A Normal Conducting 650 MHz cavity for a High Brightness Test Facility

Dario Giove, Giorgio Mauro, Elisa del Core, Rocco Paparella, Daniele Sertore, Angelo Bosotti

INFN- LASA and INFN-LNS

HB²TF

High-brightness electron beam sources are critical elements in the path to the success of upcoming projects, such as linac-based light sources and industrial-scale UV lasers.

Disparate needs are driving injector design in different directions: high beam power for IR and UV FELs, low transverse emittances for linac-based x-ray light sources, and emittance aspect-ratio control for linear colliders.

The present proposal is related to **the development of a High Brightness Beams Test Facility (HB²TF) at the INFN-LASA laboratory**.

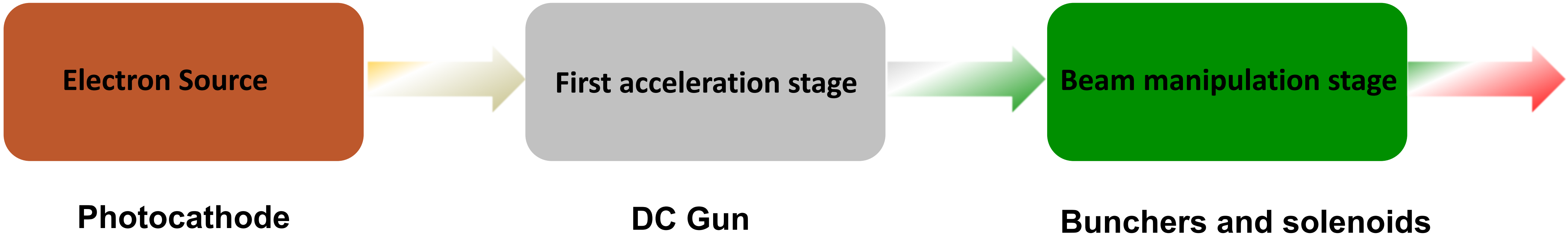
The proposal is aimed to pool different experiences and capabilities so far available in research groups at the LASA laboratory along with the contribution from accelerator groups in other INFN sites and in foreign labs.

HB²TF in a nutshell

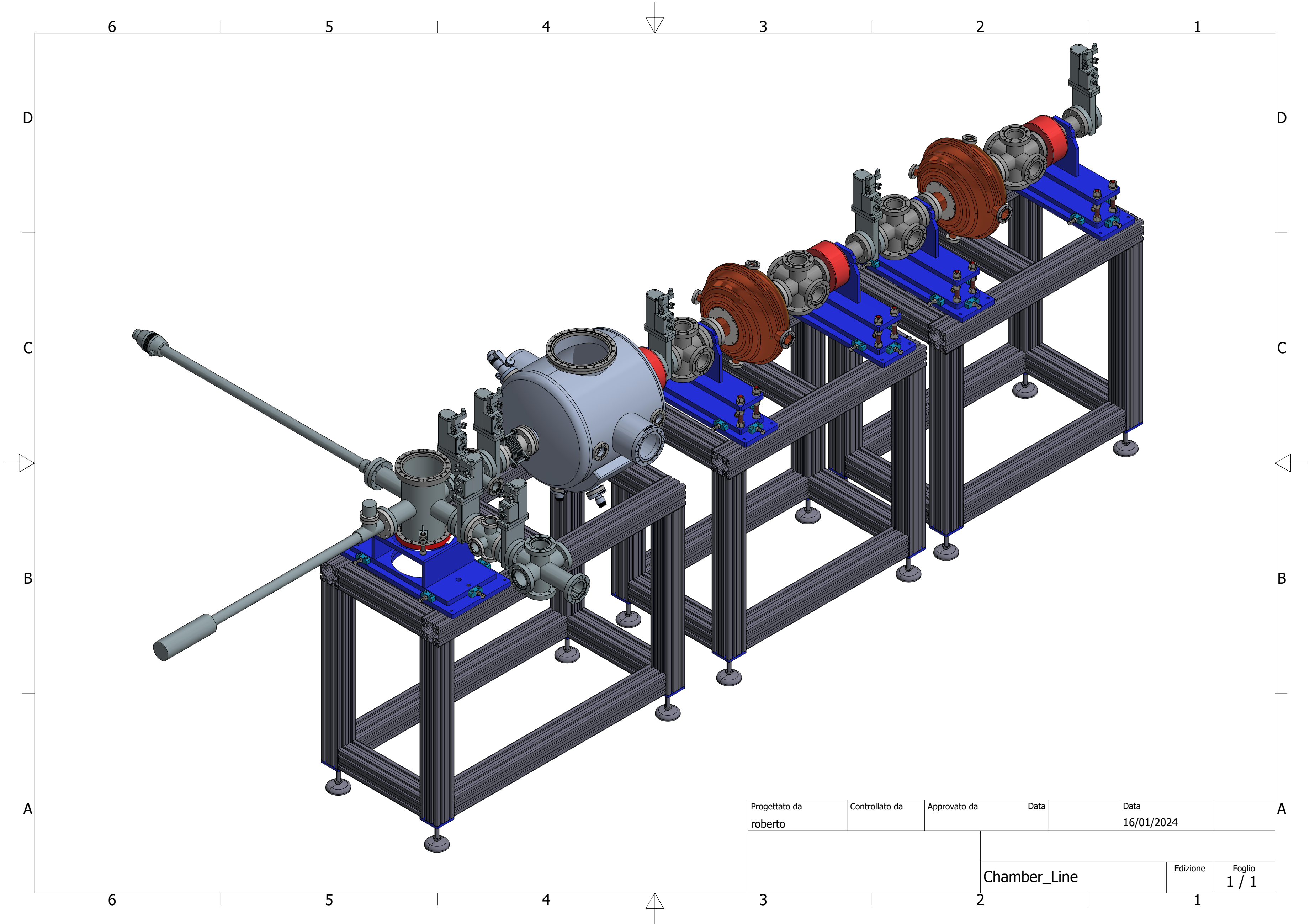
The proposal to **develop a High Brightness Beams Test Facility (HB²TF) at the INFN-LASA laboratory** has been approved by INFN-CSN5 for the period 2023-2025. HB²TF aims to provide **a high power and high brightness CW beam**. The beam will provide different bunch charges at different repetition rate and energies.
This impressive flexibility is part of the originality of the facility and will allow the usage of the beam for some advanced experiments.

Under these assumptions, the facility is composed of different elements that can be grouped into the following sections:

- An electron source.
- A first acceleration stage (DC).
- A beam manipulation and transport stage.



HB²TF Layout



Beam Manipulation

The beam dynamics study developed for this project takes as a reference the possibility to design an injector that in a near future may be used for an ERL.

This concept can be made explicit as follows: beam energies as low as possible (what will never be recovered) compatible with a beam brightness high enough to drives experiments.

Looking at this framework the beam dynamics (BD) studies carried out so far were aimed to couple the injector of HB^2TF to a SC booster to produce a beam with energy of 4.5 MeV, an emittance of about 1.2 mm- mrad and a rms bunch length of about 1.2 mm.

To obtain high brightness beam it is of paramount importance to keep emittance growth under control.

Low energy and high brightness results into a BD space charge dominated that is one of the points of interest of this proposal.

Beam Manipulation

The **electron bunches generated by the DC Gun have long longitudinal profile** so to avoid emittance dilution. But, in order **to minimize nonlinear energy spreading due to RF waveform in the foreseen booster**, bunches need to be compressed to shorter length after the gun. As the beam is still non-relativistic at this point, the simplest method of bunch compression is **the velocity bunching.**

To this end, we choose the sub-harmonic bunching solution, employing two $\beta < 1$, 650 MHz spherical re-entrant shape copper cavities. The beam energy before entering the first and second cavity are assumed to be 300 keV and 638 keV, respectively.

