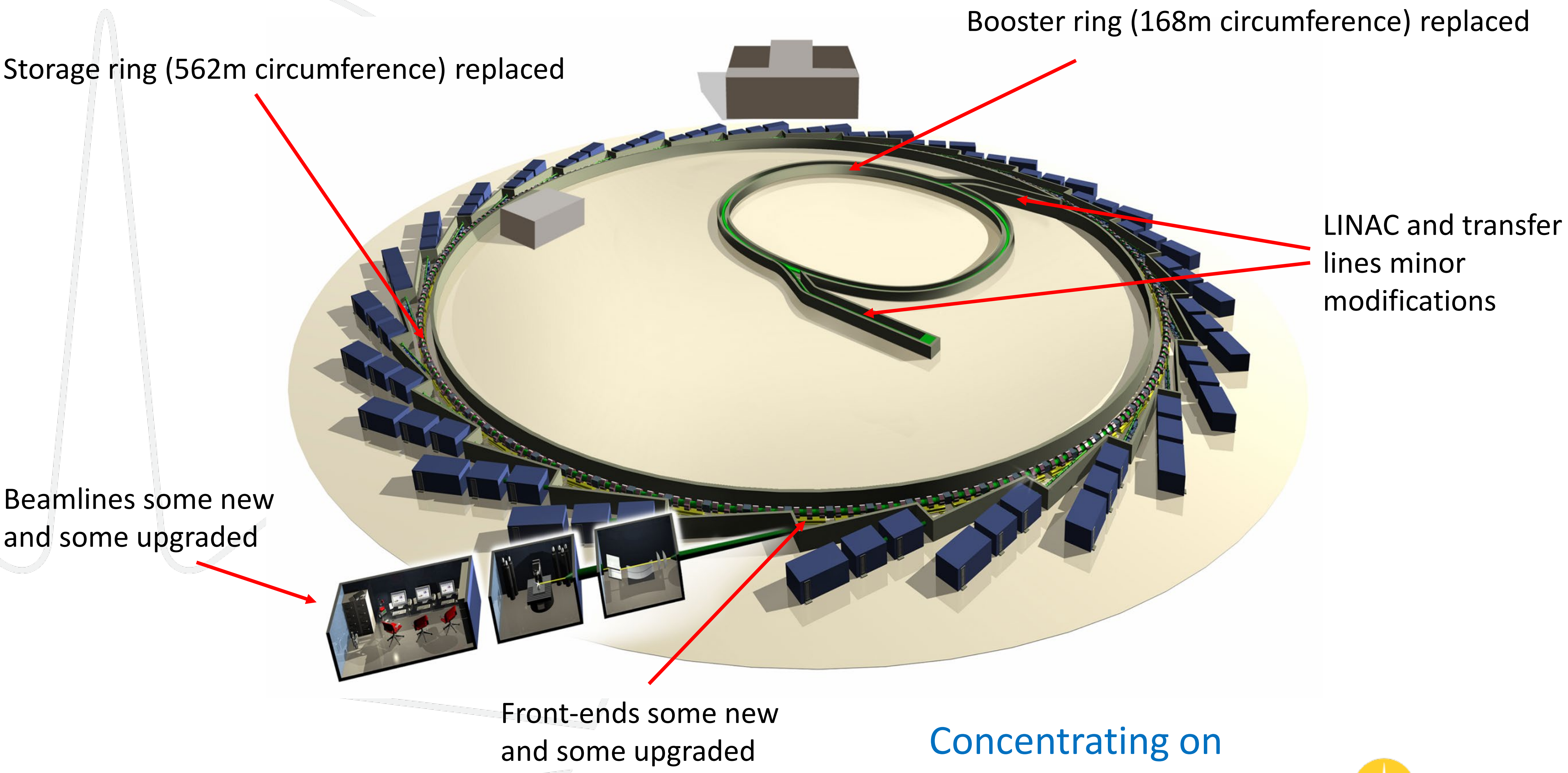
Diamond (existing machine delivering user beam since 2007)

- 3rd generation electron storage ring delivering light over a broad spectral range for science

Diamond-II Upgrade Science Drivers

- Emittance ↓ Brightness ↑
- Capacity (# of insertion devices and beamlines) ↑
- Energy ↑ 3.0 to 3.5 GeV to match the science needs better
- Current → remains at 300 mA

Vacuum scope for the Diamond-II upgrade

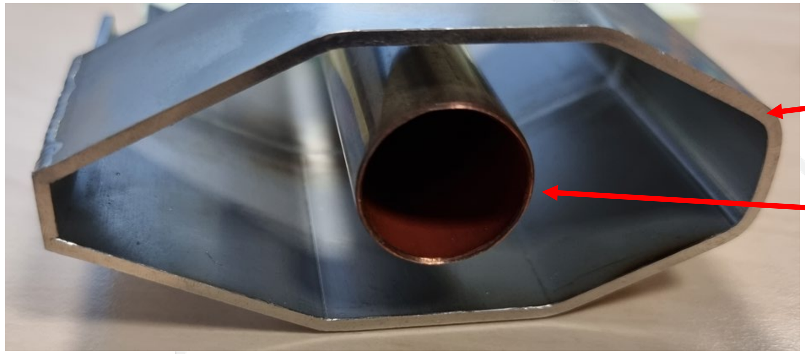


Concentrating on Storage Ring in this talk

Vacuum requirements

- Typically operating in 10^{-10} mbar range (Ultra-High Vacuum, UHV)
  - Reduce beam transport losses (electron and x-ray), scattering and instabilities
  - Reduce unwanted Gas Bremsstrahlung radiation
  - *Thermal insulation in cryogenic systems*
  - *Beamline sample environments*
- Storage Ring target pressure: $\leq 10^{-9}$ mbar at 300 mA after 100 A.h of beam conditioning
- Storage Ring vacuum system
  - Designed, built and tested to UHV standards
  - Long and thin geometry: Coatings which pump - Non-Evaporable Getter (NEG = TiVZr thin film) coating in many places
  - All materials outgas: Thermal and Photo-Stimulated Desorption (PSD) Bakeout typically 200°C, Constant pumping, Beam conditioning needed
  - Cleanliness and contamination control (+ particulates) even more critical for Diamond-II due to NEG coating and smaller diameter beam pipe
  - Inaccessible most of the time: High reliability without frequent interventions, remote monitoring
  - High heat loads in places
  - High radiation in places
  - Low beam impedance: Geometric and resistive wall – avoid gaps and steps and sudden cross section changes near the electron beam
  - Electrical conductivity (low/high) important in places, e.g. AC magnets
  - Non-magnetic (low magnetic permeability)
  - High mechanical precision (even more so for Diamond-II than Diamond): Manufacturing control, metrology and inspection

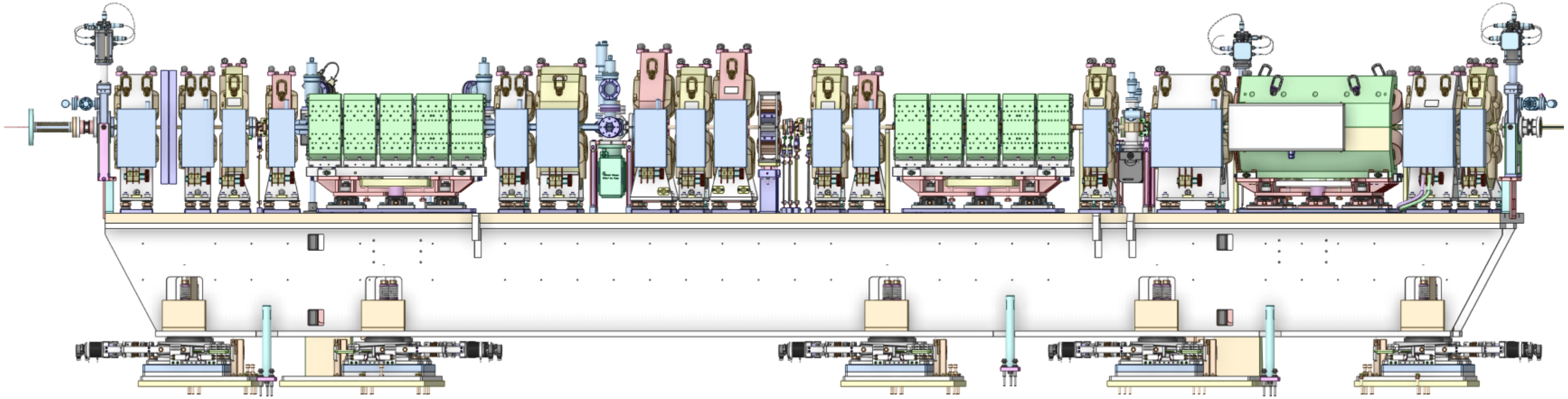
Pumping challenge



Diamond vessel cross section (typically 80mm H x 40mm V)

Diamond-II vessel cross section (typically 20 mm inside diameter)

