Mechanical & Material Aspects - Tutorial Group 3

PRESENTED BY MARCO MORRONE

Project outline

Design the mechanical system of a room temperature [operating] vacuum system for a circular collider with high intensity proton beams.

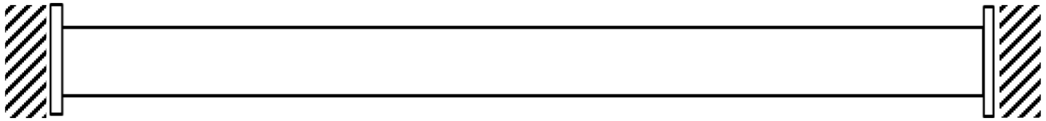
1. Inner diameter [circular aperture] = 100mm
2. Length of vacuum chamber = 10m
3. Operating temperature = 20°C
4. Maximum temperature = 230°C
5. External pressure = atmospheric pressure [1 atm]
6. Internal pressure = <10^{-9} mbar
7. No magnetic field

Temperature induced Forces

Thermal deformation $\varepsilon = \alpha \Delta T$

Thermal expansion $\Delta l = \varepsilon l$

Thermal stress $\sigma = E \varepsilon$



The bellows are needed to allow the thermal expansion and for alignment purposes.

Material	Thermal deformation	dl [mm]	Thermal stress [MPa]	sigma y [MPa]	Cost [€/kg]
Copper OF	0.00357	35.7	410.55	35	~25-40
Aluminium	0.00462	46.2	355.74	393	~15
Stainless steel 316 L	0.00336	33.6	655.2	240	~11-32
Titanium Grade 5	0.001869	18.69	214.94	880	~50

Structural stability

For an infinite elastic tube subjected to external pressure:

$$P_{cr} = \frac{E}{4 \cdot (1-\nu^2)} \left(\frac{t}{R}\right)^3$$

Safety factor of 3 is usually applied.

Design rule for stainless steel: $t \geq \frac{D}{100}$

For the *316 L* ss chamber the minimum thickness to avoid the tube to collapse is around 1 mm.

The thickness decided for the chamber is **1.5 mm** (only available thickness for d=100 standard tube).

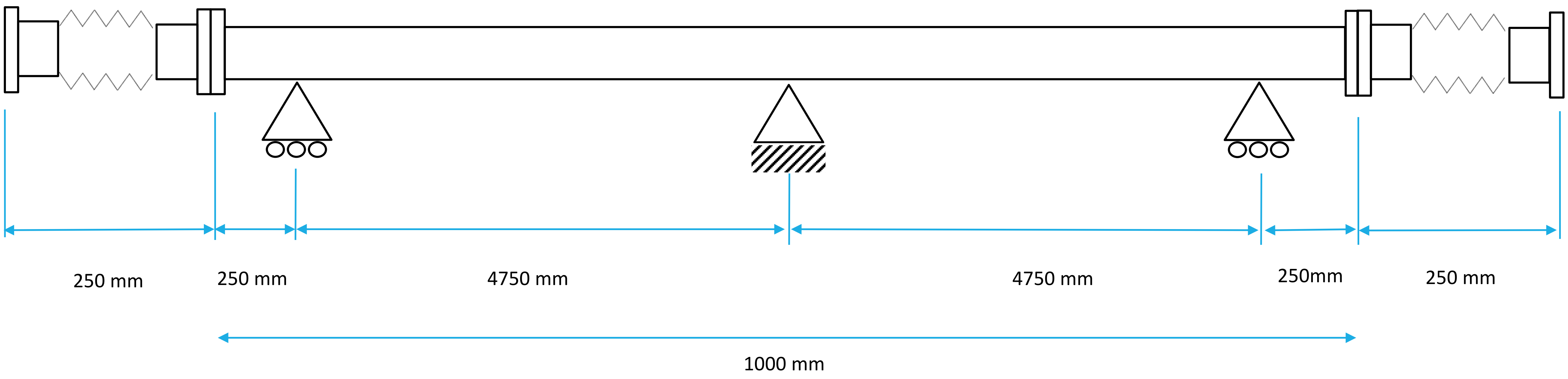
Hoop stress: $\sigma_1 = \frac{pD}{2t}$ =3.3 MPa

Longitudinal stress: $\sigma_2 = negligible\ because\ of\ the\ bellow$

Chamber supports

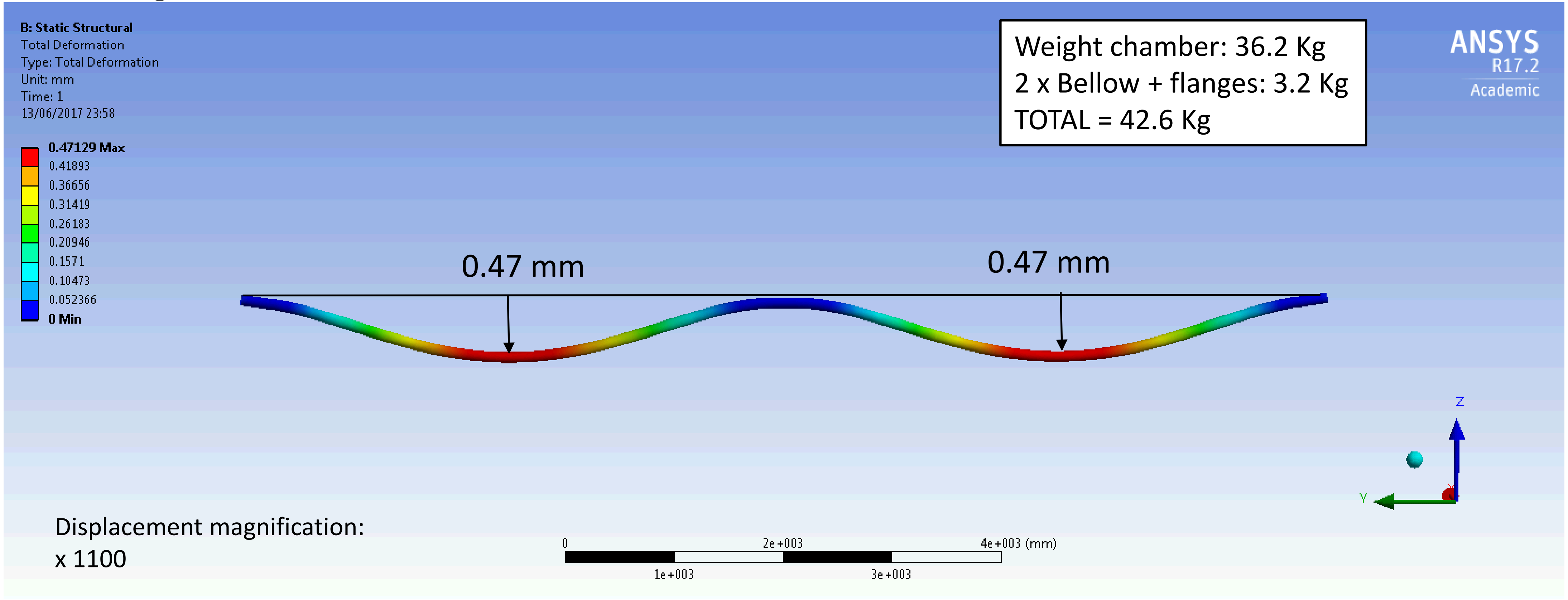
-2x sliding supports

-1 x fixed support



Finite elements modelling

Self-weight deformation



Bellows specification

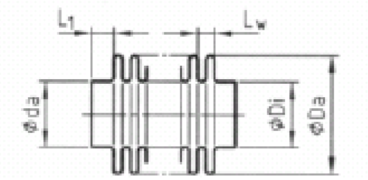
- Total chamber expansion during bake-out = 33.6 mm
- 2x individual bellows chambers to be installed at each end of the chamber
- Using standard industry item