The specific frequency of the buncher has been chosen as a subharmonic of the foreseen 1.3 GHz SC booster.

This makes the HB2TF buncher quite unique, with the requirement to accelerate the beam.

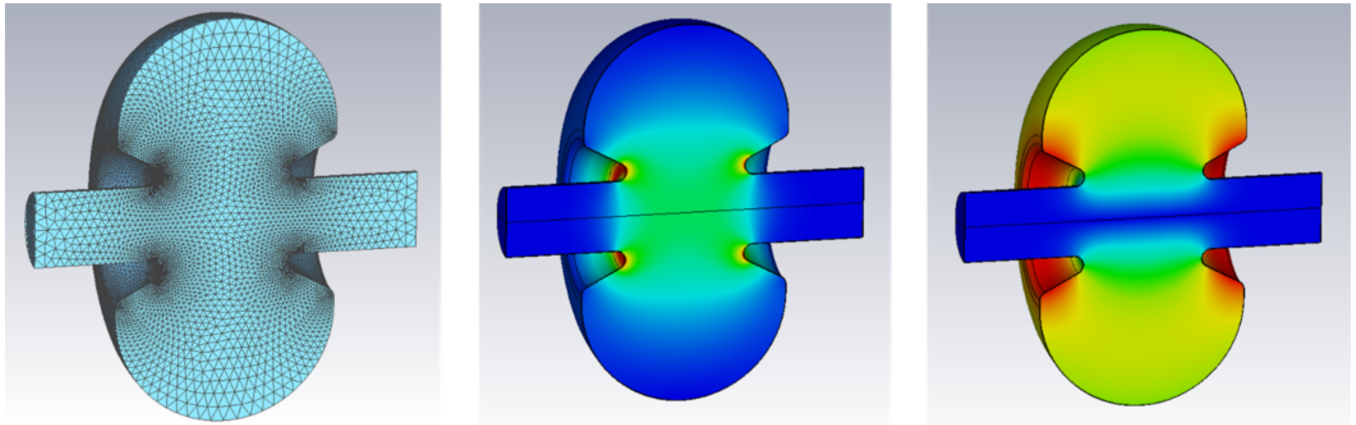
HB2TF Current Activities – RF Bunchers

The buncher cavity geometries have been designed using Superfish and CST simulations, using as a reference the KEK cERL buncher cavity and scaling to the requested frequency

The electromagnetic design of the 2 RF bunchers has been completed at the end of 2023.

We just report a table that summarizes the result of the study along with some pictures that describes the fields reached.

	Buncher 1	Buncher 2
f_0 (π-mode) [MHz]	650	
β (v/c)	0.74	0.906
Input beam energy [MeV]	0.3	0.638
E-field ampl. [MV/m]	2.7	
Cell per cavity	1.0	
Active cavity length [m]	0.171	0.209
Cavity quality factor Q_0	3.2 10^4	3.67 10^4
Ext.quality factor Q_{ext}	3.02 10^4	3.24 10^4
R/Q [Ω]	195.7	223
Geometry factor G [Ω]	211	244
E_{pk}/E_{acc}	3.07	3.88
B_{peak}/E_{peak} [mT/(MV/m)]	0.96	0.96
B_{peak}/E_{acc} [mT/(MV/m)]	2.94	3.73

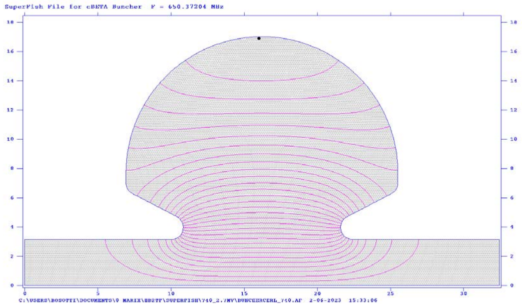


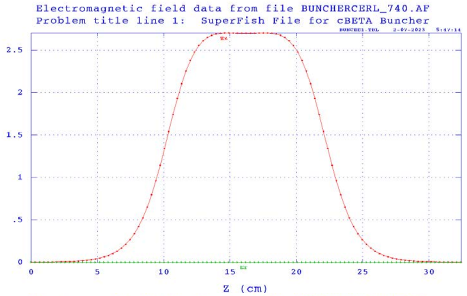
3D mesh and profile for E and H field in Buncher 1.
Parameter “g ” is the effective gap length that is 17 cm corresponding to a cavity beta 0.74.

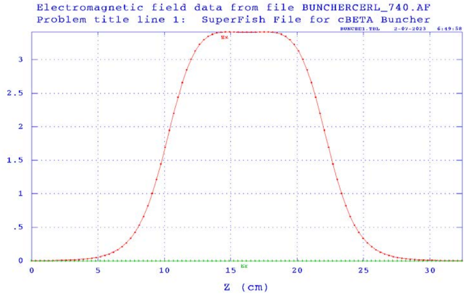
HB2TF Current Activities – RF Bunchers

2023 Update

SHB1 - cERL scaled to 650 MHz – β = 0.740





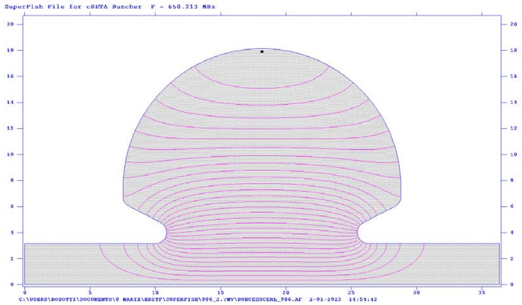


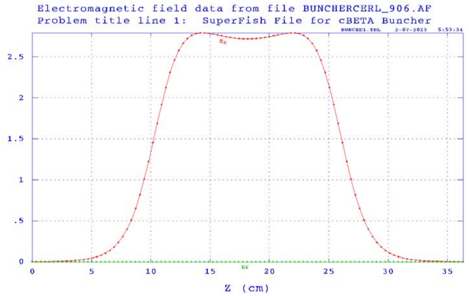
Highlights from Superfish SFO file		
SHB1	Ez max 2.7 MV/m	Ez max 3.4 MV/m
L [m]	0.171	0.171
f [MHz]	650.372	650.372
TTF	0.741	0.741
U [J]	0.080	0.127
Rs [mΩ]	6.653	6.653
Pc [kW]	10.280	16.411
Q0	31710.6	31710.6
RL [MΩ/m]	66.176	66.176
G [Ω]	210.982	210.982
E_0T [MV/m]	1.48	1.87
R/Q [Ω]	195.681	195.681

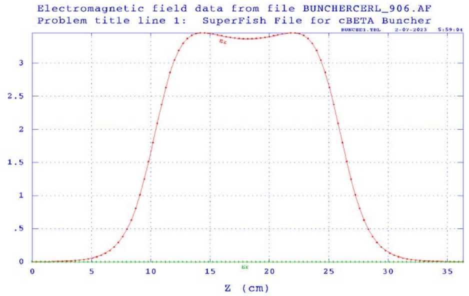
Due to the results obtained in BD simulations a possible configuration of the E_{zmax}= 2.7 and 3.4 MV/m may be considered with a significant reduction in power requirements

	Ez Max = 3.4 MV/m		Ez Max = 2.7 MV/m	
	SHB1	SHB2	SHB1	SHB2
Pbeam [kW]	2	2	2	2
Pcav [kW]	17.0	21.3	11.0	14.0
Ptot [kW]	19.0	23.3	13.0	16.0
+20%	22.8	28.0	15.6	19.2
+15%	21.9	26.8	15.0	18.4
Proposta [kW]	25	30	20	20