Strongly conductance limited

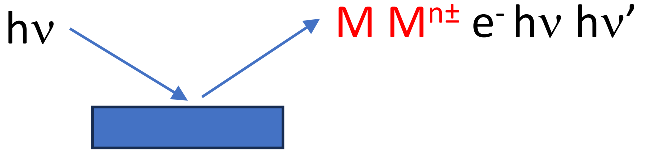


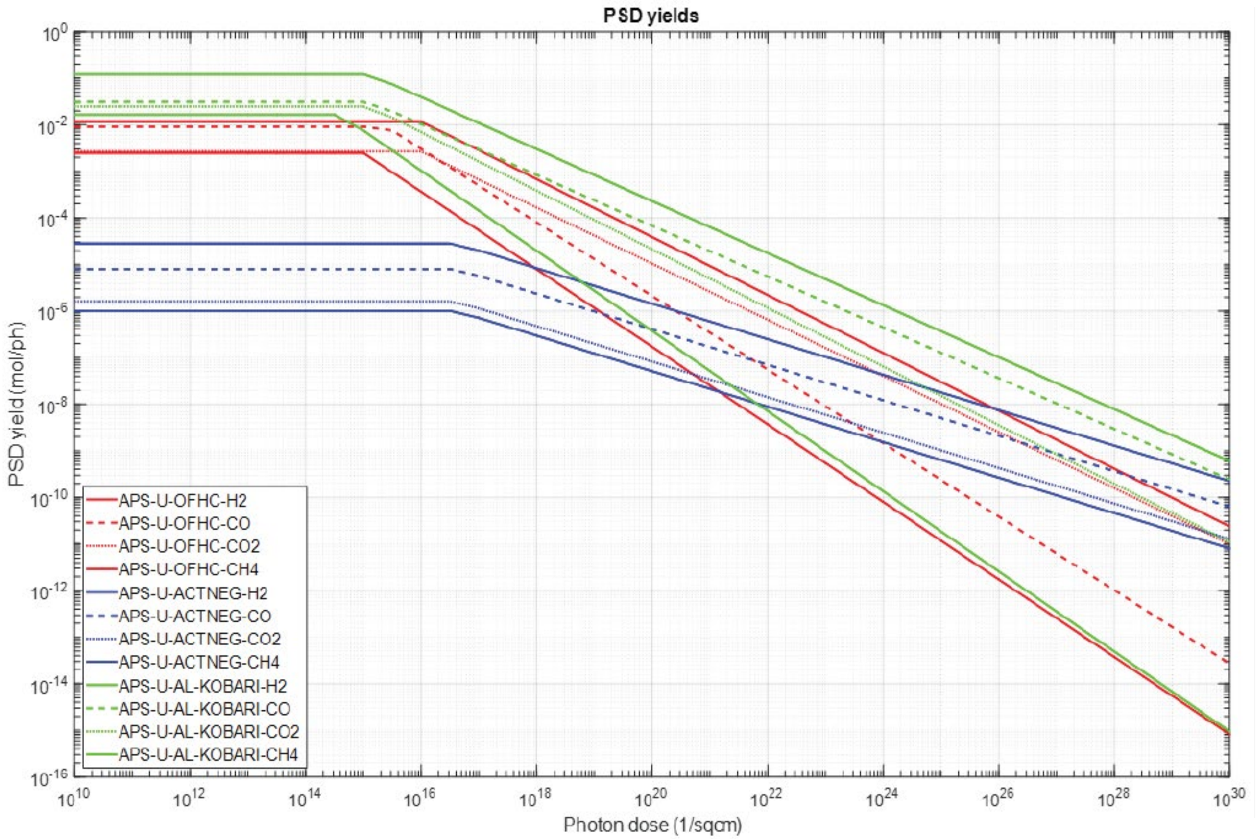
8m section of Diamond-II storage ring (LM girder) showing dense magnetic lattice and little opportunity for fitting discrete pumps

Photon-stimulated desorption (PSD) can increase the pressure by many orders of magnitude

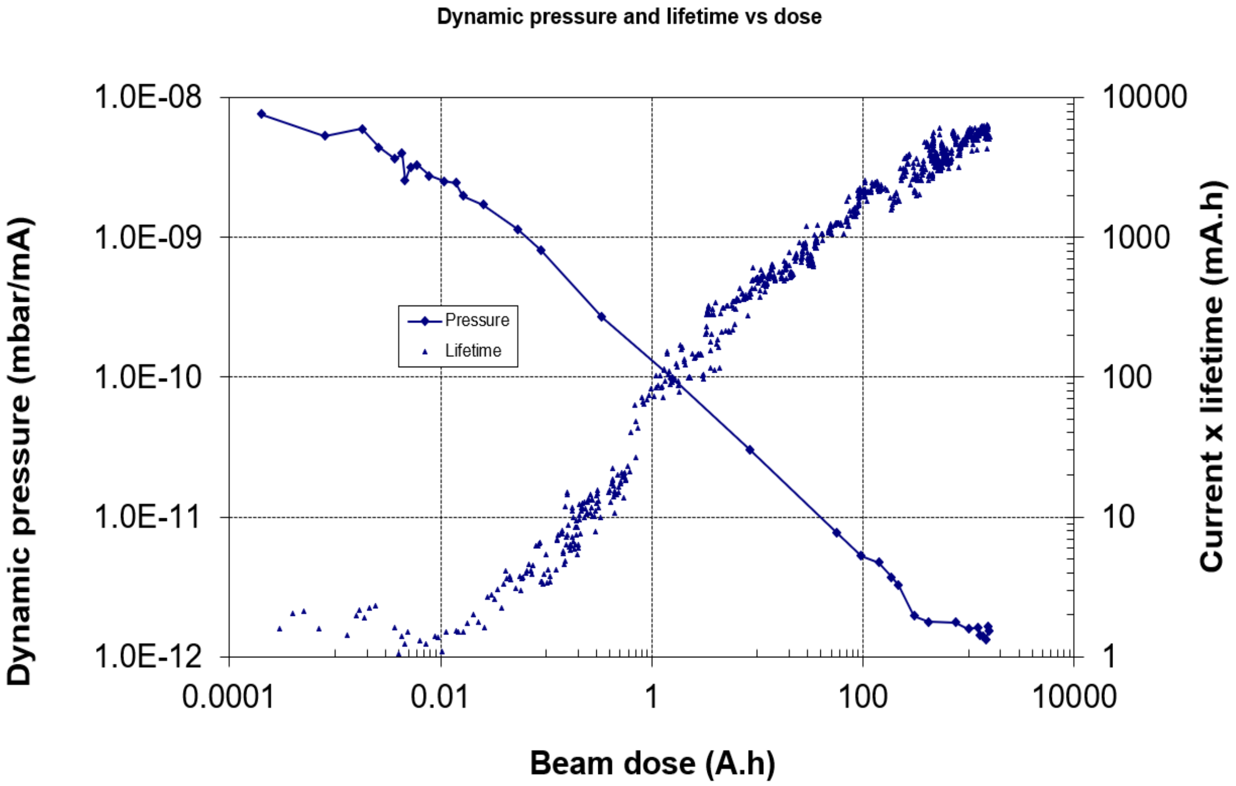
Small vessel cross section and wide spacing of discrete pumps + PSD $\Rightarrow$ Distributed pumping [Non-Evaporable Getter (NEG) coating]

Photon-stimulated desorption (PSD)





PSD yield data for different materials, gases and photon doses obtained from fits to several different published datasets. Data at high doses is extrapolated. Courtesy of Jason Carter Advanced Photon Source.



Practical effect of PSD on pressure and beam lifetime during Diamond storage ring commissioning and initial operations

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Non-evaporable (NEG) coating

What it is

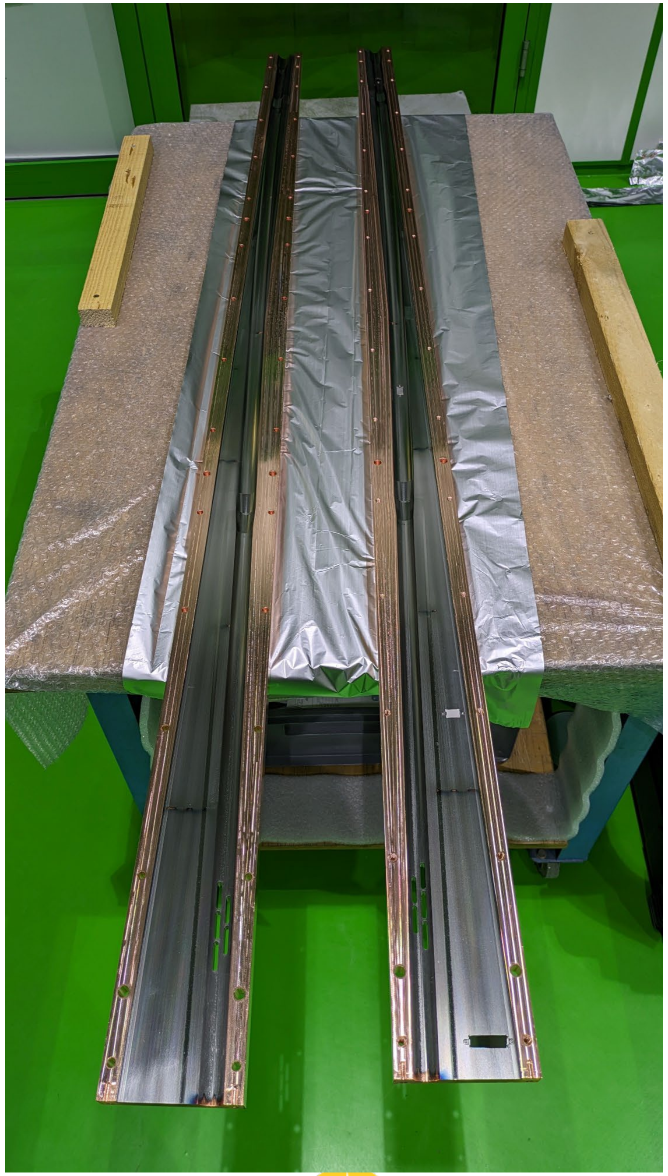
- Thin (≈1μm) reactive metal layer (usually Ti/V/Zr alloy) sputter coated on the inside of the vacuum vessel
- Can be applied to copper, stainless-steel, aluminium etc.
- Developed at CERN and widely adopted in newer accelerators
- Already in use at Diamond in some insertion device vessels

Reasons to use it

- Pumps chemically-active gases (H_2, CO, CO_2, H_2O, N_2 etc) locally, no conductance limitation
- Barrier layer reducing thermal outgassing from the bulk material
- Low thermal outgassing from the NEG material itself
- Low PSD
- No power or cables or electronics needed for operation