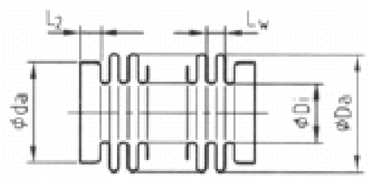
Spec:

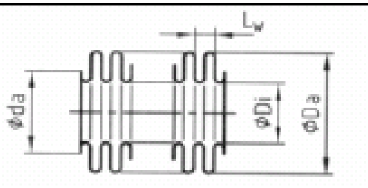
- UHV specification
- 316L bellow hydroformed
- DN100CF 316LN ESR 3D forged flanges (1x rotatable)
- $Ø_{inner}$ 100mm
- Convolutions needed = 2*thermal displacement / convolution stroke (6.5 mm) = 11

Bellows specification

Matériau de base 1.4541

HB


AB


SAG


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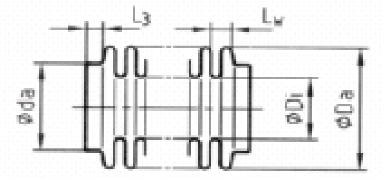
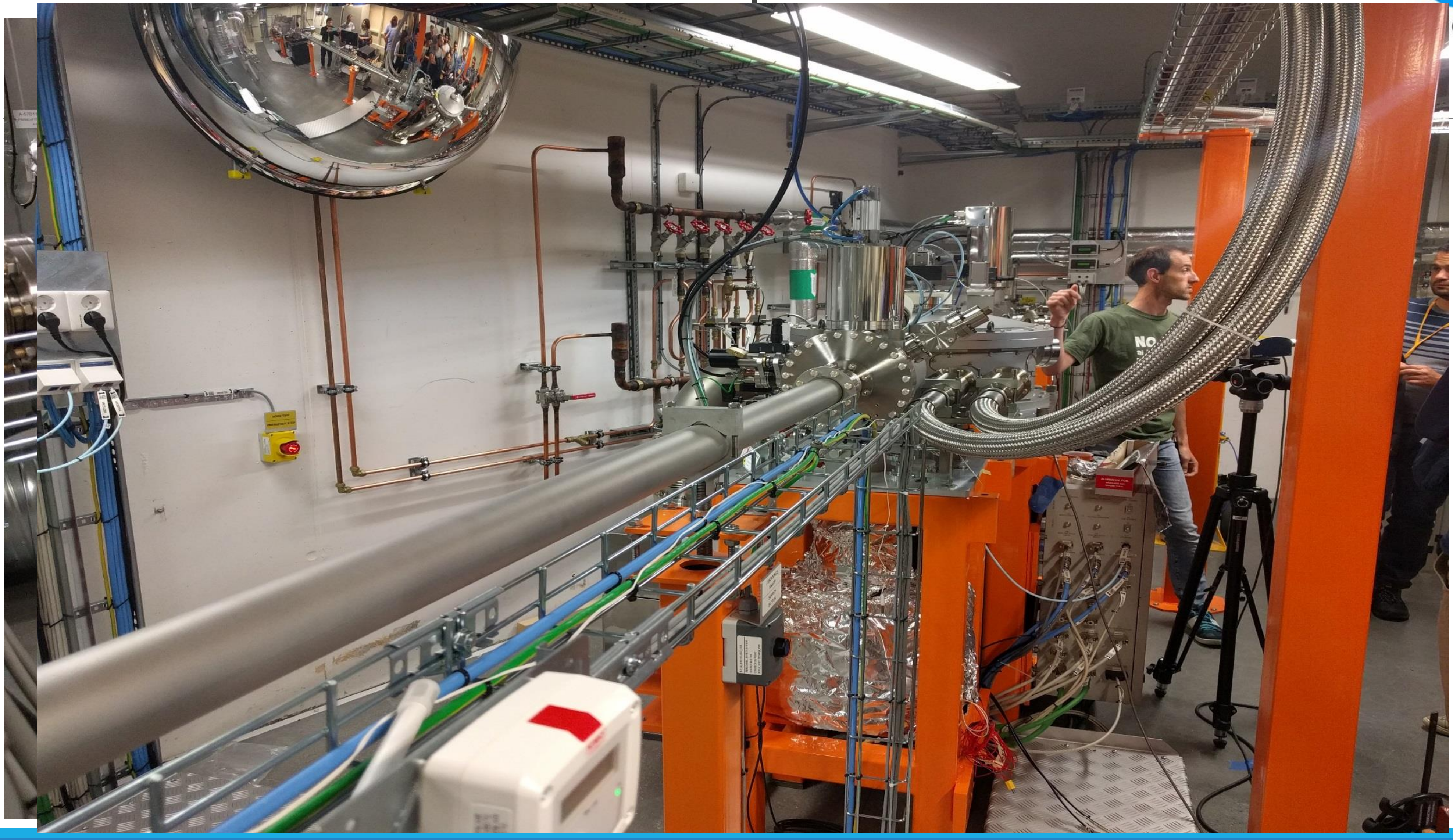