SHB2 - cERL scaled to 650 MHz – β = 0.906



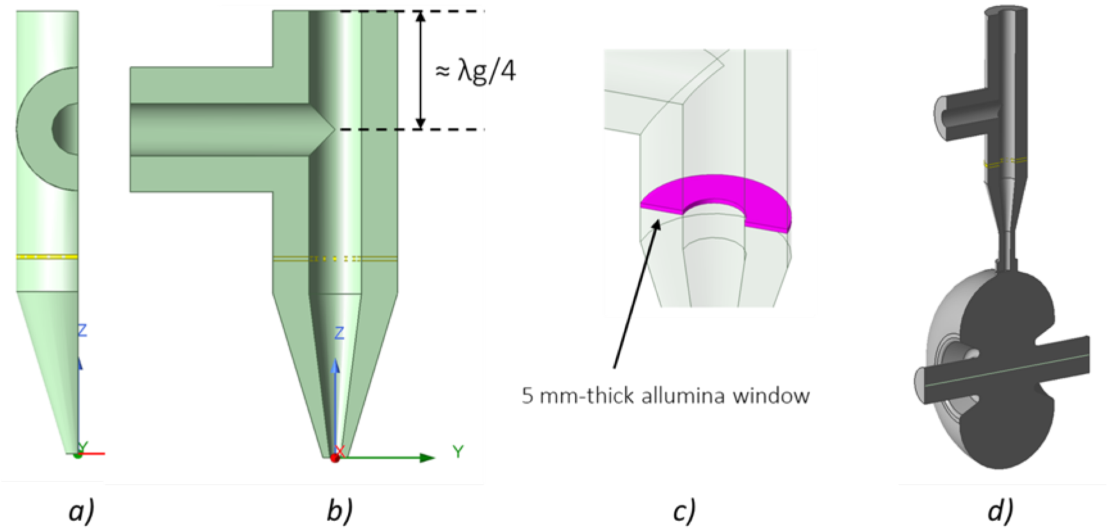




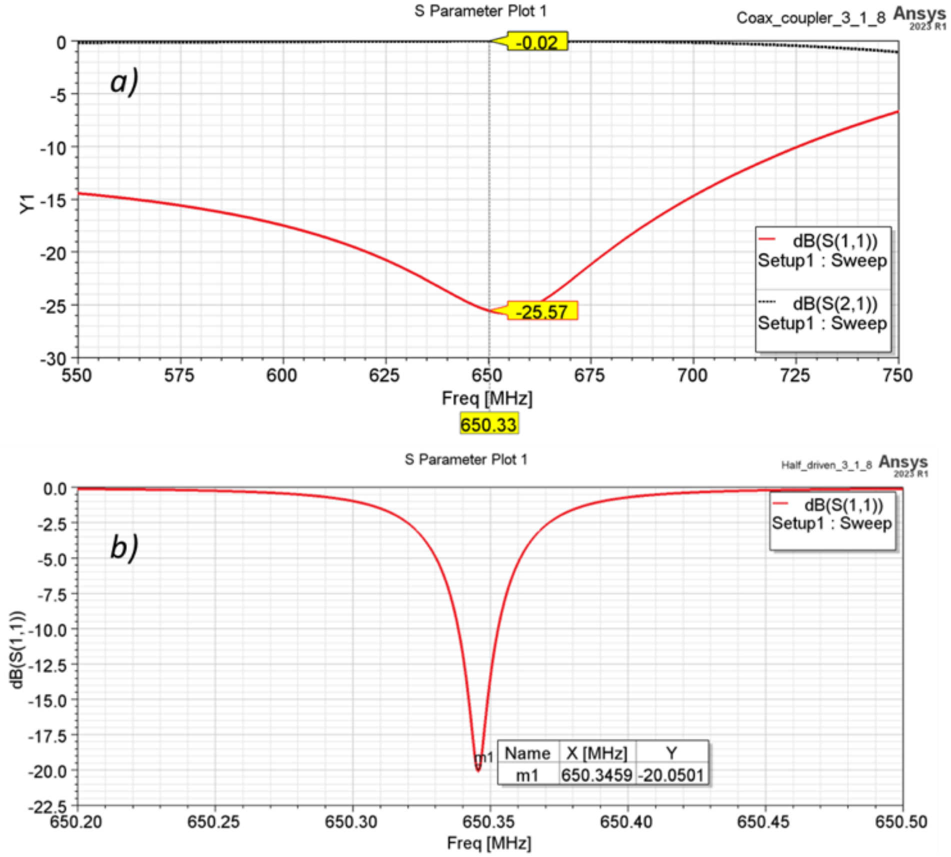
Highlights from Superfish SFO file		
SHB2	Ez max 2.7 MV/m	Ez max 3.4 MV/m
L [m]	0.209	0.209
f [MHz]	650.213	650.213
TTF	0.730	0.730
U [J]	0.123	0.188
Rs [mΩ]	6.653	6.653
Pc [kW]	13.639	20.886
Q0	36743.1	36743.1
RL [MΩ/m]	73.658	73.658
G [Ω]	244.436	244.436
E_0T [MV/m]	1.6	1.98
R/Q [Ω]	222.932	222.932

HB2TF Fundamental Power Coupler

Baseline design: coaxial line coupler, tapered and tuned through a *λg/4* section, to feed the cavity via the 3 1/8” standard line. Rotatable loop tip to perform magnetic coupling.



Schematic EM layout of the fundamental power coupler of Buncher 1: EM volume cross-sections in *a)* and *b)*, ceramic window detail in *c)* and full-view of the system coupled through a loop at the cavity equator in *d)*.



S-parameter analysis of the coupled Buncher 1 with HFSS: plot *a)* refers to the power coupler alone for both transmission (s21) and reflection (s11) coefficients, plot *b)* is instead for the coupler system cavity + coupler.