Issues

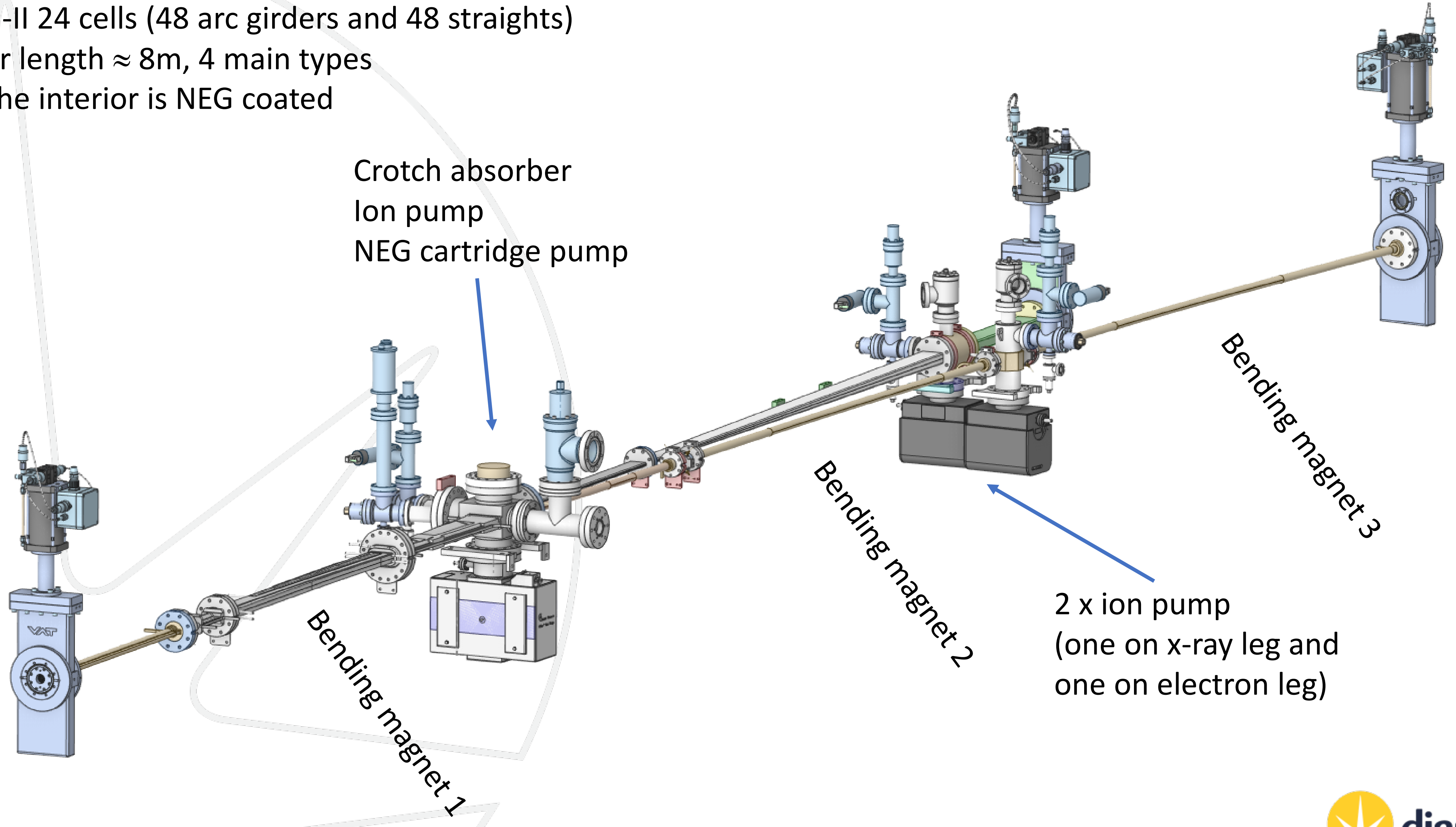
- Requires thermal activation after each venting (≈180°C) to achieve pumping properties. Limited number of activation cycles
- Does not pump inert gases (He, Ne, Ar …) or alkanes (CH_4 etc) although some alkane pumping possible in the presence of synchrotron radiation
- Very limited capacity for most gases (few monolayers) except H_2 before re-activation – however synchrotron radiation seems to help
- Challenging to coat complex internal geometries requiring individual trials and process optimisation. Strict contamination control needed to avoid poor performance / peel off
- Offered by only a few vessel suppliers and labs
- Can easily become poisoned (particularly halogens)
- If too thick can affect the beam impedance. Aim at 0.5μm near the electron beam)



Diamond-II LMVC2 copper vessel NEG coating trials

Pumping solution: LM girder

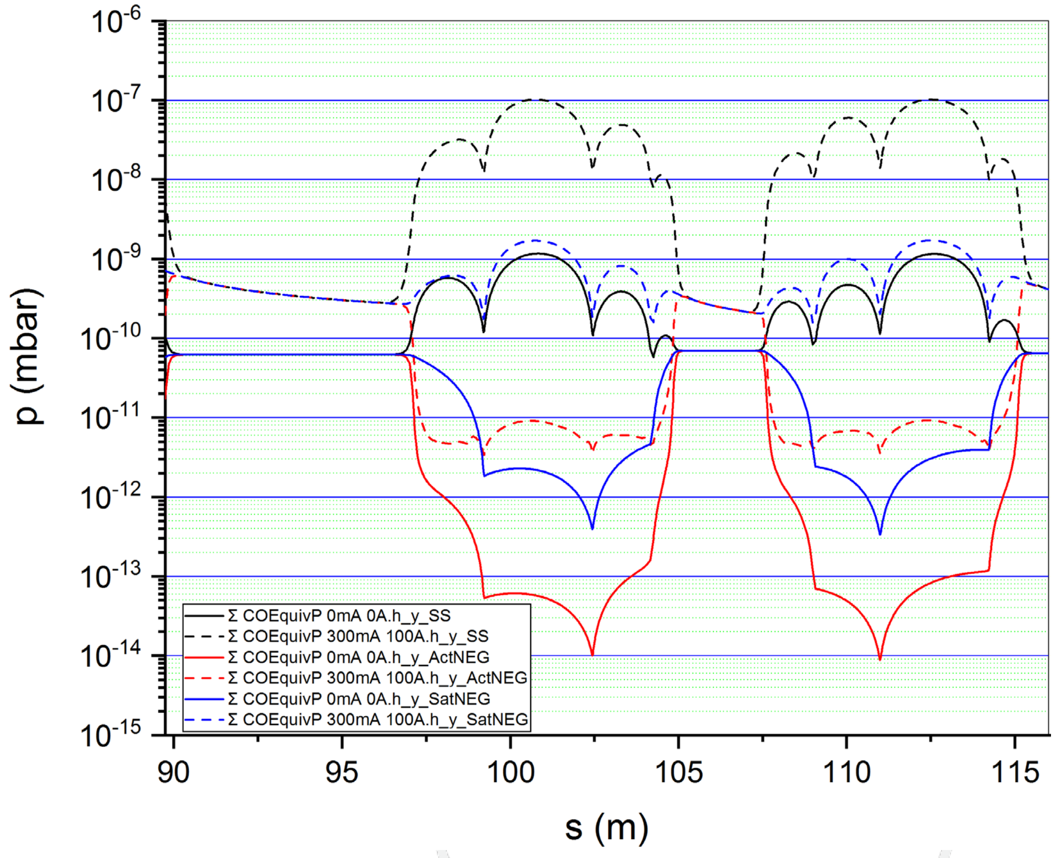
Diamond-II 24 cells (48 arc girders and 48 straights)
Arc girder length ≈ 8m, 4 main types
>90% of he interior is NEG coated

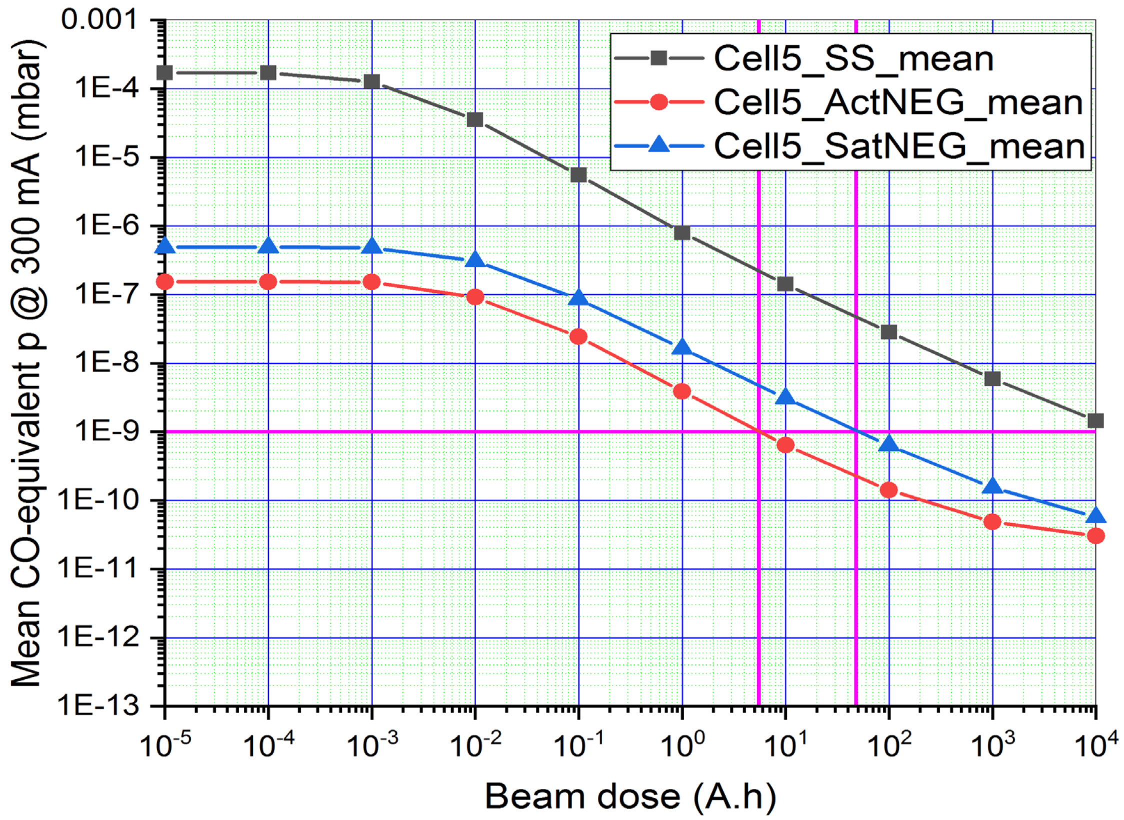


Vacuum simulations

Simple geometries can be simulated analytically using 1-dimensional diffusion equation