Diamètre nominal	Position	Soufflet-Ø: intérieur Ø	Soufflet-Ø: Tolérance	Soufflet-Ø: extérieur Ø	Soufflet-Ø: Tolérance	Nombre de parois	Épaisseur de paroi	Pas	Nombre d'ondulations maxi	Forme des collets: cylindrique HB Ø d_a	cylindrique HB L_1	extérieur AB Ø d_a	extérieur AB L_2	SAG Ø d_a	intérieur IB Ø d_a	intérieur IB L_3	Surpression théorique	Déplacement par onde lors de 10^4 cycles: axial	angulaire	latéral	Raideur par ondulation: axial	angulaire	latéral	Surface effective du soufflet	Masse par onde
		D_i	±	D_a	±	n	s	L_W	W								P_R	Δ_{ax}	°	Δ_{lat}	C_{ax}	C_a	C_{lat}	A_b	
		mm	mm	mm	mm	–	mm	mm	–	mm	mm	mm	mm	mm	mm	mm	bar	± mm	± °	± mm	N/mm	Nm/ °	N/mm	cm^2	g
100	1	99,7	0,5	117,0	0,6	1	0,14	3,4	43	100,5		112,3	6,0	114,2	104,0	6,0	2	1,21	1,25	0,012	91	2,332	135397	92,39	6,59
	2	100,0	0,5	117,0	0,6	1	0,15	6,5	40	100,8		112,3	6,0	114,2	104,0	6,0	3,5	1,37	1,45	0,027	112	2,885	47496	92,64	7,60
	3	99,8	0,5	121,0	0,6	1	0,25	6,7	33	100,8		116,5	6,0	114,2	104,0	6,0	8	1,02	1,05	0,020	270	7,210	111672	96,01	15,21
	4	99,7	0,5	120,0	0,6	1	0,50	9,3	32	101,2		116,0	6,0	114,2	104,0	6,0	35	0,52	0,50	0,014	2475	65,807	518244	95,02	30,63

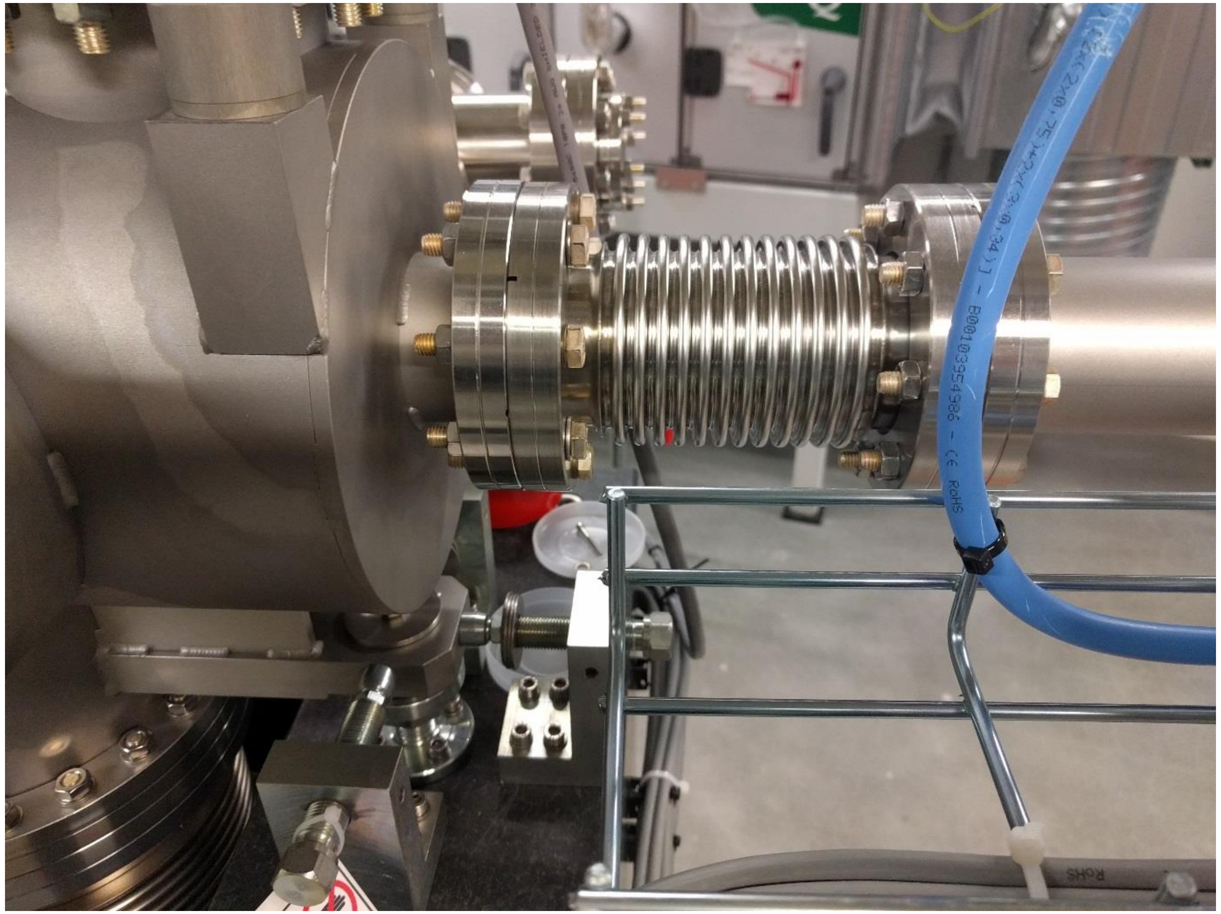
Chamber Manufacture

- Stainless steel tube [Ø100mm],
  - Typical length of tube 6m,
  - 100% weld penetration orbital 6 + 4 m (due to length)
- Internal welding DN100CF flanges
- Fixed support bracket to be mounted on the chamber
- Leak detection
- UHV cleaning to CERN specification EDMS:1626970
- Copper electroplating to reduce the impedance seen by the beam
- NEG coating for distributed pumping.