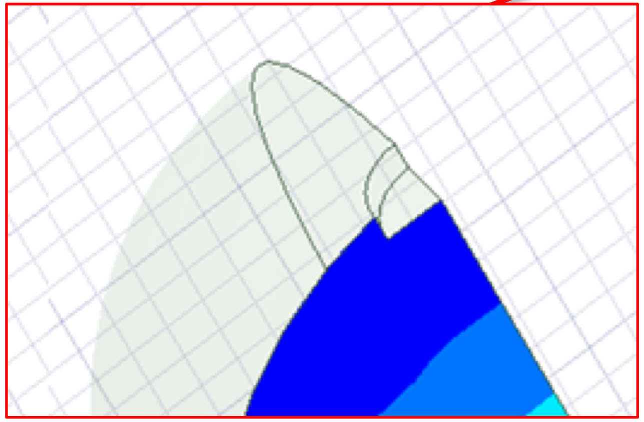
HB2TF Frequency Tuner Design

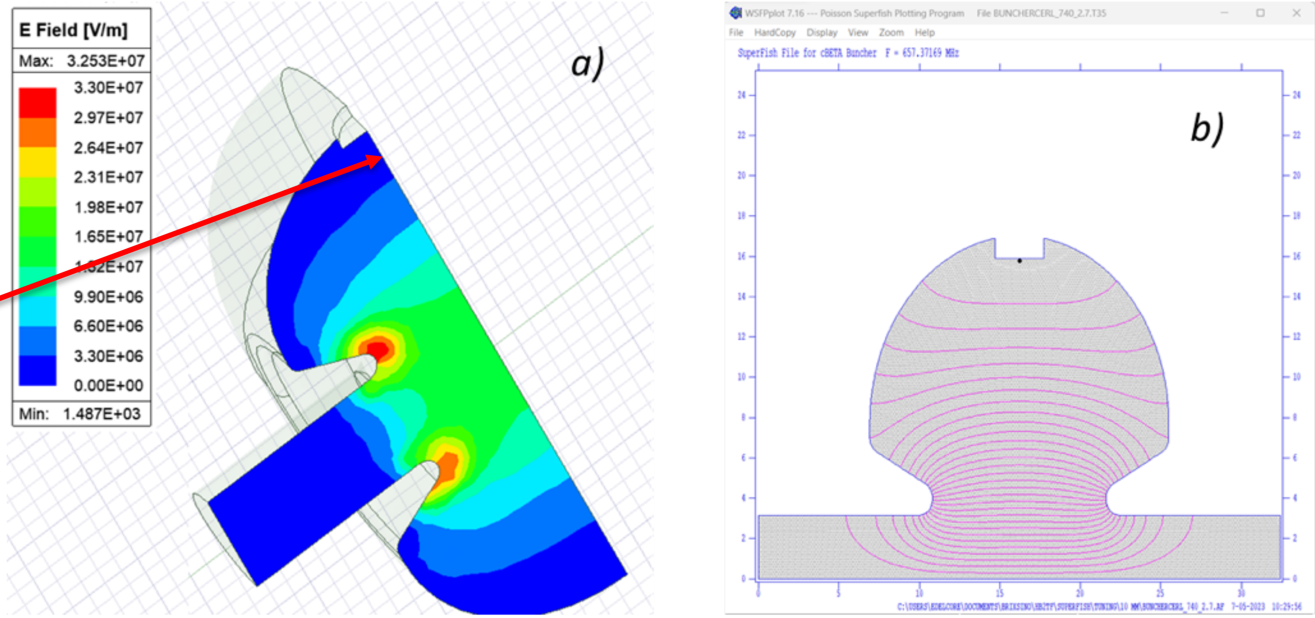
Baseline design: movable plunger tuning solution through one of the four ports symmetrically distributed along the cavity equator.

Tuning sensitivity has been assessed through both 2D and 3D (HFSS) solvers for a realistic implementation, a 30 mm OD copper plunger through a CF40 vacuum port.

Simulated tuning sensitivity value sets to about 20 kHz/mm

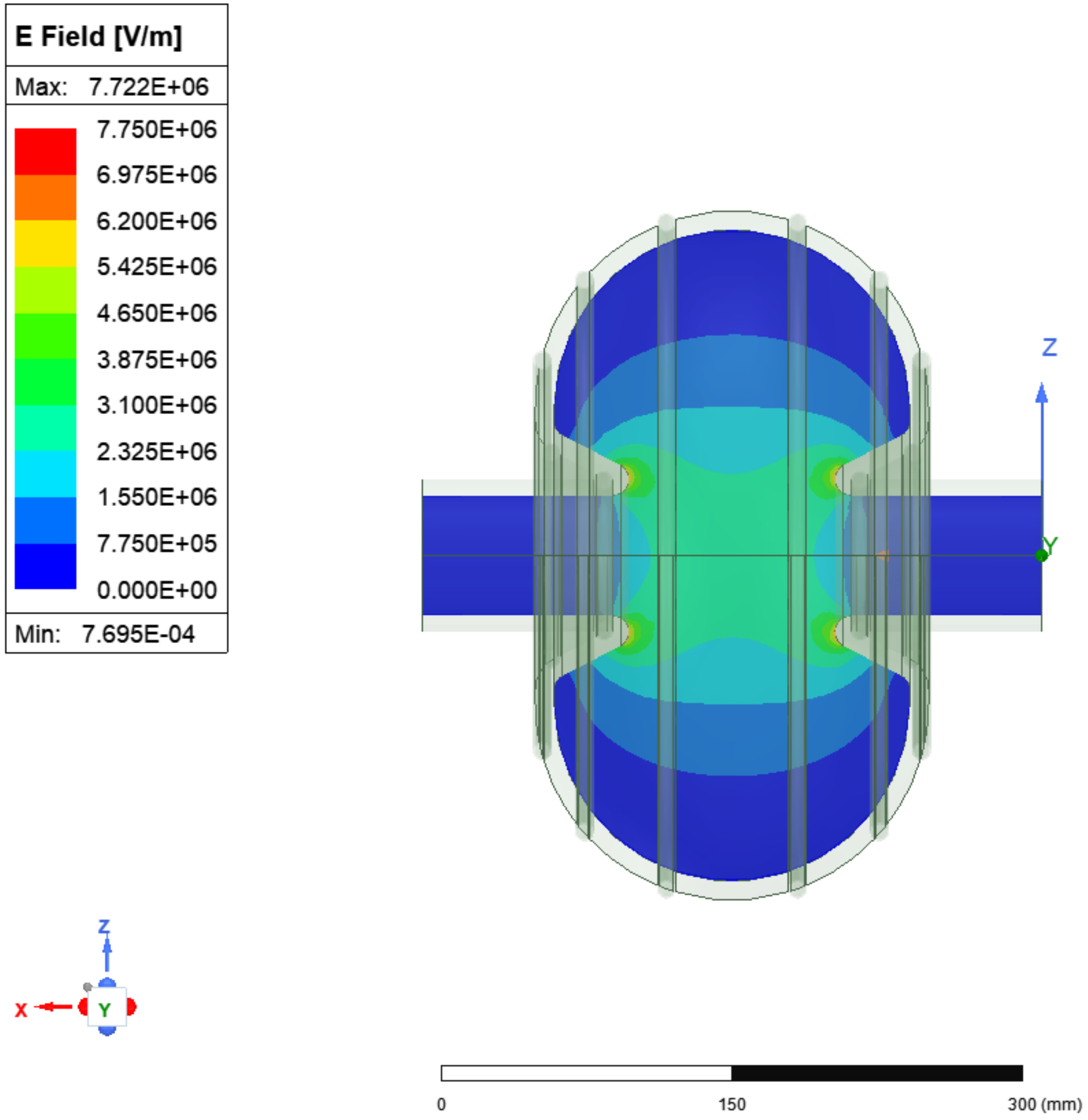
Proved throughout a 10 mm tuning stroke, in good agreement with the expected reference value calculated by means of Slater's perturbative theory.