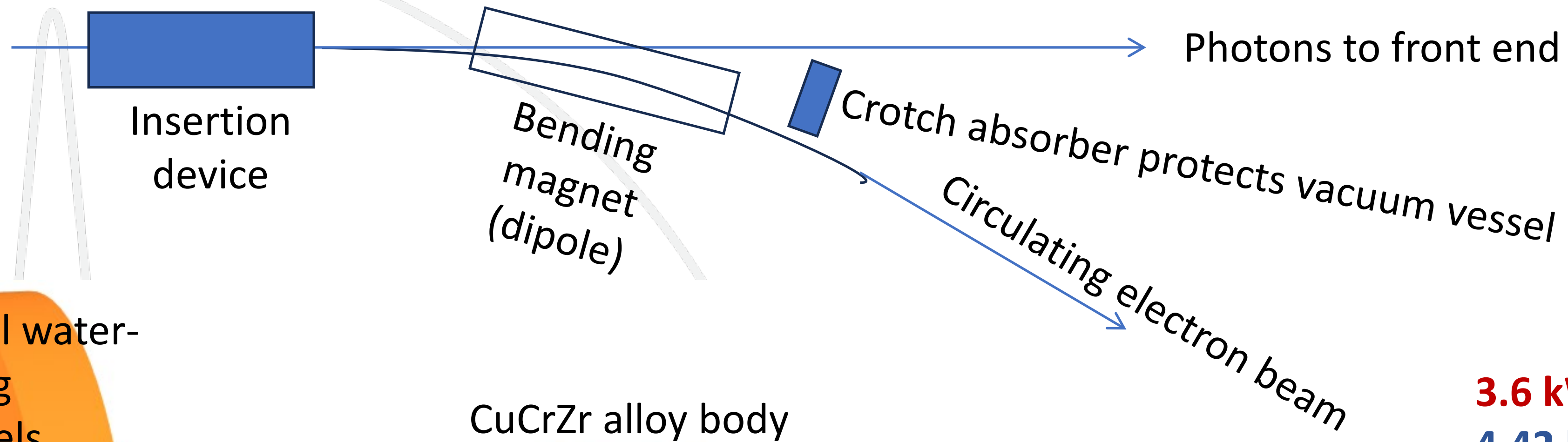
More complex geometries require Monte-Carlo simulations. M-C tools Synrad+ and Molflow+ have been made freely available by CERN





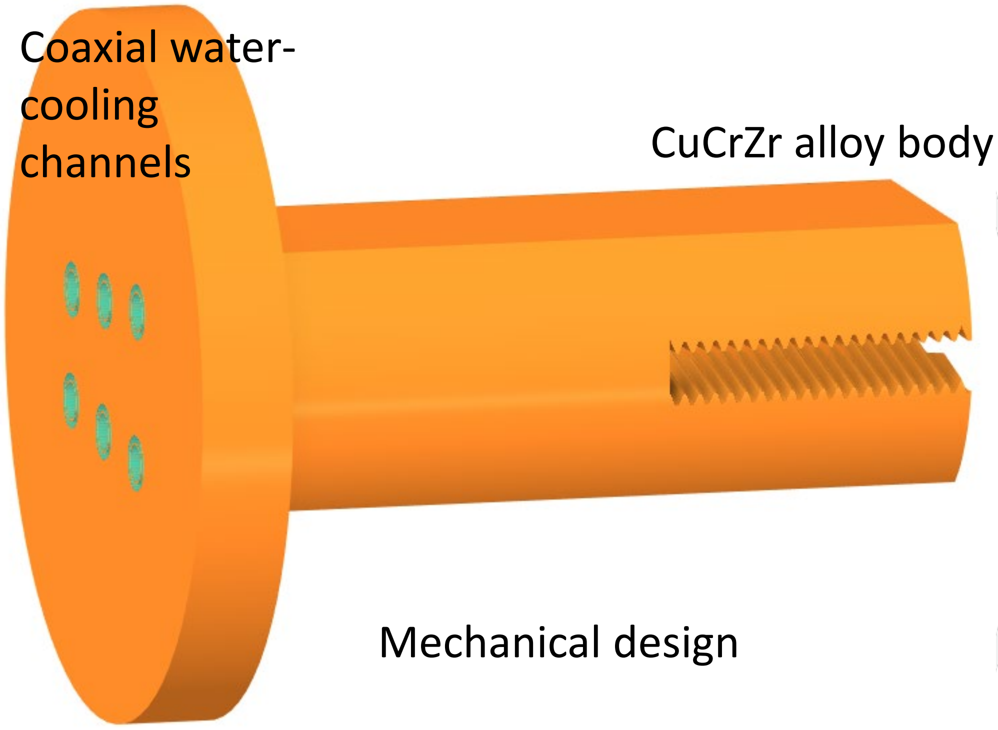
Comparison of vacuum performance for Uncoated, Fully activated NEG coated and Saturated NEG coated surfaces for identical photon fluxes and vessel geometries. (Not quite the final geometry)

Thermal management case study: LM crotch absorber

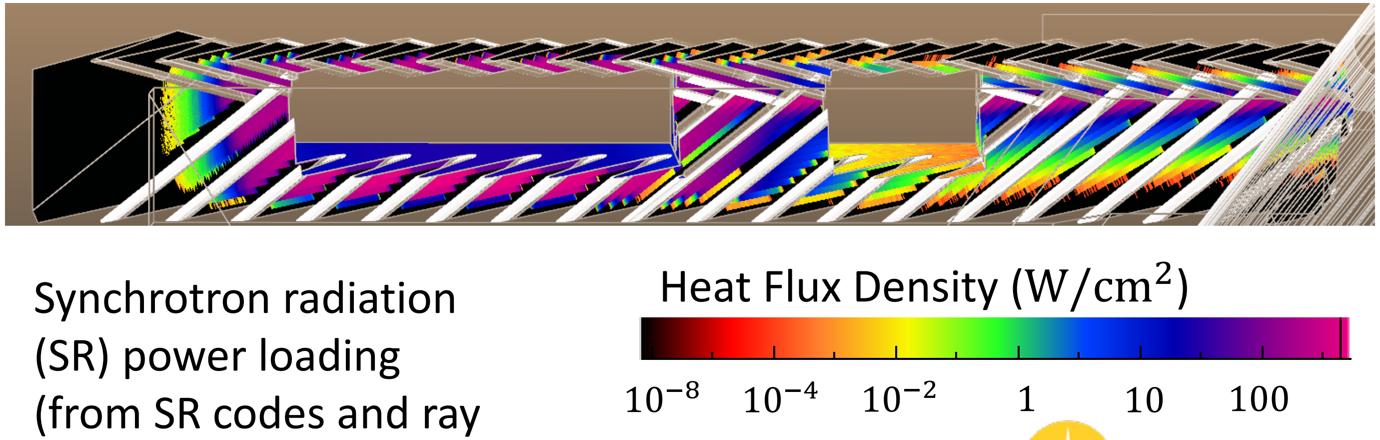


3.6 kW on crotch
4.42 kW through left aperture
0.2 kW through right aperture

8.2 kW total beam



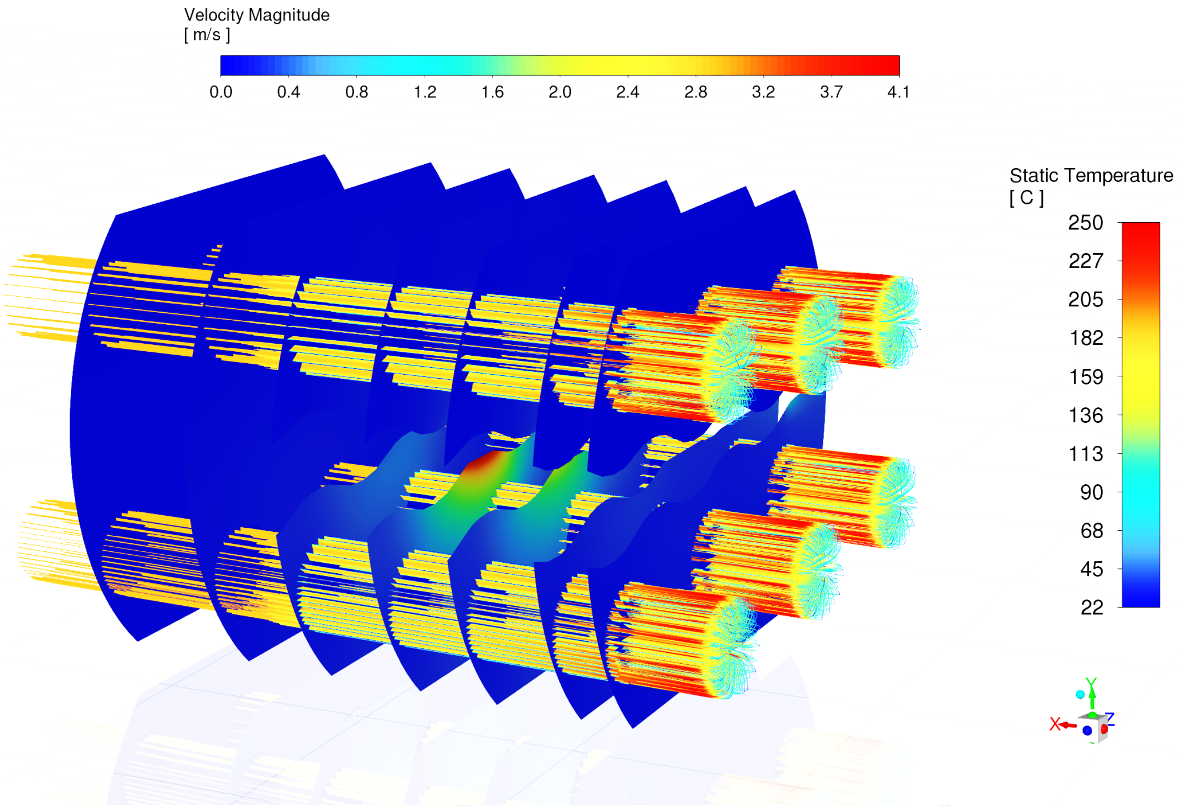
Mechanical design



Synchrotron radiation (SR) power loading (from SR codes and ray tracing)