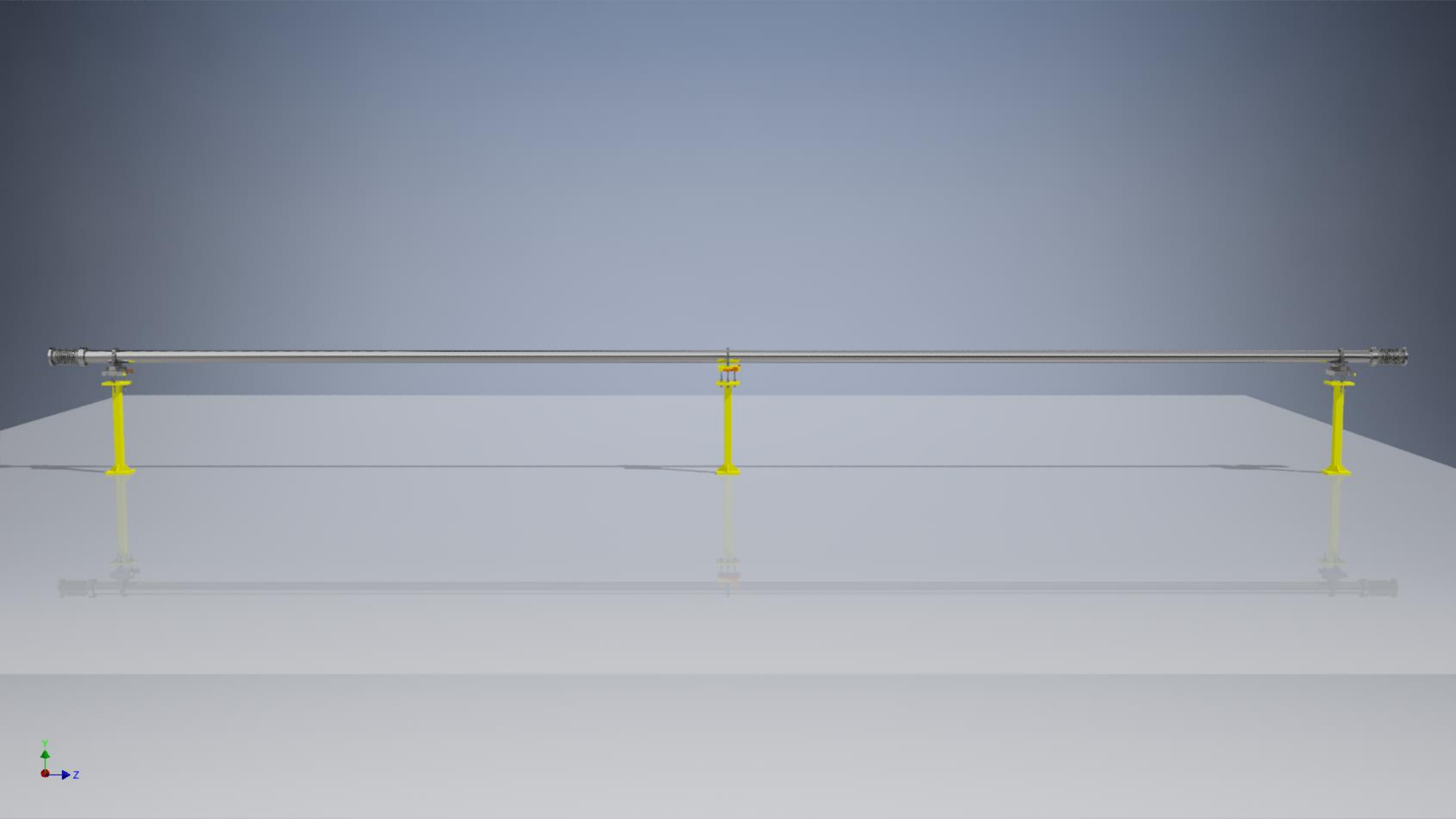
Chamber Max 4 - Experiment room

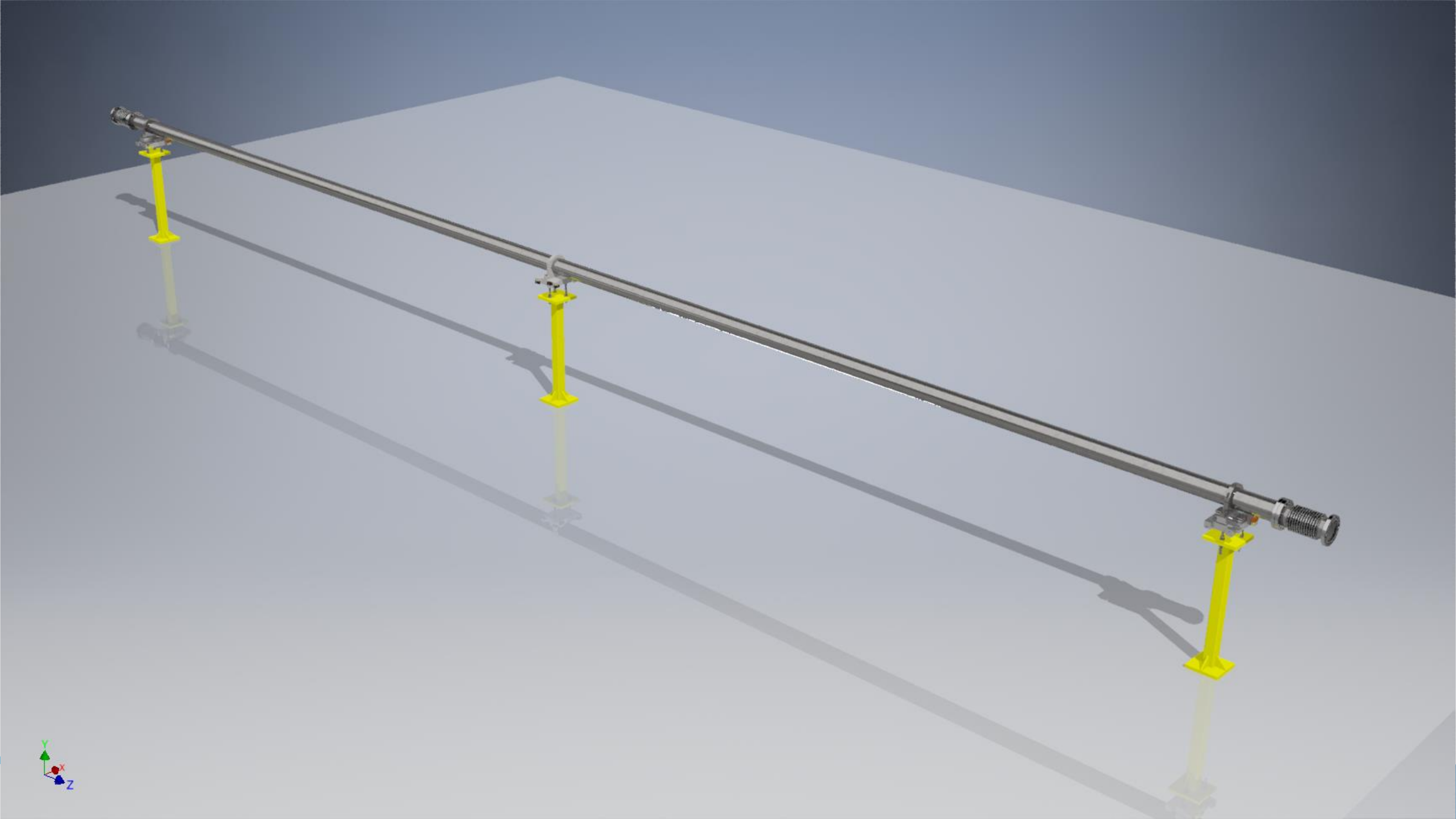


