

VACUUM TUBE DESIGN FOR THE EINSTEIN TELESCOPE

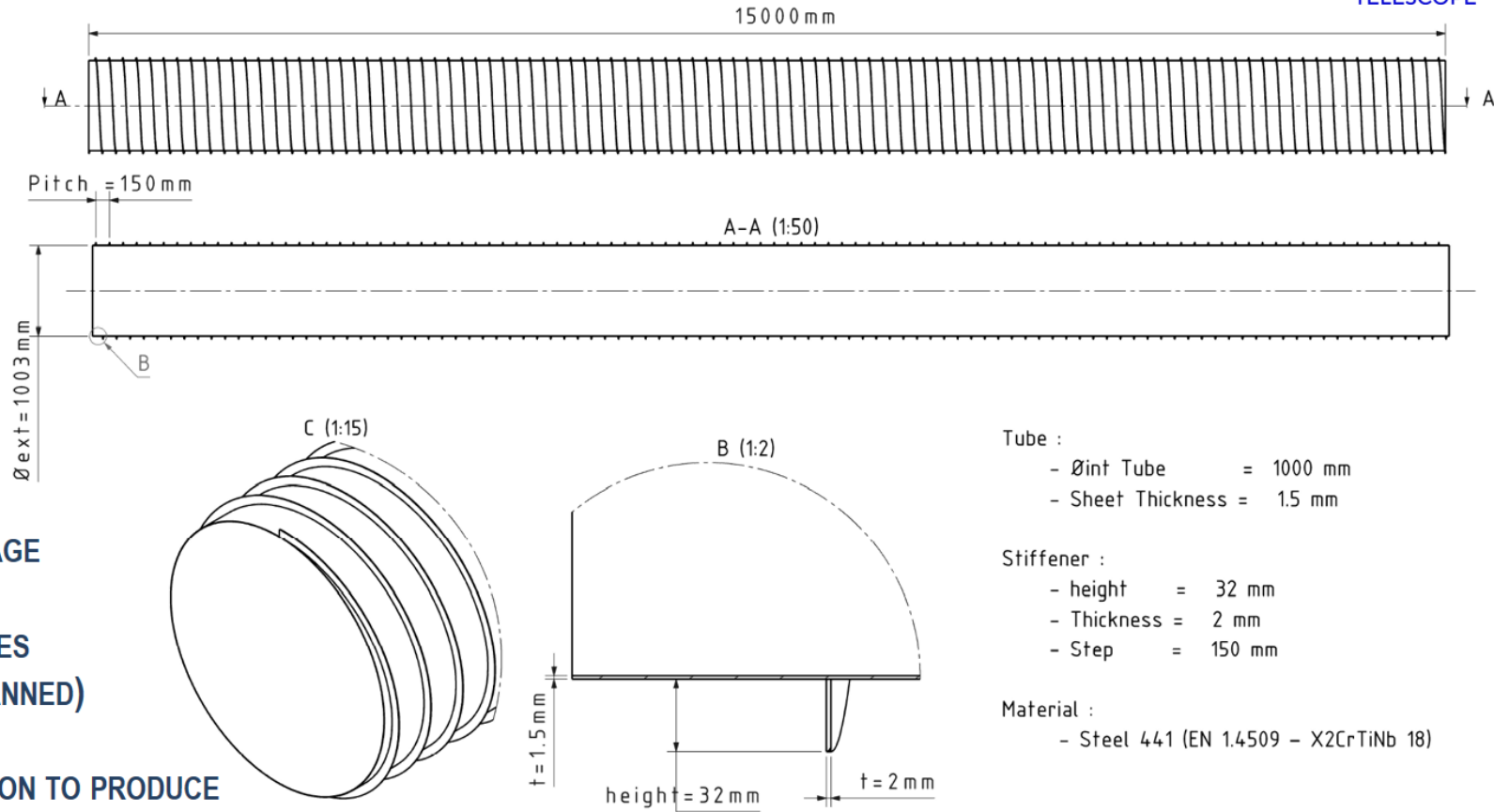
ALEXANDRE LACROIX (CNRS LAPP)
CE-ET BEAMTUBE WORKSHOP III

01/02/2025

- TUBE DESIGN
- SUPPORT
- SIMULATION
- ACTION IN PROGRESS AND TO BE CONTINUED



- **LENGTH :**
 - 15 m,
 - Φ_{int} : 1 m,
 - wall thickness: 1.5 mm
- **EXTERNAL SPIRAL STIFFENER :**
 - 2 mm thickness,
 - pitch 150 mm
- **TOTAL WEIGHT: ~750 KG →**
LIGHTWEIGHT, REDUCED STEEL USAGE
- **COST-EFFECTIVE FOR MEDIUM-SERIES**
PRODUCTION (120 KM OF TUBE PLANNED)
- **EXPLOITS AUTOMATION/ROBOTIZATION TO PRODUCE**
SLIGHTLY MORE COMPLEX GEOMETRY THAN VIRGO