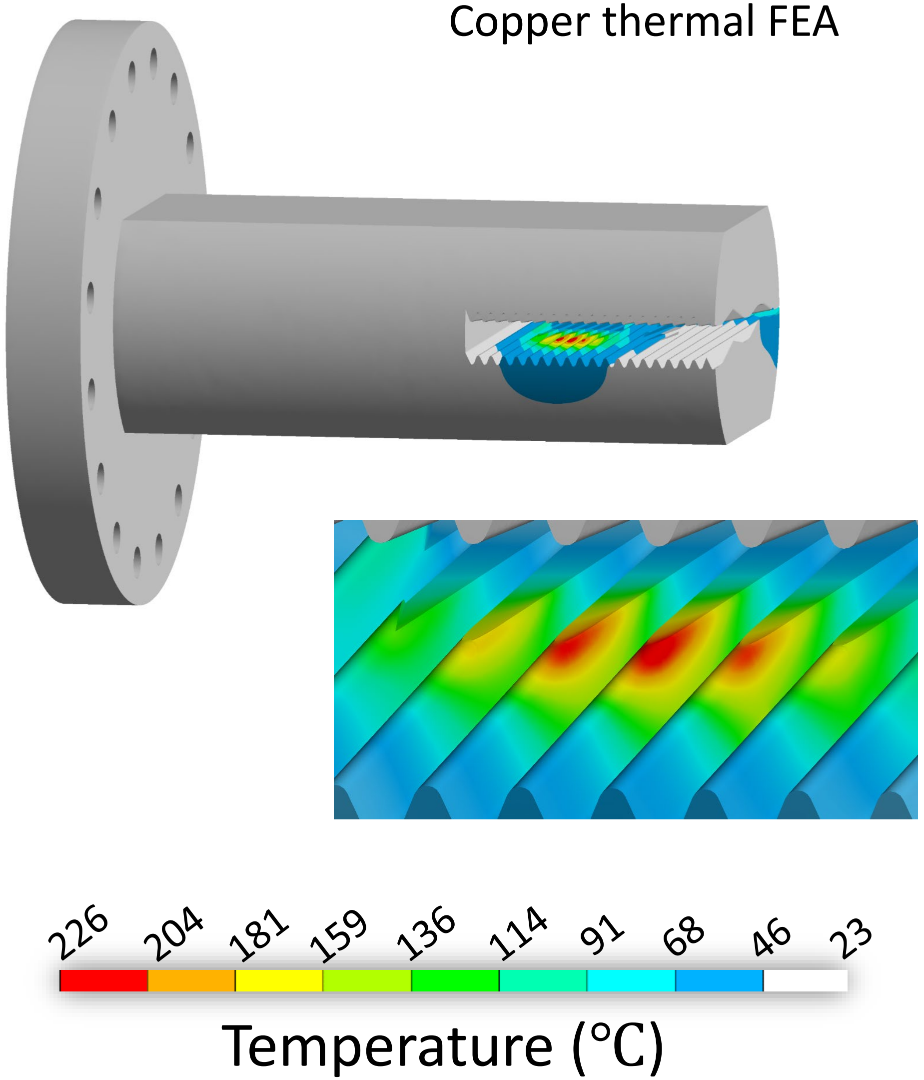
Thermal management case study: LM crotch absorber

Water flow CFD



Heat Transfer Coefficient: 16.7 kW/m^2K

Copper thermal FEA



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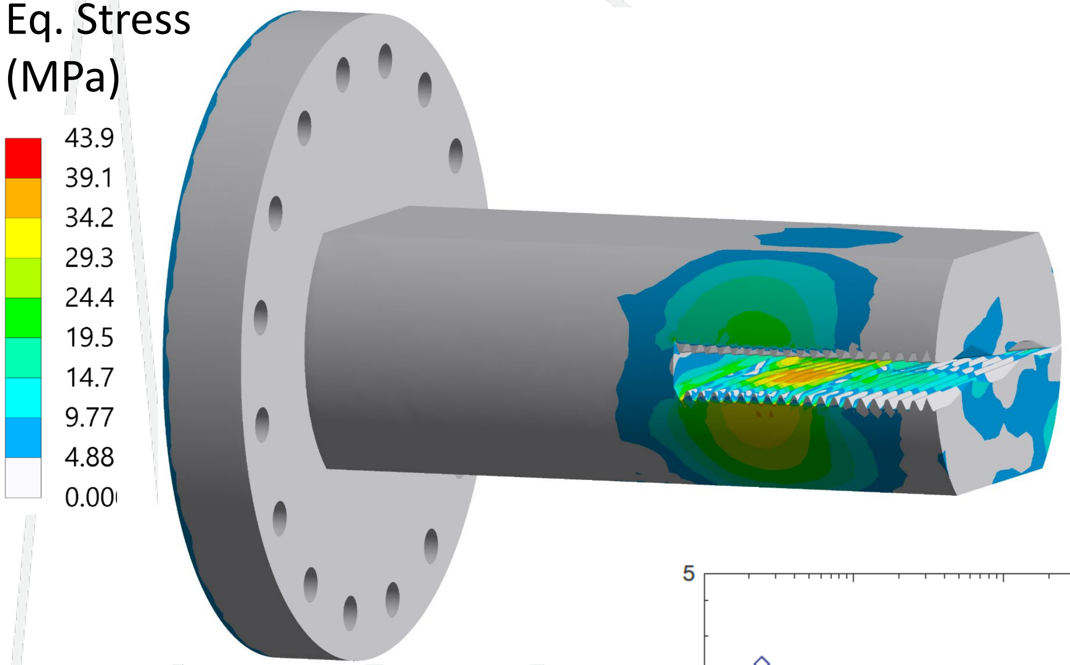
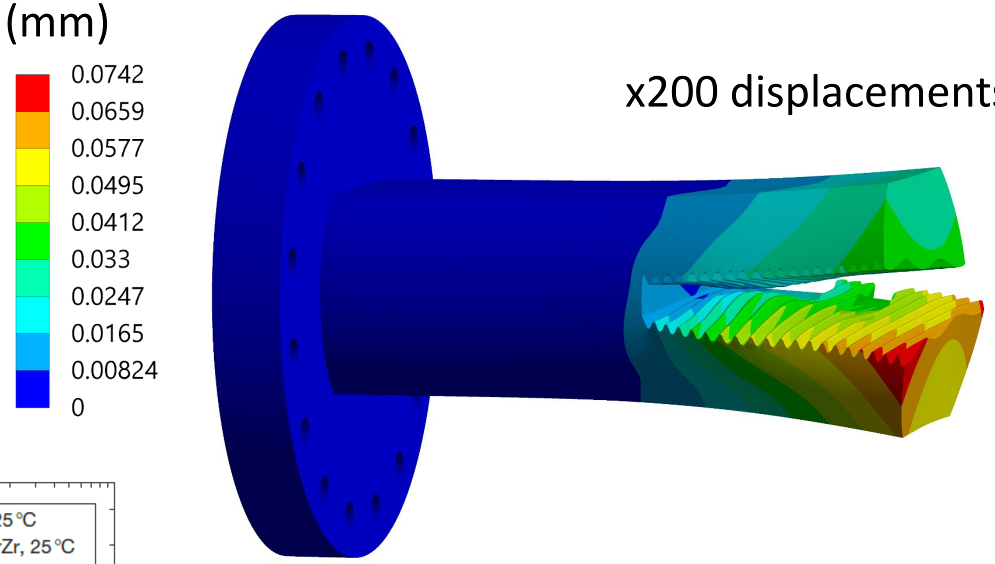
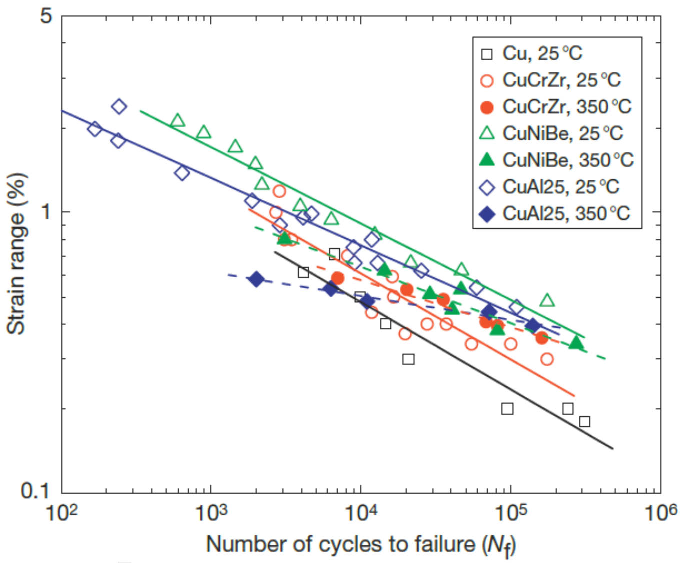
Thermal management case study: LM crotch absorber

Static Structural and Fatigue Analysis including Operating Pressure + Heat Load







No fatigue expected below 10^6 heating and cooling cycles
(10 cycles/day $\Rightarrow$ 90k cycles over 25 years)

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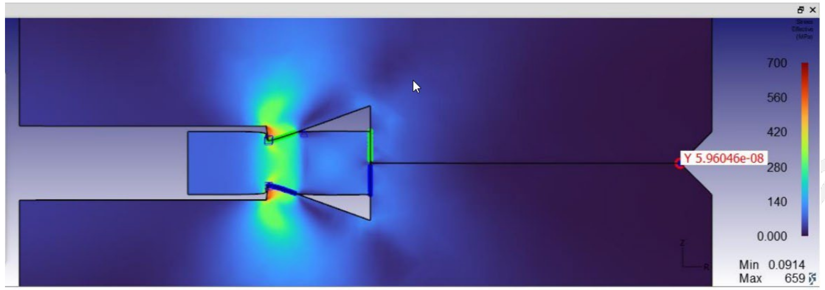
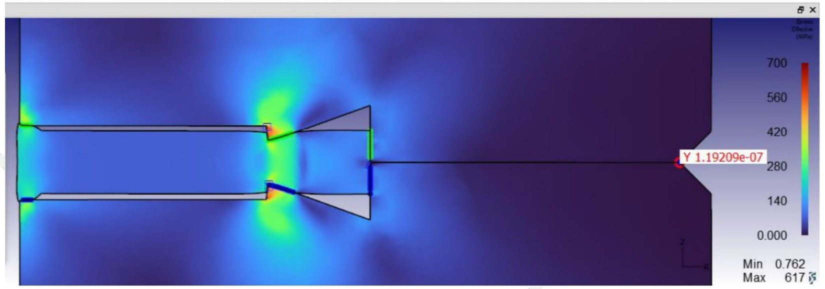
Beam impedance

To avoid beam heating and adverse effects on the beam physics, all components along the electron beam path must be designed for low geometric impedance and modelled, e.g.