Chamber Max 4 - Experiment room



Chamber Max 4 - Experiment room


Y
Z


Y
X
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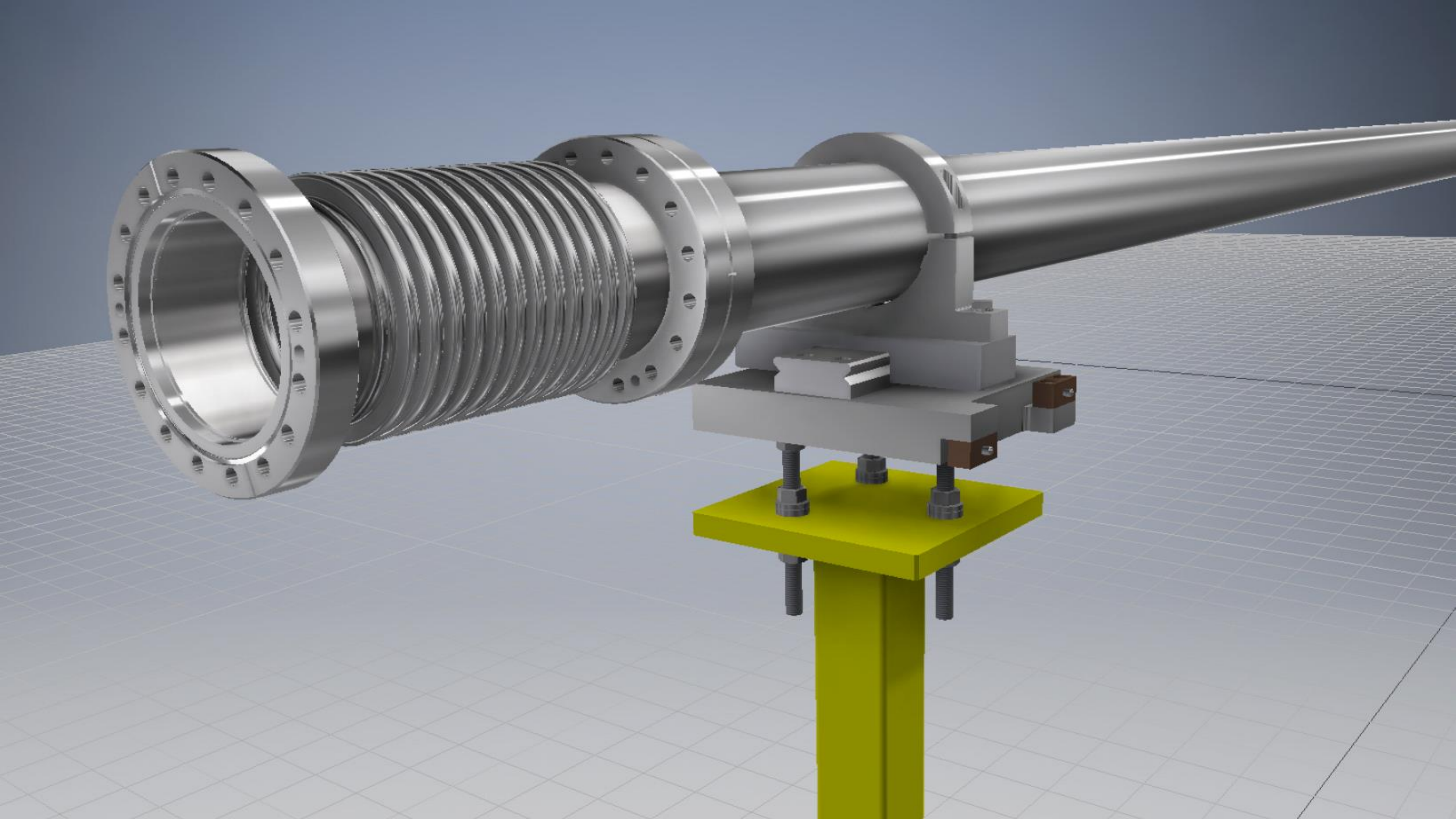
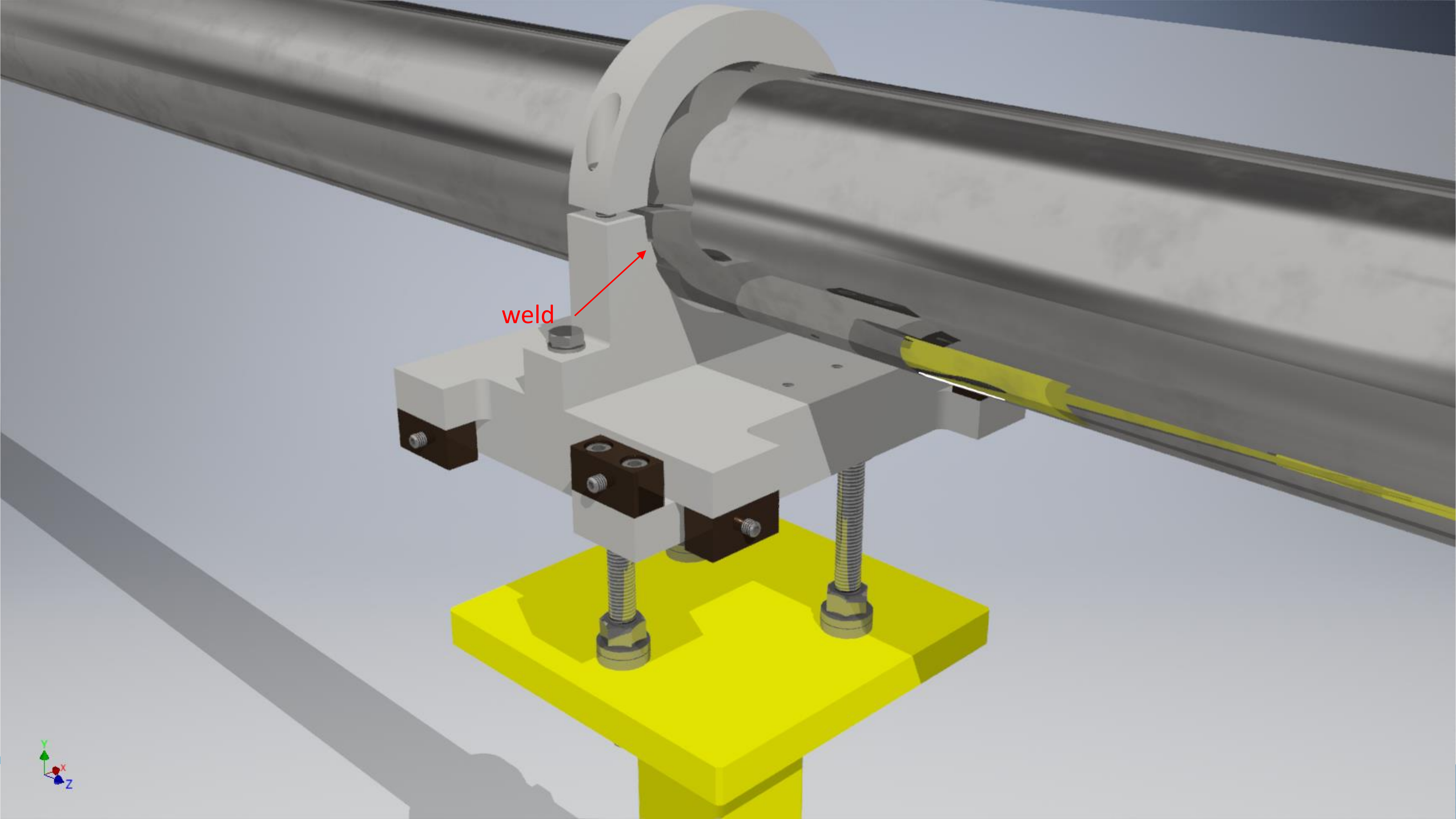
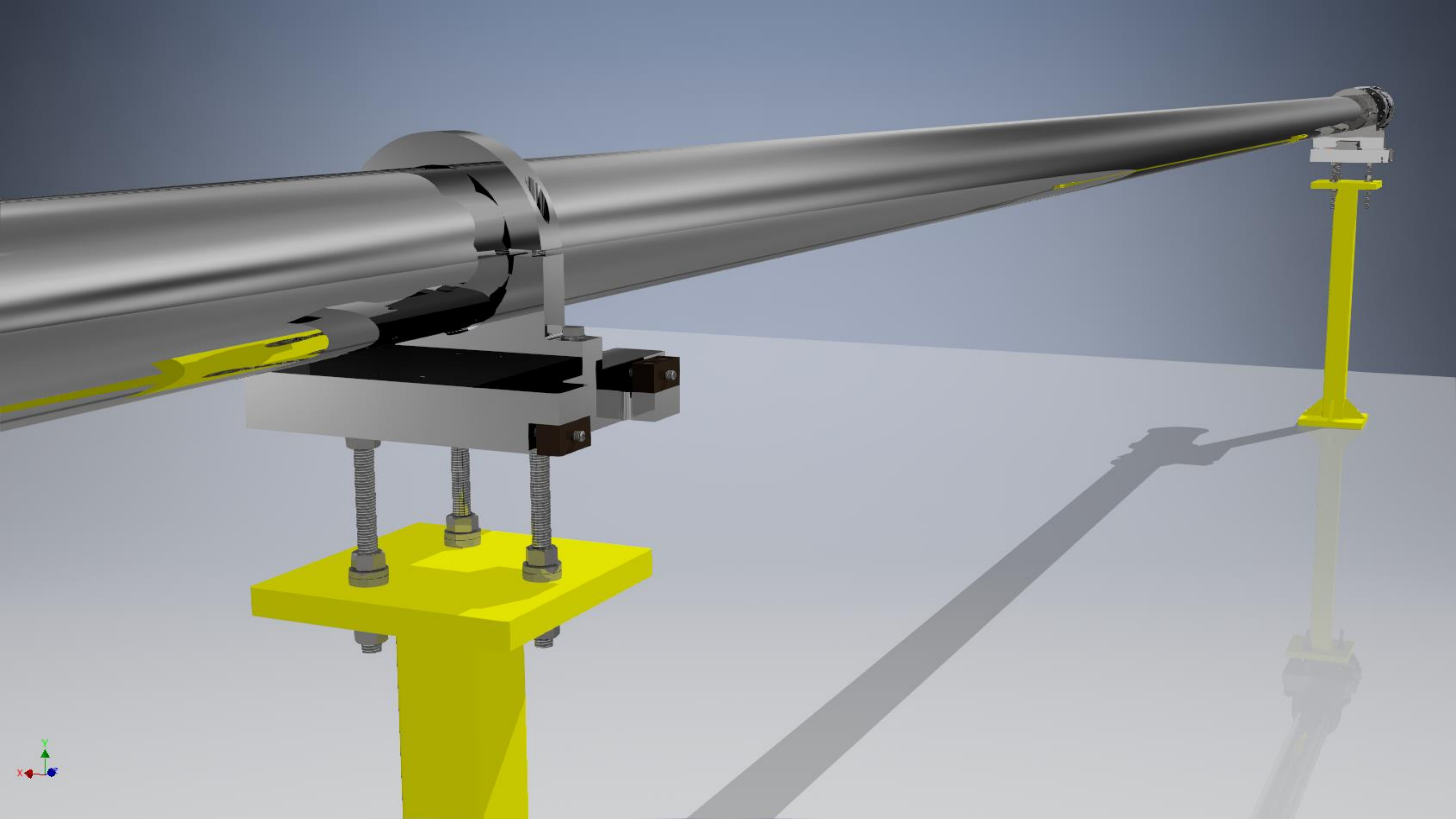