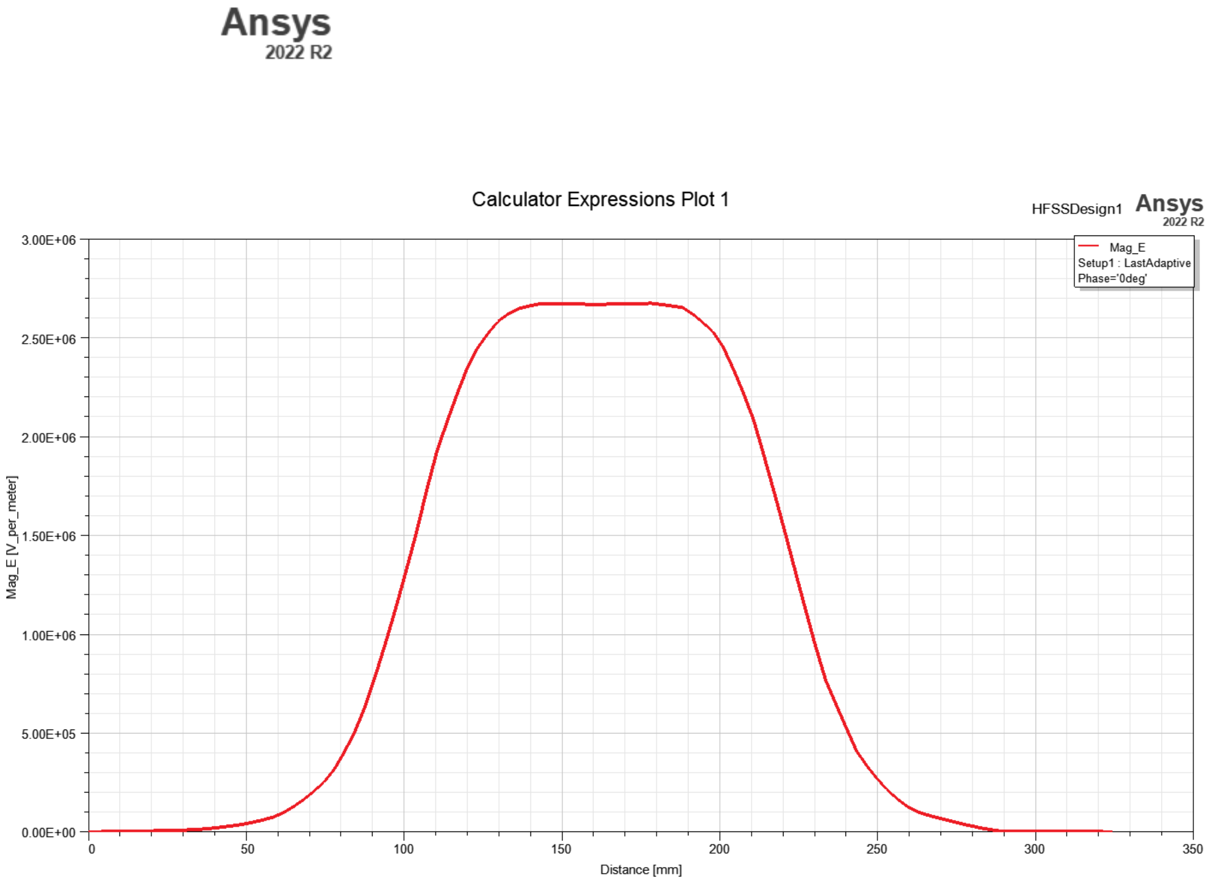




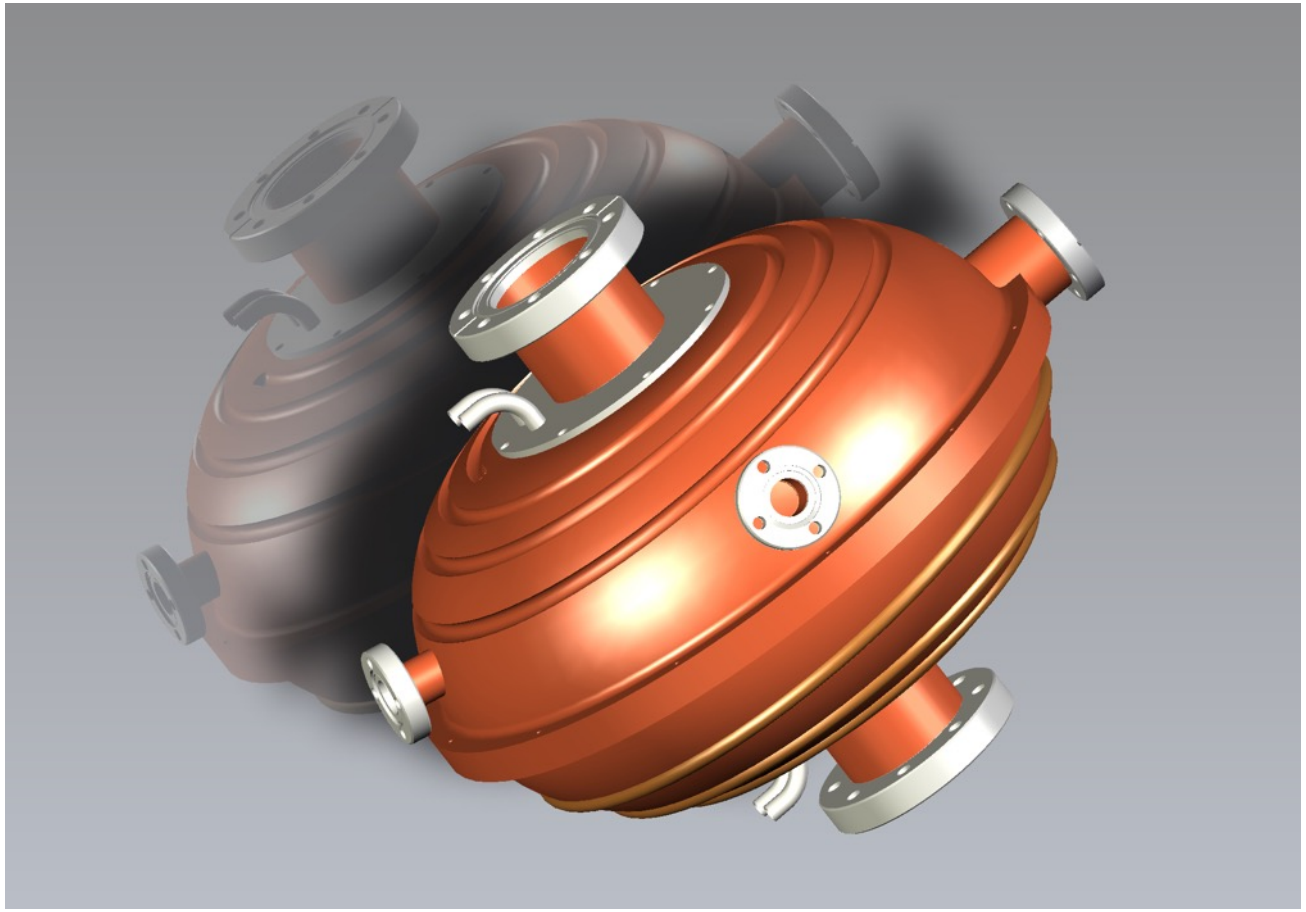
3D (on the left, *a)*) and 2D (on the right, *b)*) simulations of the movable plunger tuner. In the 3D case, the tuning volume is visible in the upper corner of the buncher 1 section, together with the electric field profile.