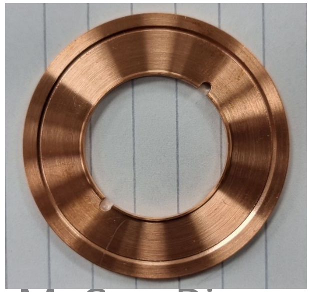
- No gaps or sudden changes in cross-section near the electron beam
- All gate valves and bellows must incorporate internal RF shield
- RF gasket on flange joints
- Grilles on pump ports

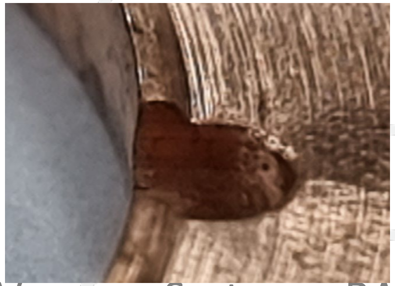


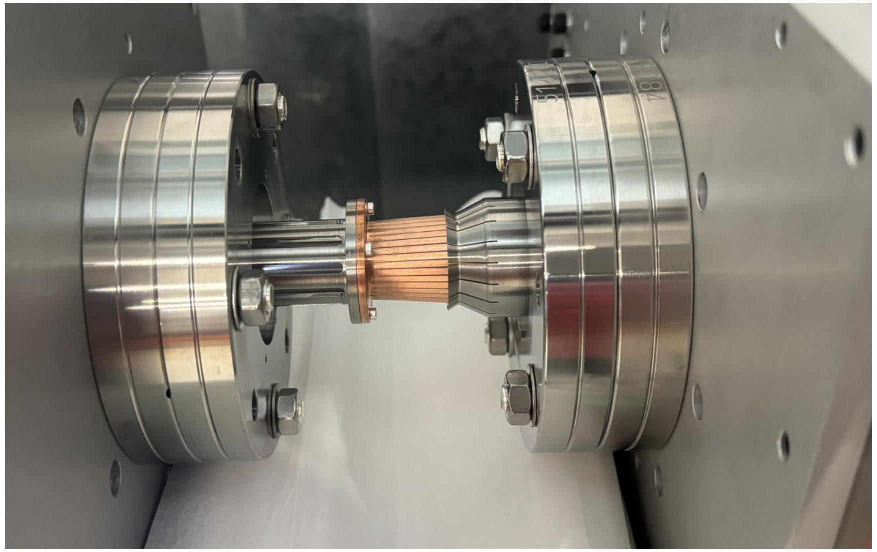
Standard CF flange joint has a ≈2mm internal gap which is unacceptable



Special RF gasket used to fill the gap and improve the impedance





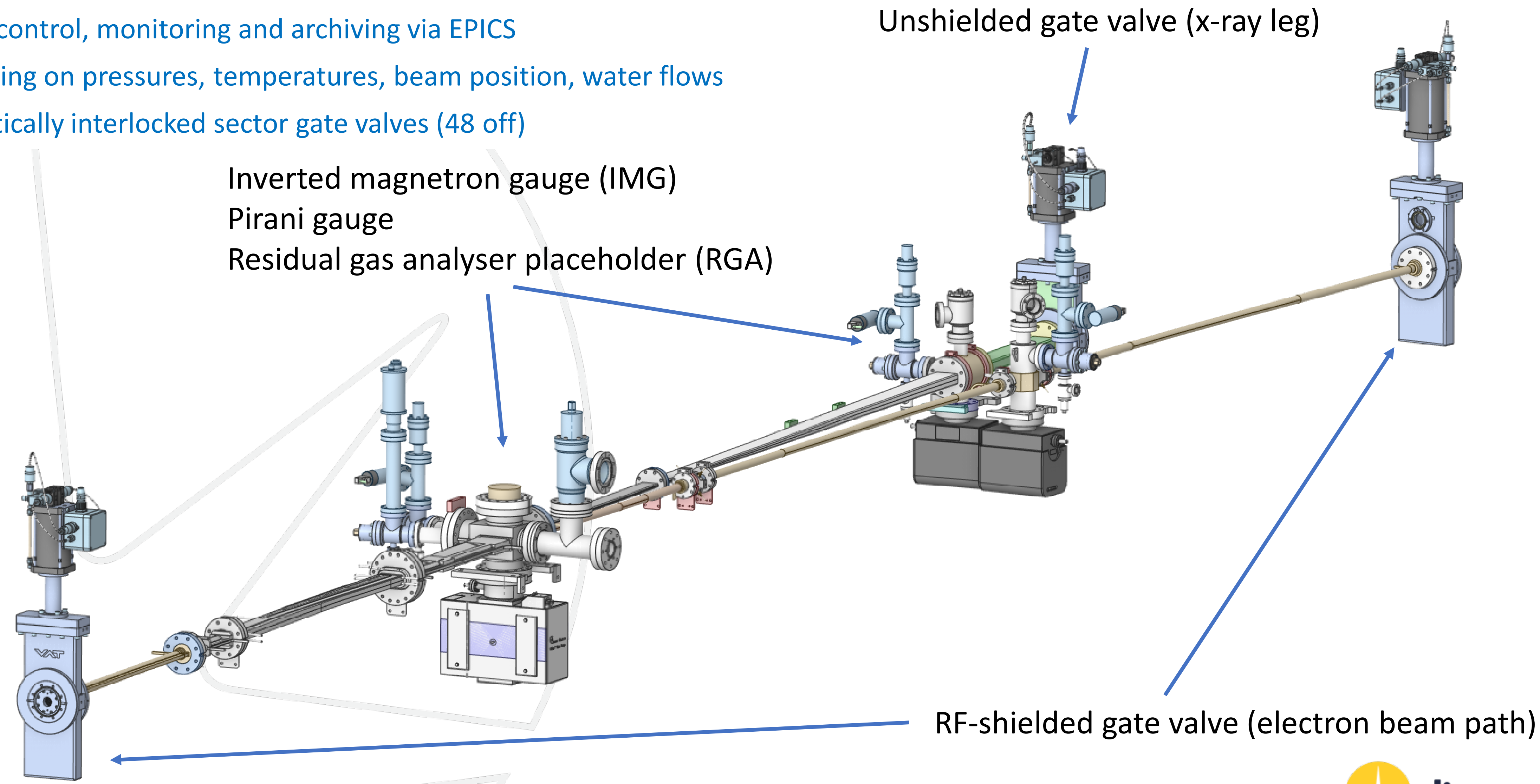


RF-shielding inside bellows

Gate valve with internal RF shield

Controls and Instrumentation

- No local electronics (high radiation environment)
- Remote control, monitoring and archiving via EPICS
- Interlocking on pressures, temperatures, beam position, water flows
- Pneumatically interlocked sector gate valves (48 off)



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Procurement

A lot of vacuum hardware contracts and delivery schedules to manage

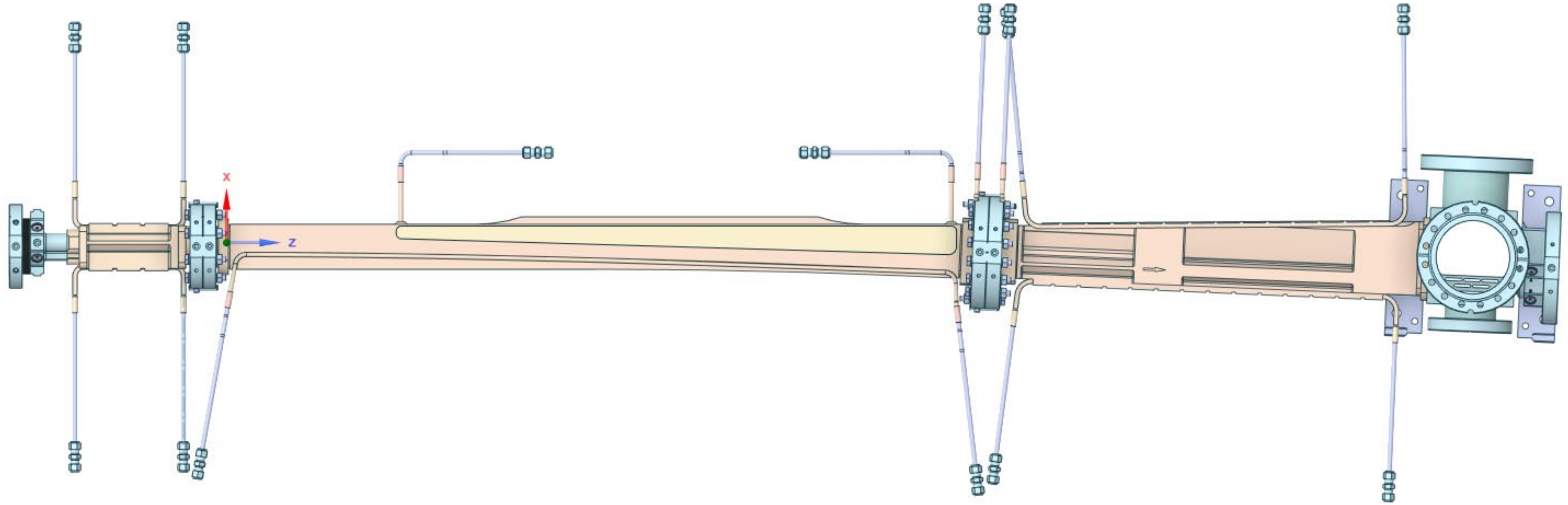
- Vacuum vessels (>1000 in total)
- Vacuum construction components and fittings
- Vacuum assemblies
- Vacuum equipment and instrumentation
- Vacuum processing and handling equipment