weld
Y
X
Z


Y
X
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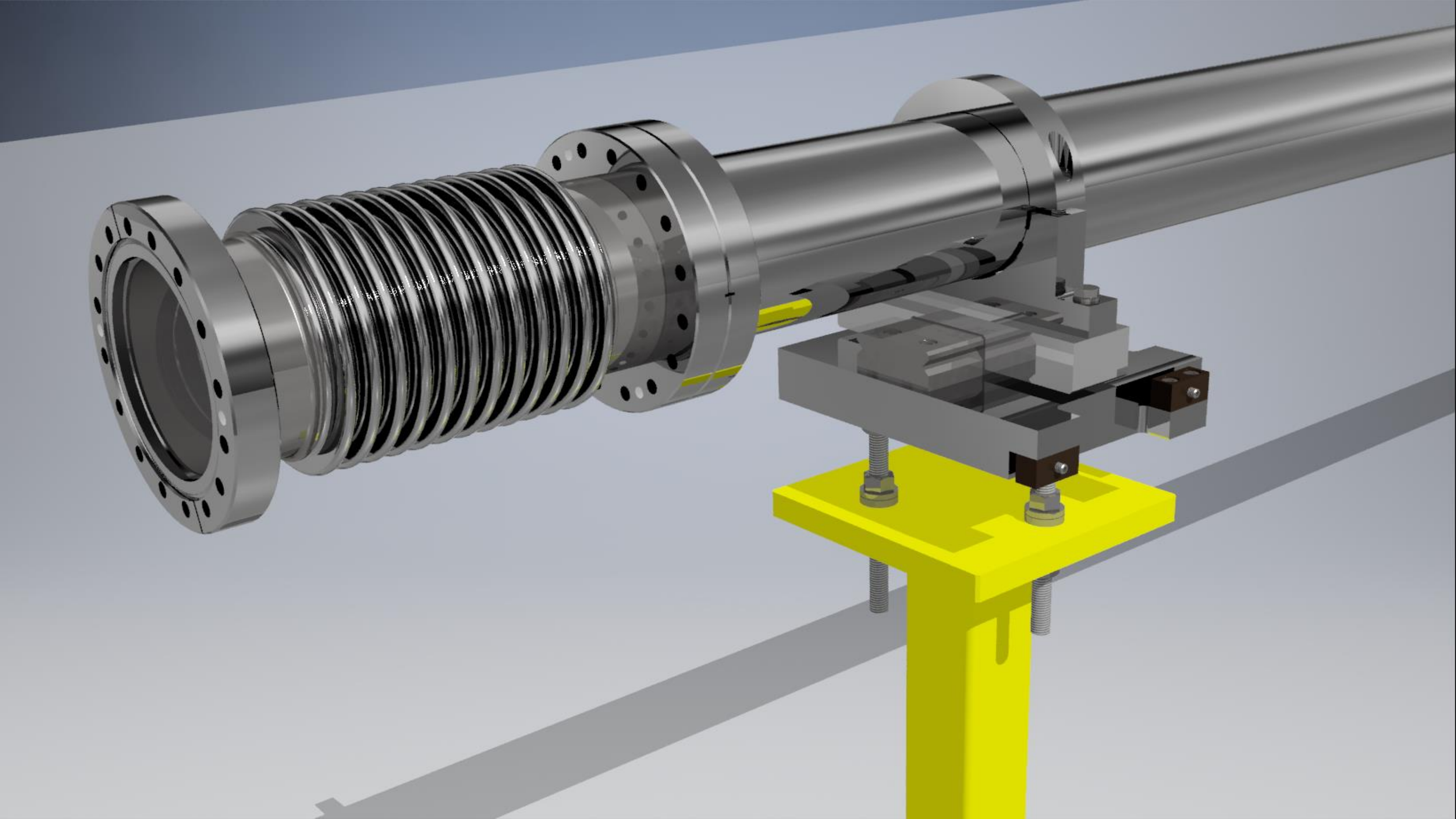
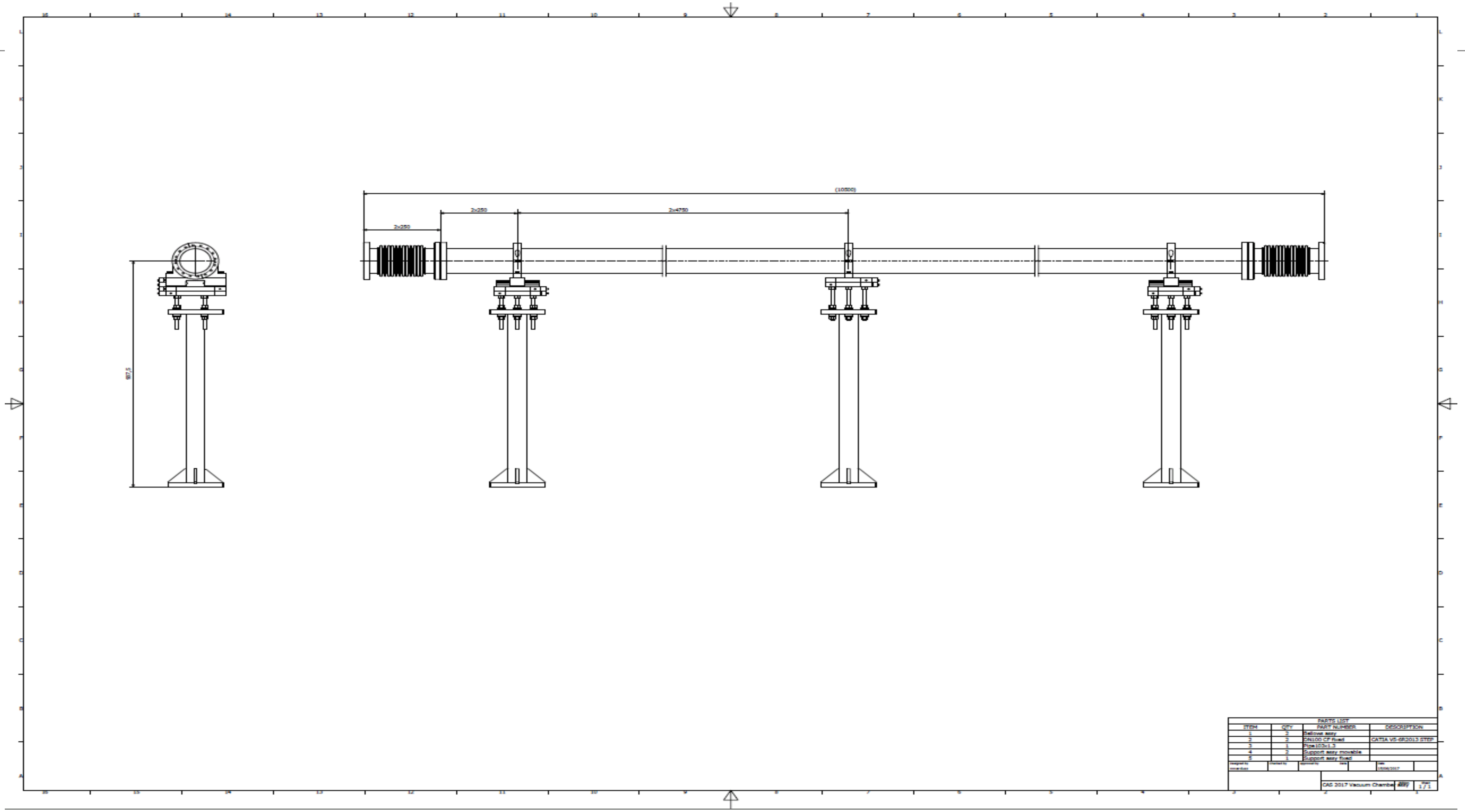
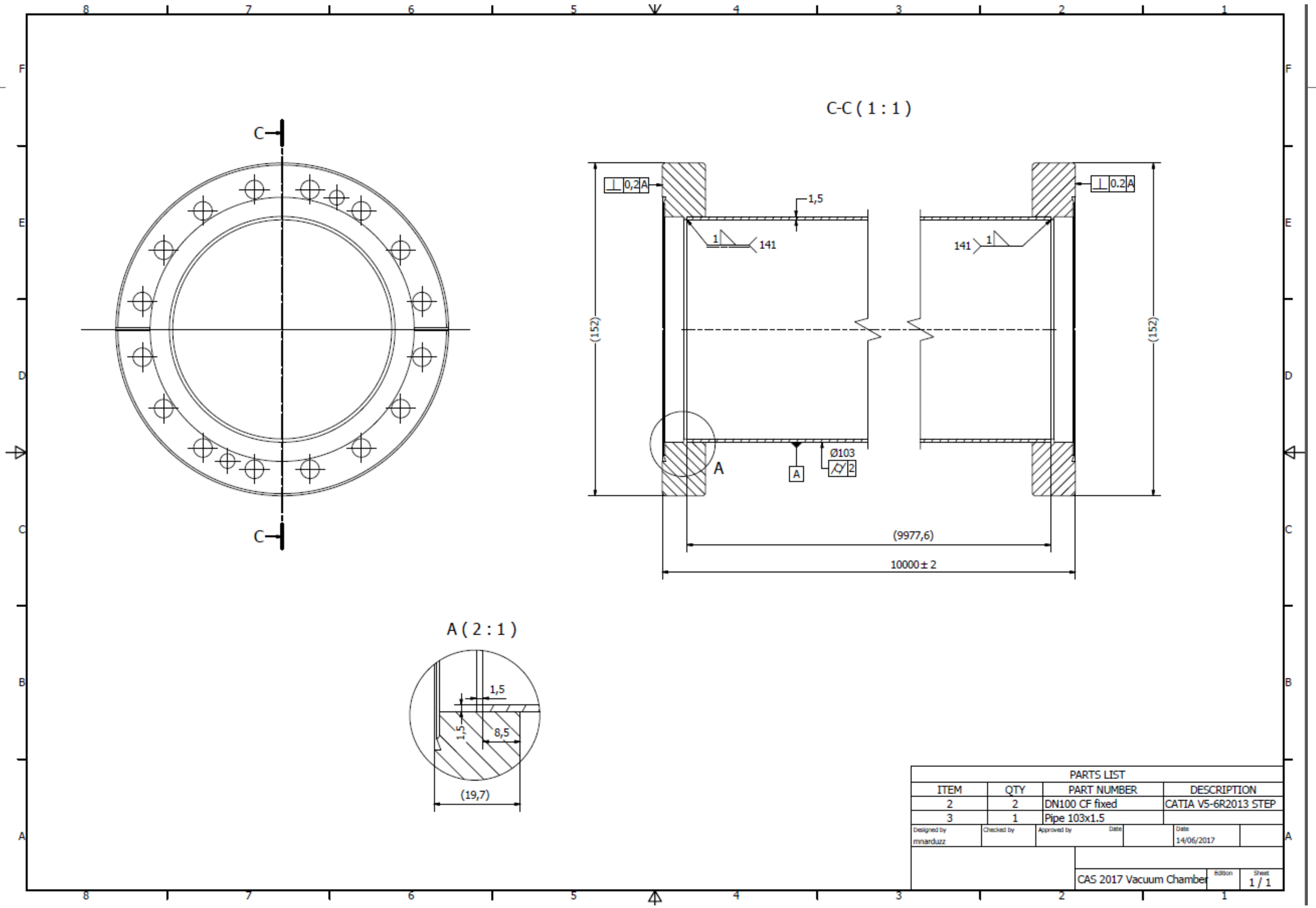