HB2TF Buncher Electromagnetic Simulation

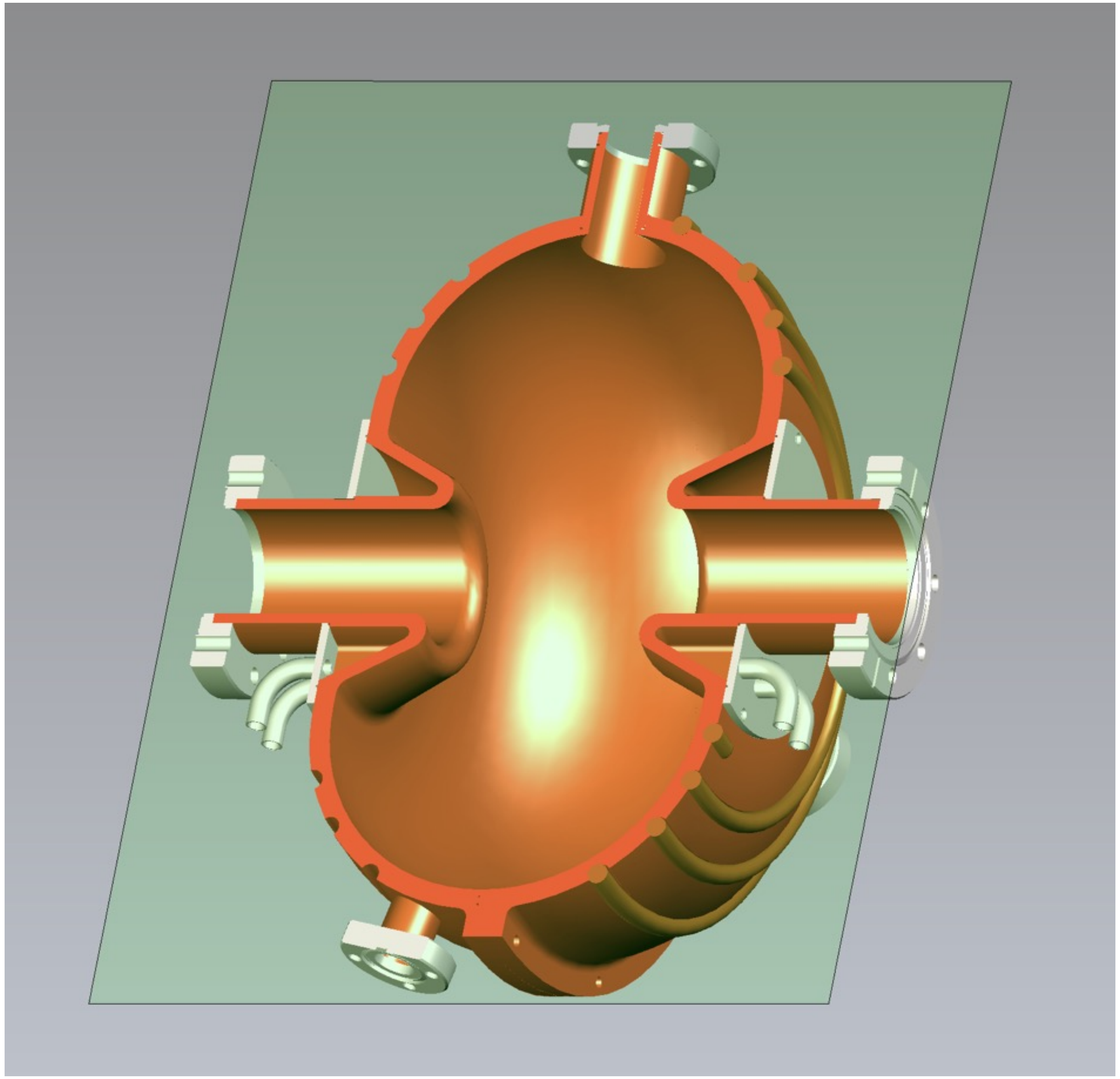




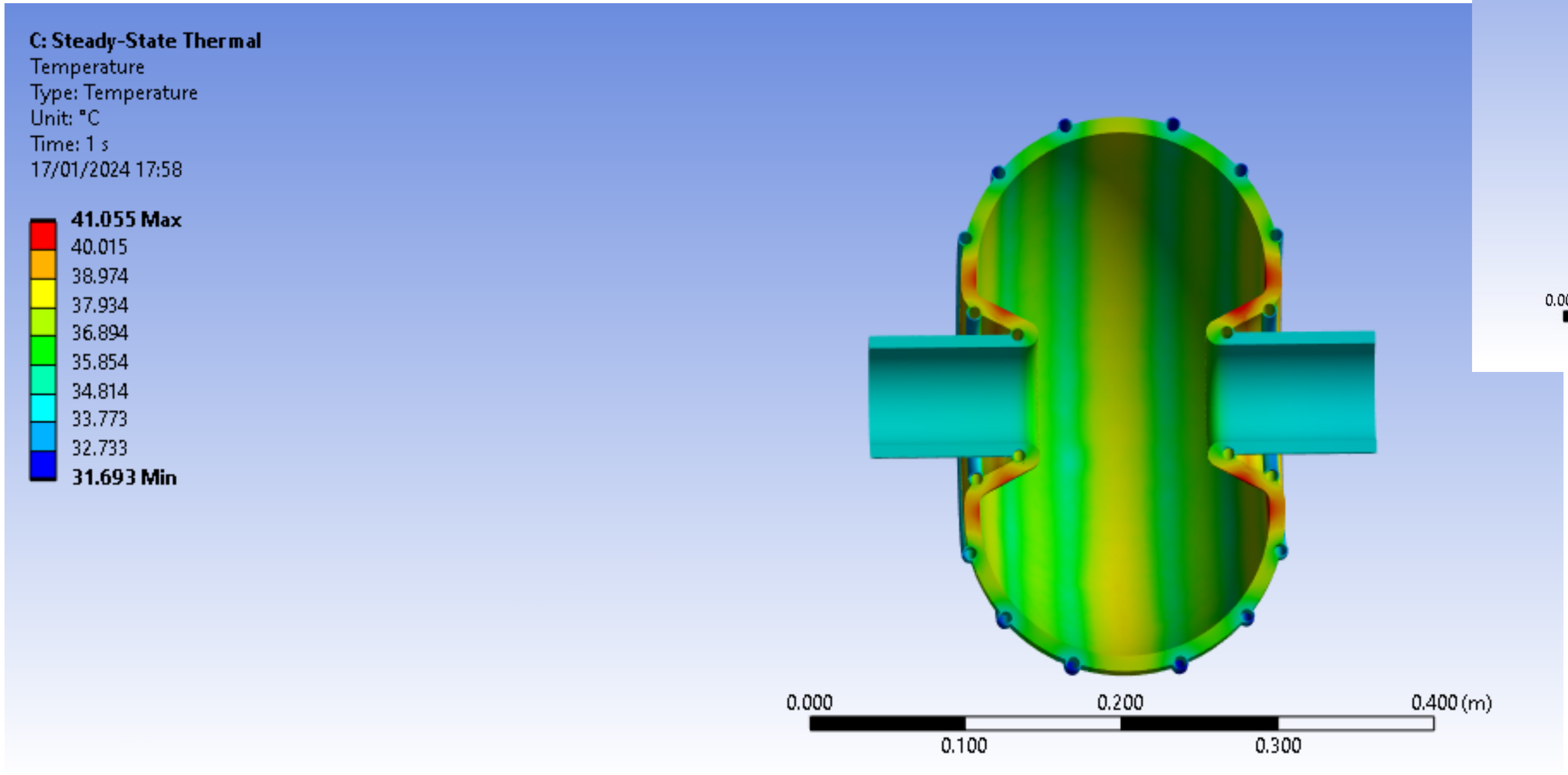
HB2TF Buncher Mechanical Proposal

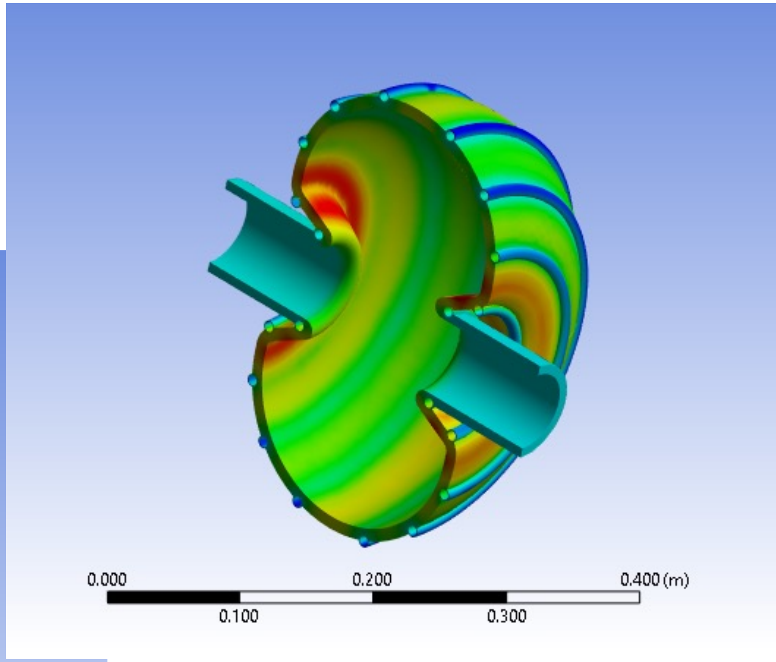


HB2TF Buncher Mechanical Proposal