Supplier contract management and QA are critical

Need good logistics, e.g. stock / deliveries management, warehousing and kitting space, control of movements, records

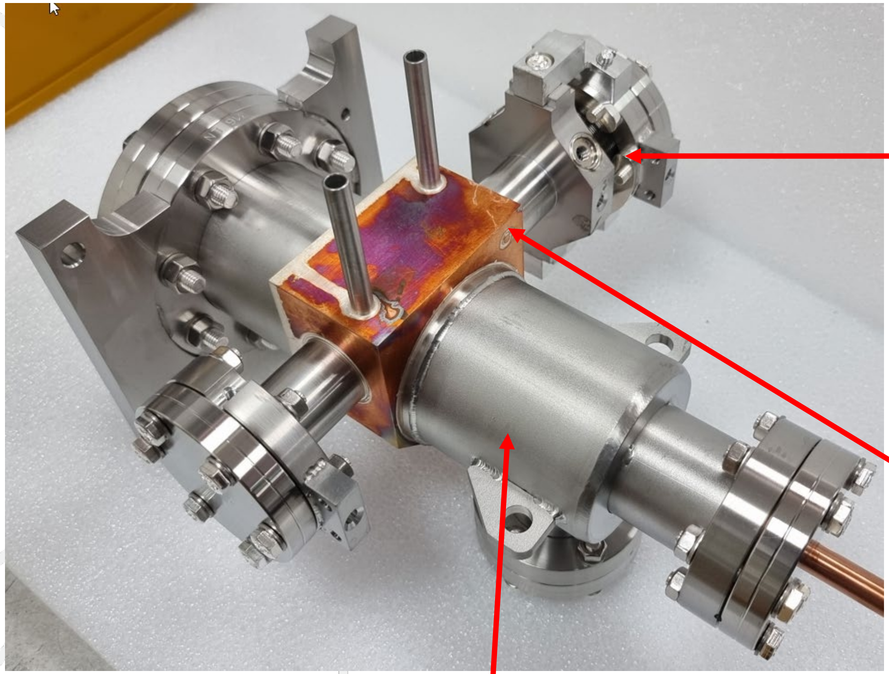
Vessel manufacturing example: VC2

Probably the single most challenging vacuum vessel type
≈50 off – 4 main variants



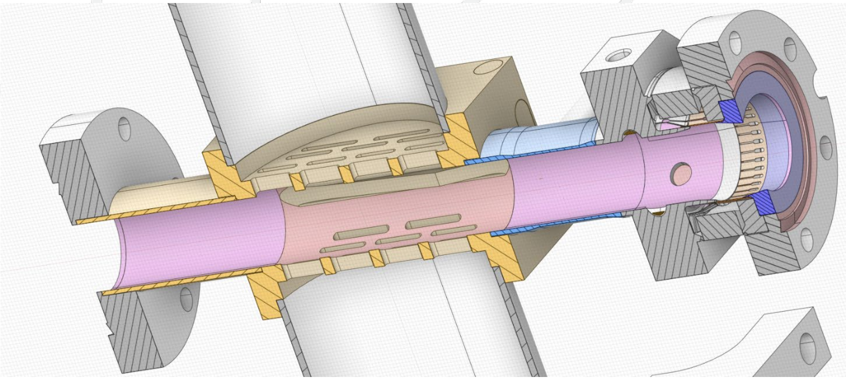
≈2m long
Machined copper alloy and stainless steel (316LN)
NEG coated internally
Integrated water-cooling channels
Highly precise geometry
- Complex internal geometry – Conventional machining, EDM, manufactured in sections
- Complex external geometry as it needs to fit into magnet poles
- Complex joining sequences

Vessel manufacturing example: VC6



Edge-welded bellows with Beam Position Monitor (BPM) button feedthroughs and internal RF shield

Water cooled OFS copper block with internal pumping slots



316LN stainless-steel body and flanges
NEG coated internally

200 mm long
50 off- several variants

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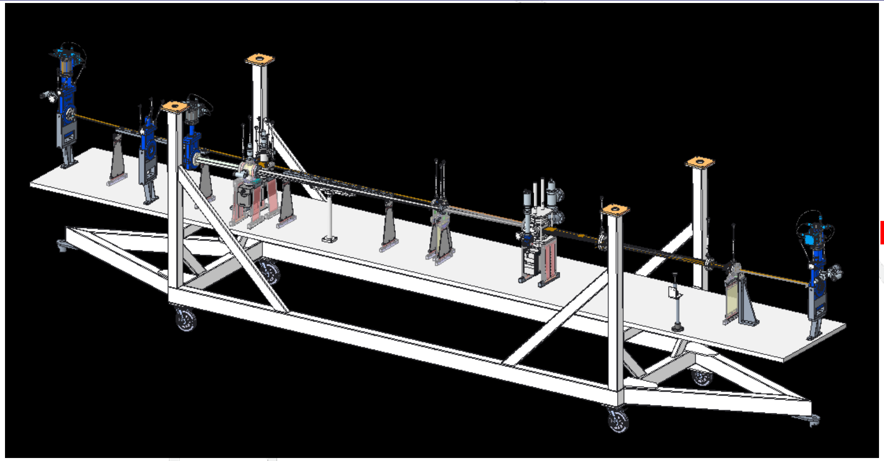
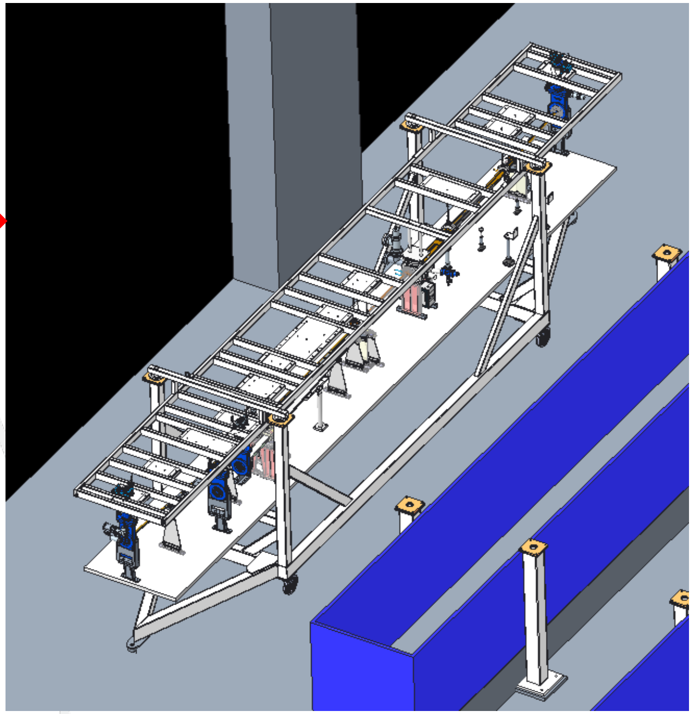
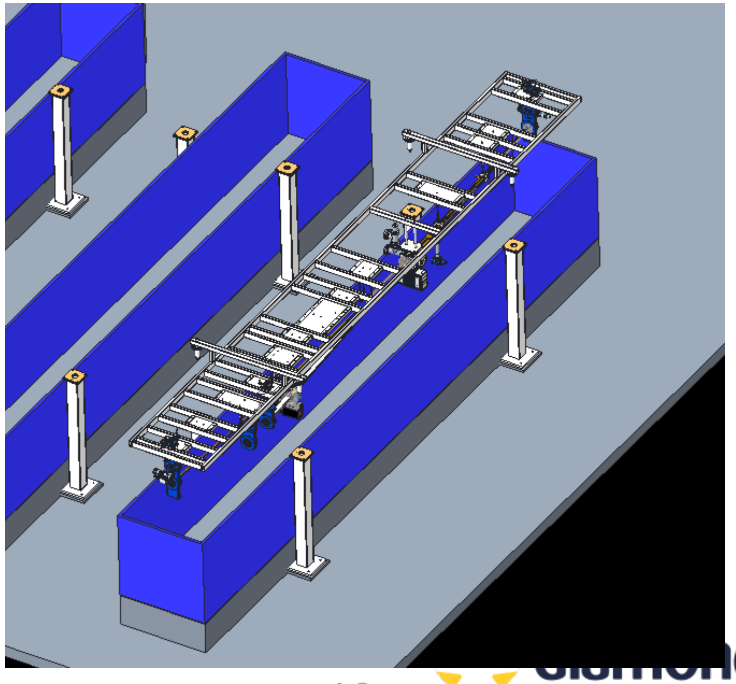
Girder vacuum assembly in new building (DEB)