Technical drawing



PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	2	Bellows assy	
2	2	DN100 CF fixed	CATIA V5-6R2013 STEP
3	1	Pipe103x1.3	
4	2	Support assy movable	
5	1	Support assy fixed	

Technical drawing



Meet the Team: Tutorial Group 3

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Valentine	Petit	GSI
Ulrich	Popp	ESR
Thibaut	Richard	CERN
Andre	Rocha	CERN
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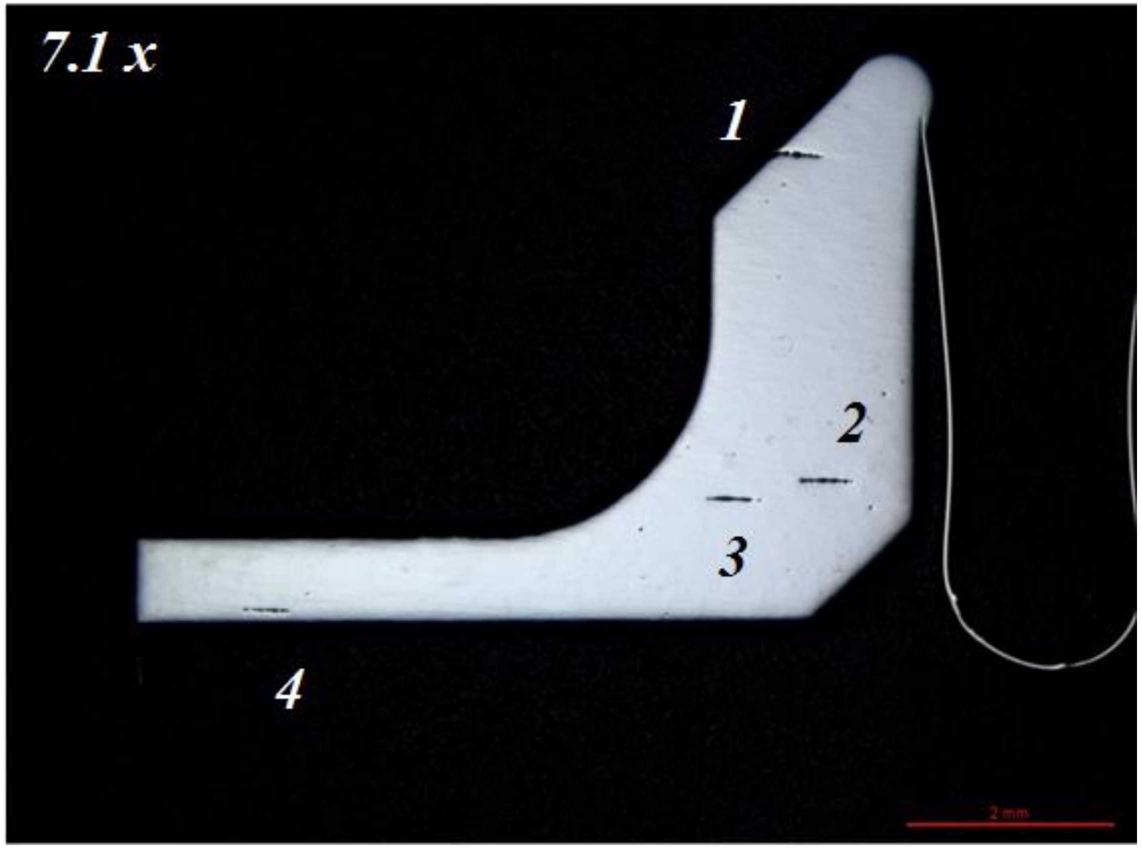
References

- Materials & Properties I: Introduction. CAS, Vacuum for Particle Accelerators 2017
  Dr. Stefano SGOBBA (CERN)
- Materials & Properties II: Thermal & Electrical Characteristics. CAS, Vacuum for Particle Accelerators 2017
  Dr. Cedric GARION (CERN)
- Surface Cleaning & Finishing. CAS, Vacuum for Particle Accelerators 2017
  Dr. Mauro TABORELLI (CERN)

Material selection

	Copper OF annealed	Al-6082-T6	Stainless steel 316L	Titanium Ti-6Al-4V (Grade 5)
Density	8950 kg/m^3	2830 kg/m^3	7970 kg/m3	4430 kg/m3
Young's modulus	115 GPa	77 GPa	195 GPa	115 GPa
Yield strength	35 MPa	393 MPa	240 MPa	880 MPa
Thermal expansion coefficient	$17 \cdot 10^{-6}$ 1/K	$22 \cdot 10^{-6}$ 1/K	$16 \cdot 10^{-6}$ 1/K	$8.9 \cdot 10^{-6}$ 1/K



Esr to reduce inclusions