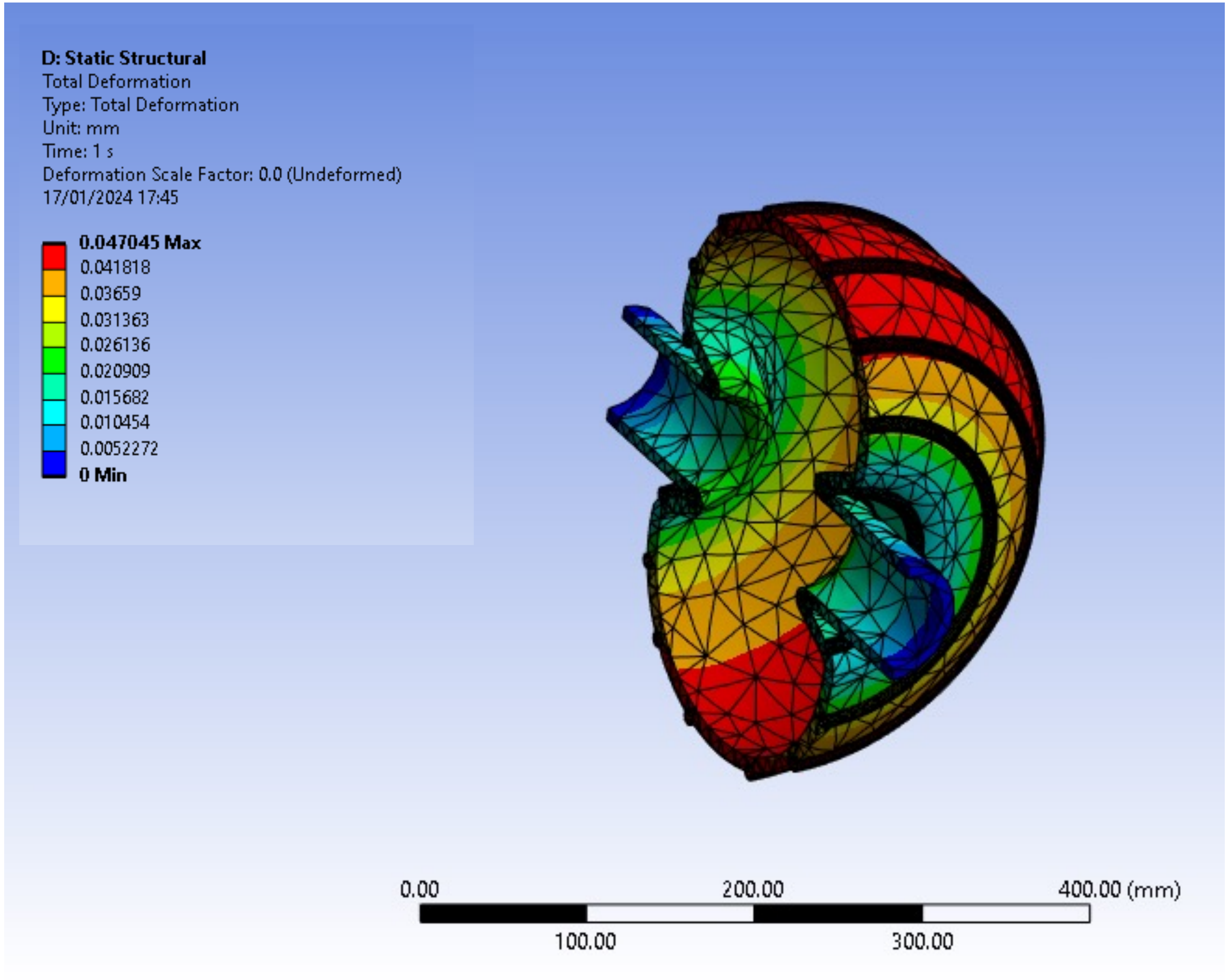


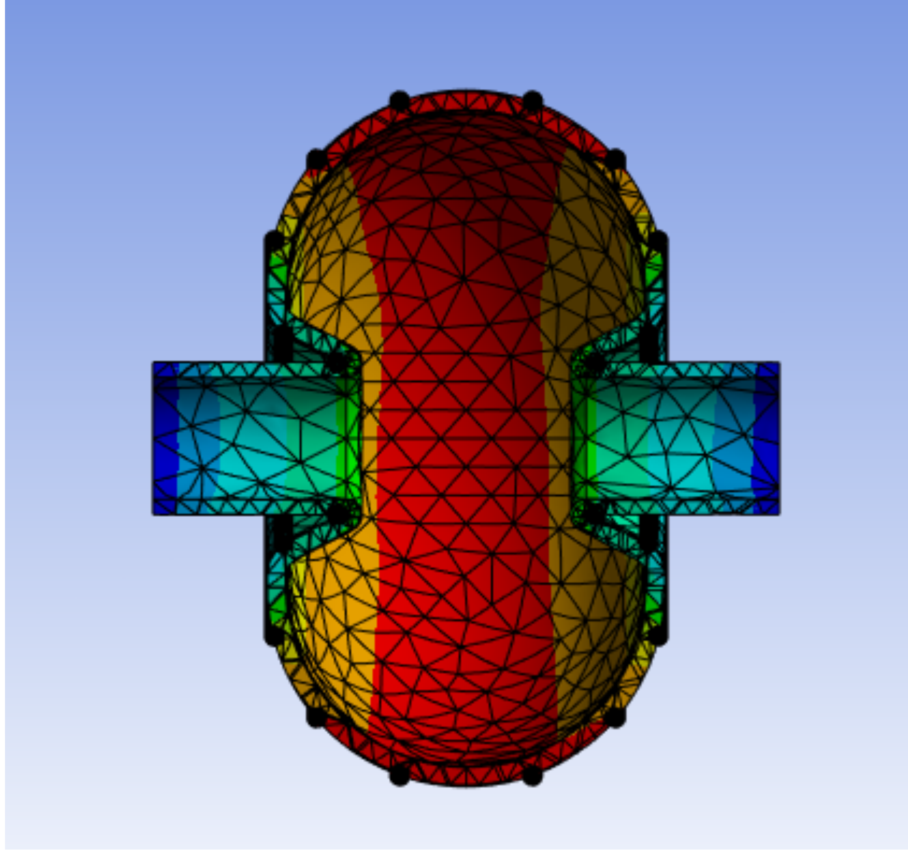
HB2TF Buncher Thermal Simulation



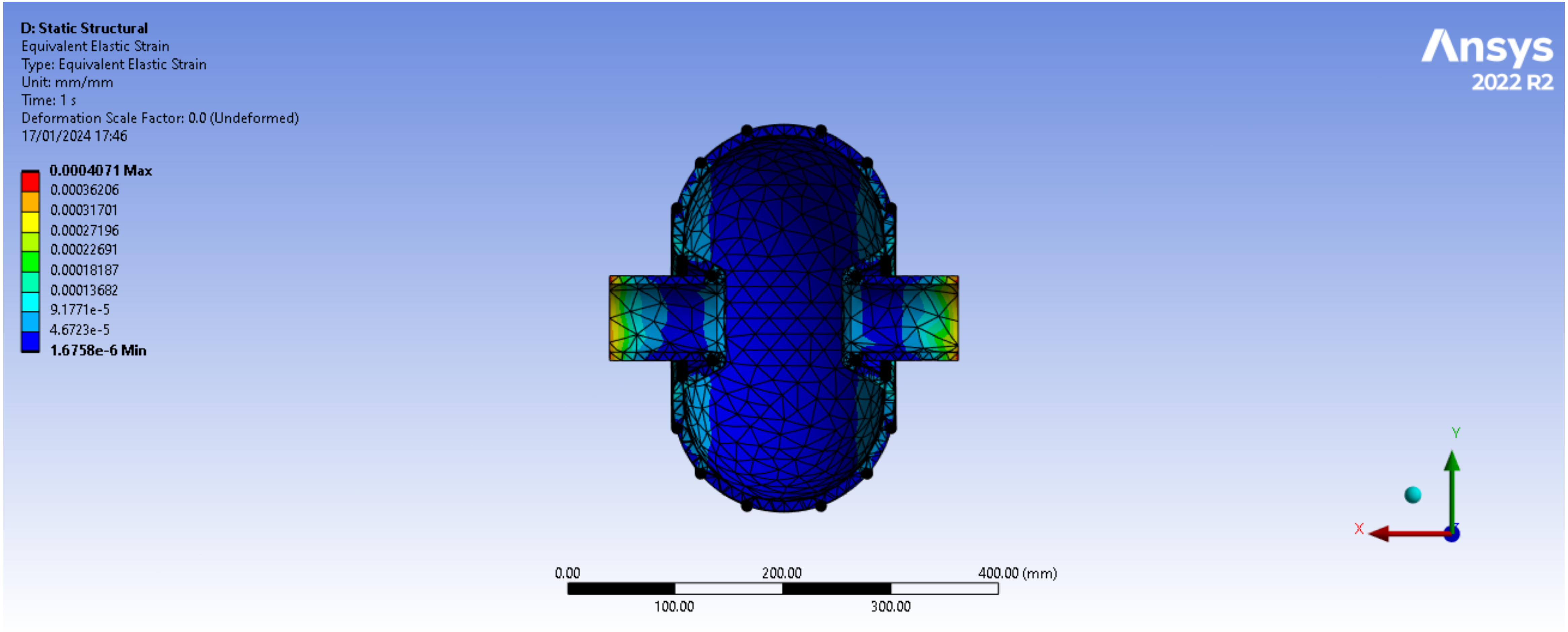


HB2TF Structural: Total Deformation

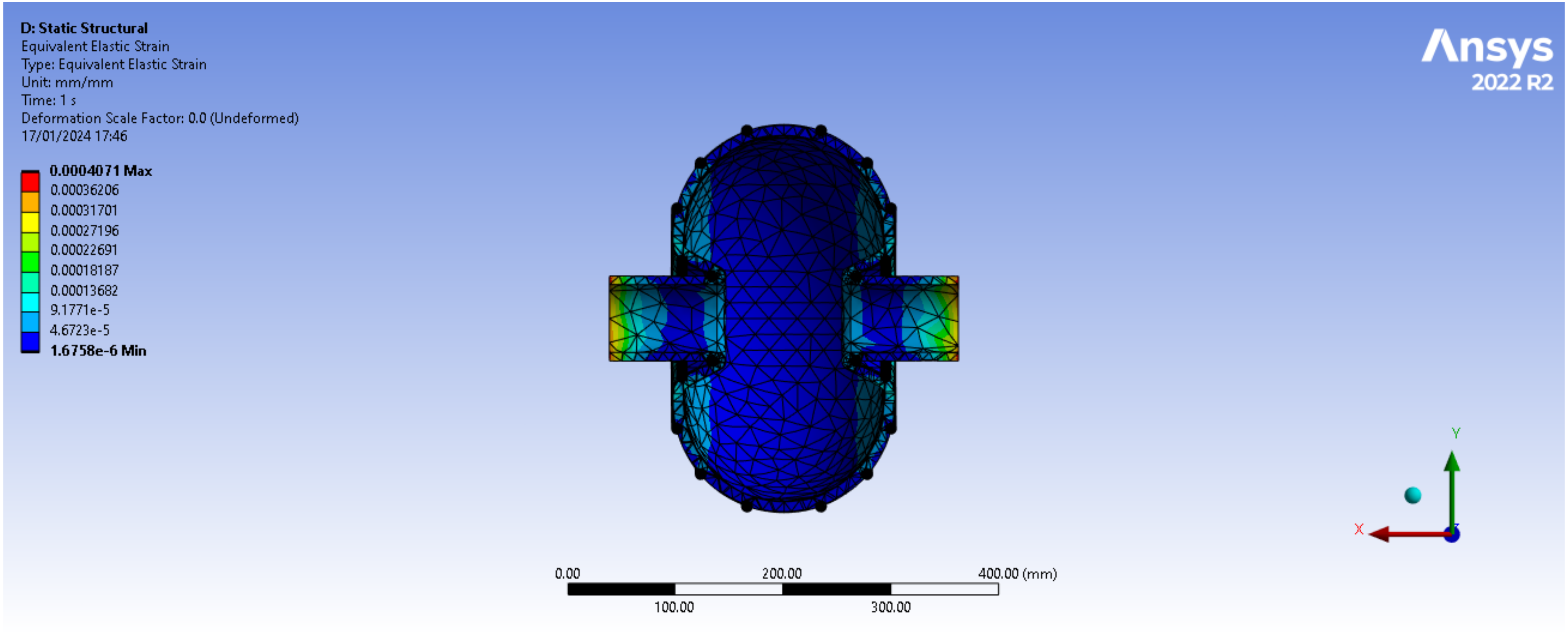