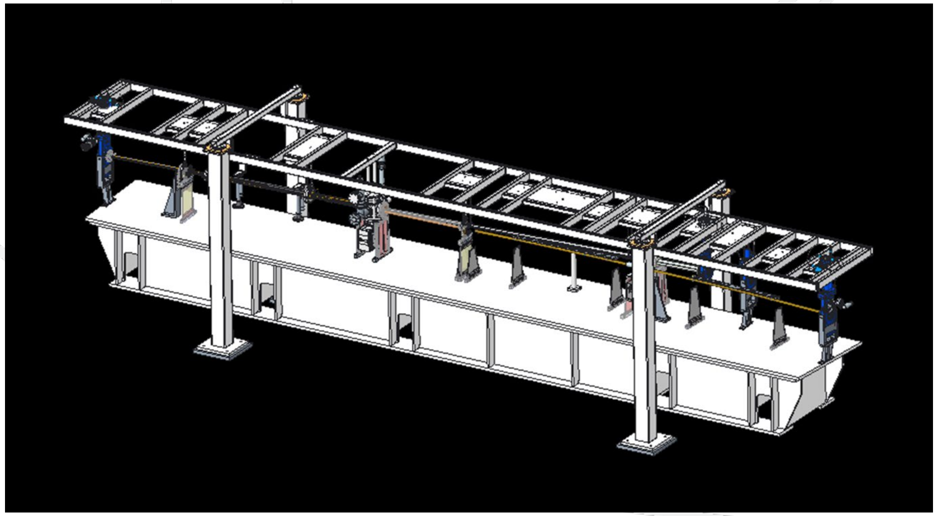
Assemble and leak test 8 m girder vacuum "string" on trolley in ISO 8 clean room



Wheel into the bakeout area using tug
Transfer to the lifting frame

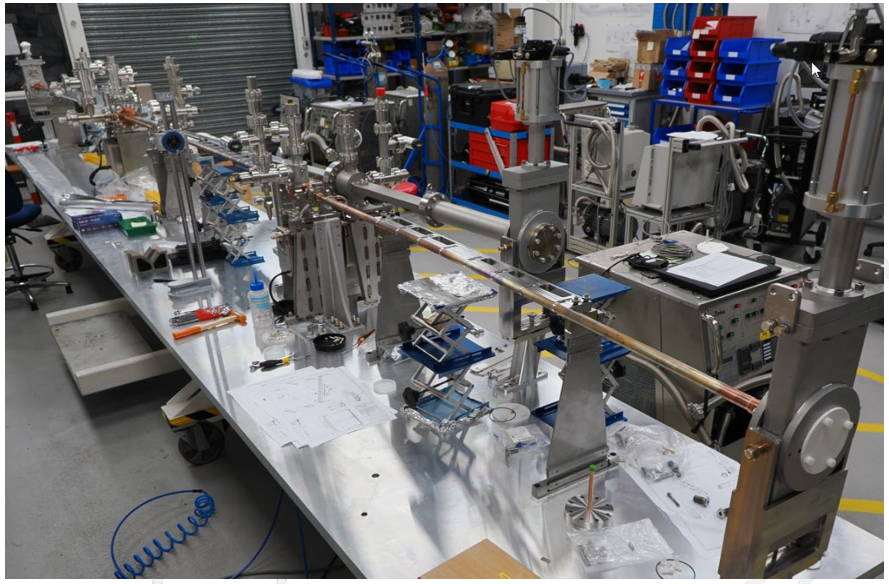


Lift "string" and lower into the oven
Bake out and activate the NEG coating (180-200°C) allowing for thermal expansion

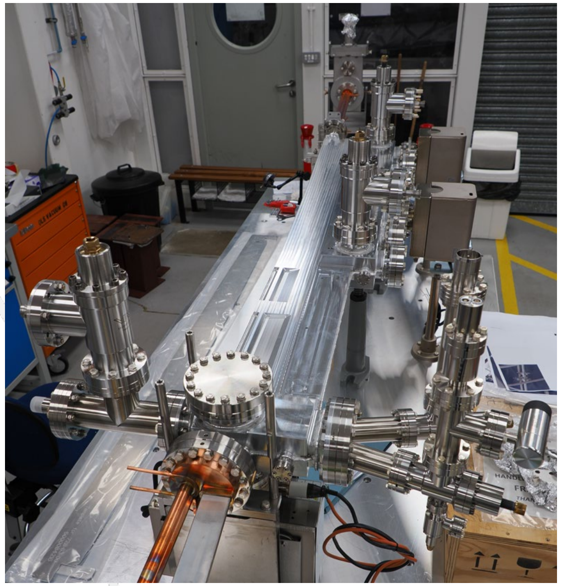


Integrate and align on the girder with magnets, cabling etc
Install under vacuum

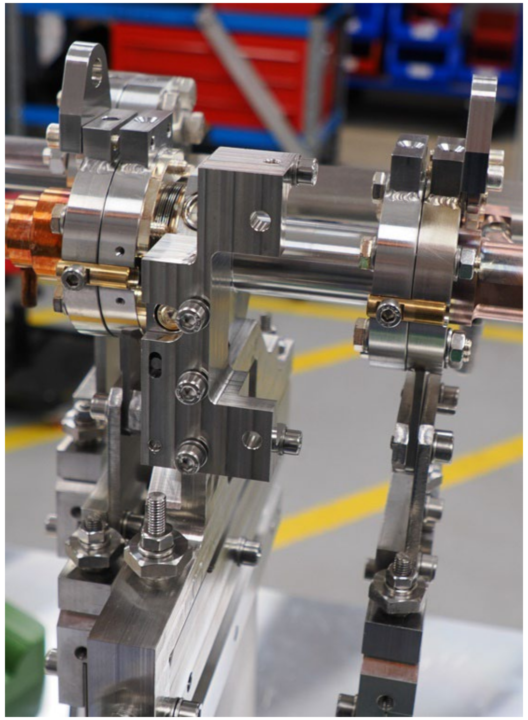
Prototype trials



Complete LM vacuum string assembly (Al LM VC2)



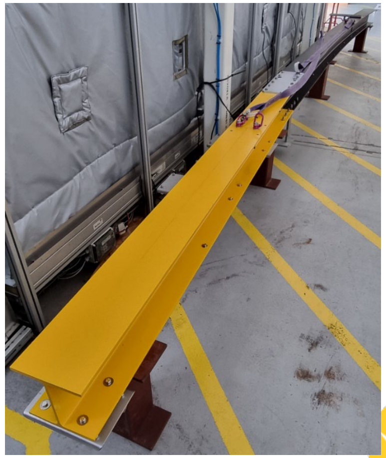
Dipole 1 crotch region (LM VC2 and VC3)



LMVC4 BPM

LMVC7 strongback support

Existing Diamond oven



Trial lifting beam

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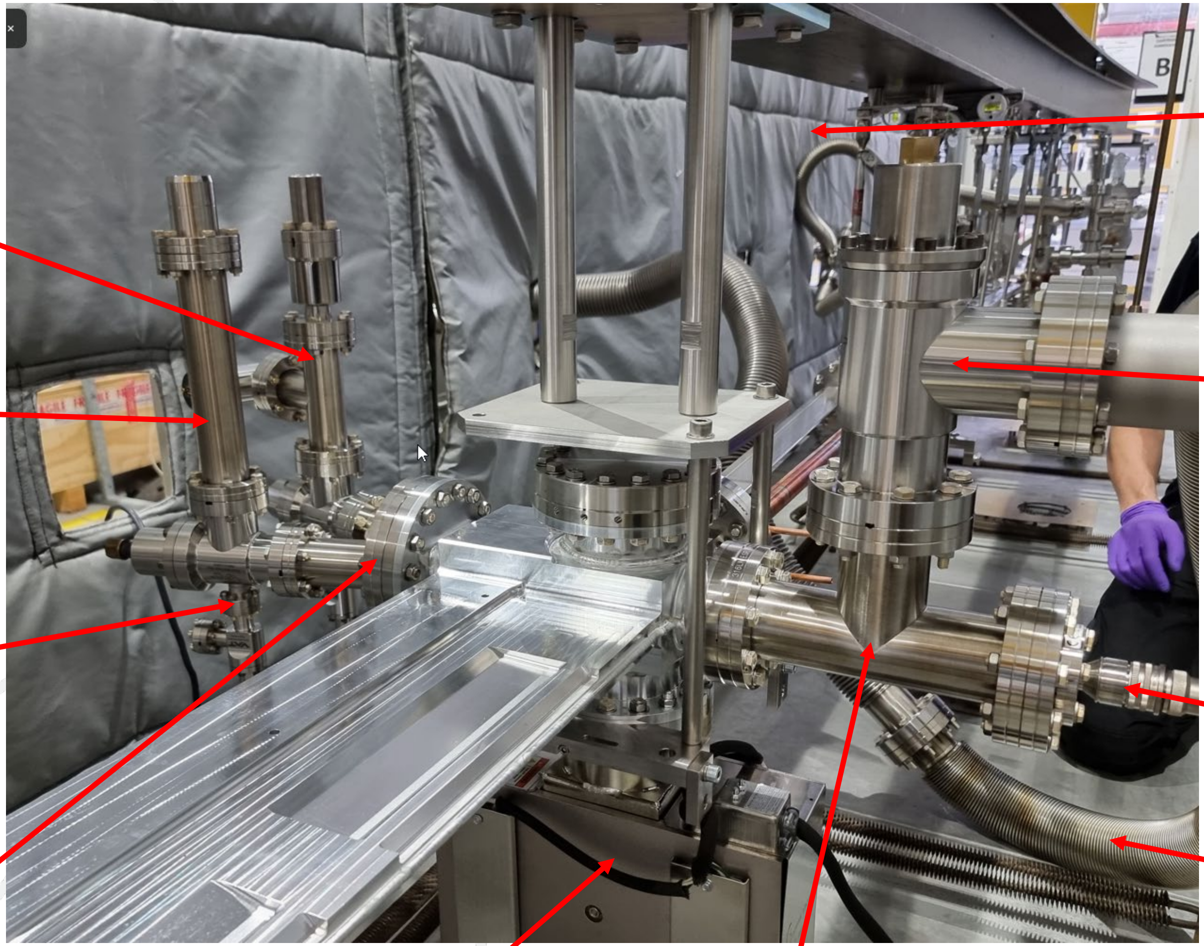
Prototype trials

Total pressure gauges

Residual gas analyser (RGA)

DN40 isolation valve

Cluster flange with tees, elbows, isolation valves and spool pieces



Ion pump

DN63CF 'Tee'

Suspended inside bakeout oven

DN63 isolation valve

NEG cartridge pump

Flexible pumping lines

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Finally

Thank you for listening

Questions?