HB2TF Structural : Von-Mises Strain

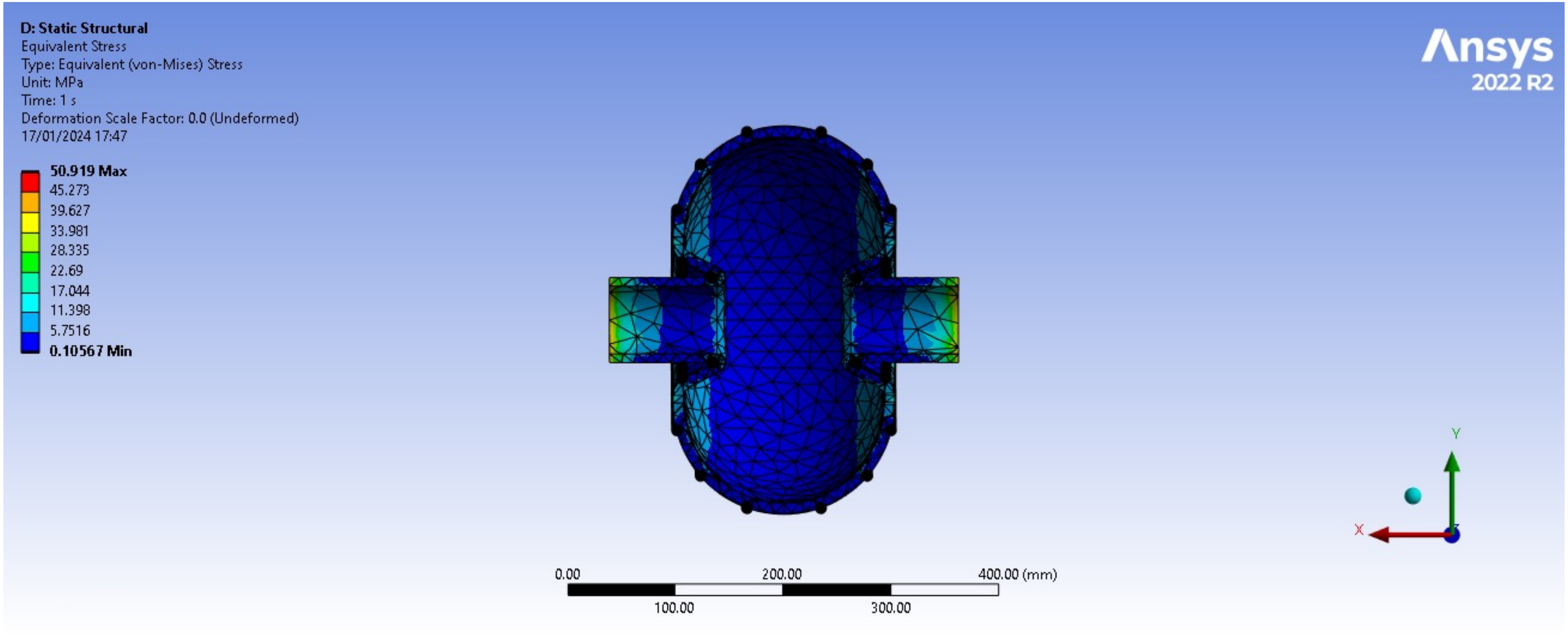


HB2TF Structural : Von-Mises Strain



HB2TF Structural : Von-Mises Stress

Copper Young's Modulus: 130 Gpa
Copper Yield Strength ~ 200 Mpa



Thanks for your attention !