Tube :

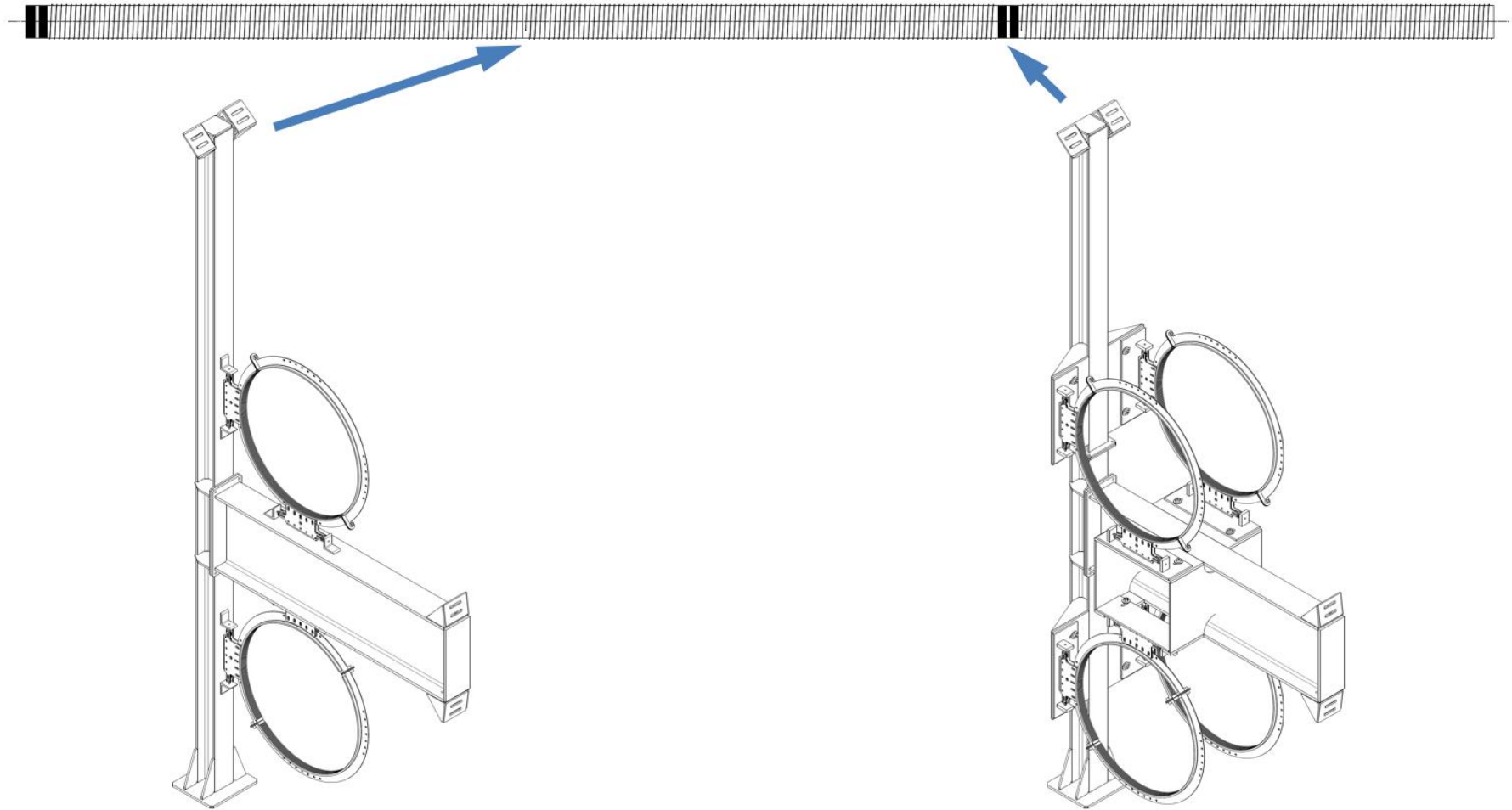
- Φ_{int} Tube = 1000 mm
- Sheet Thickness = 1.5 mm

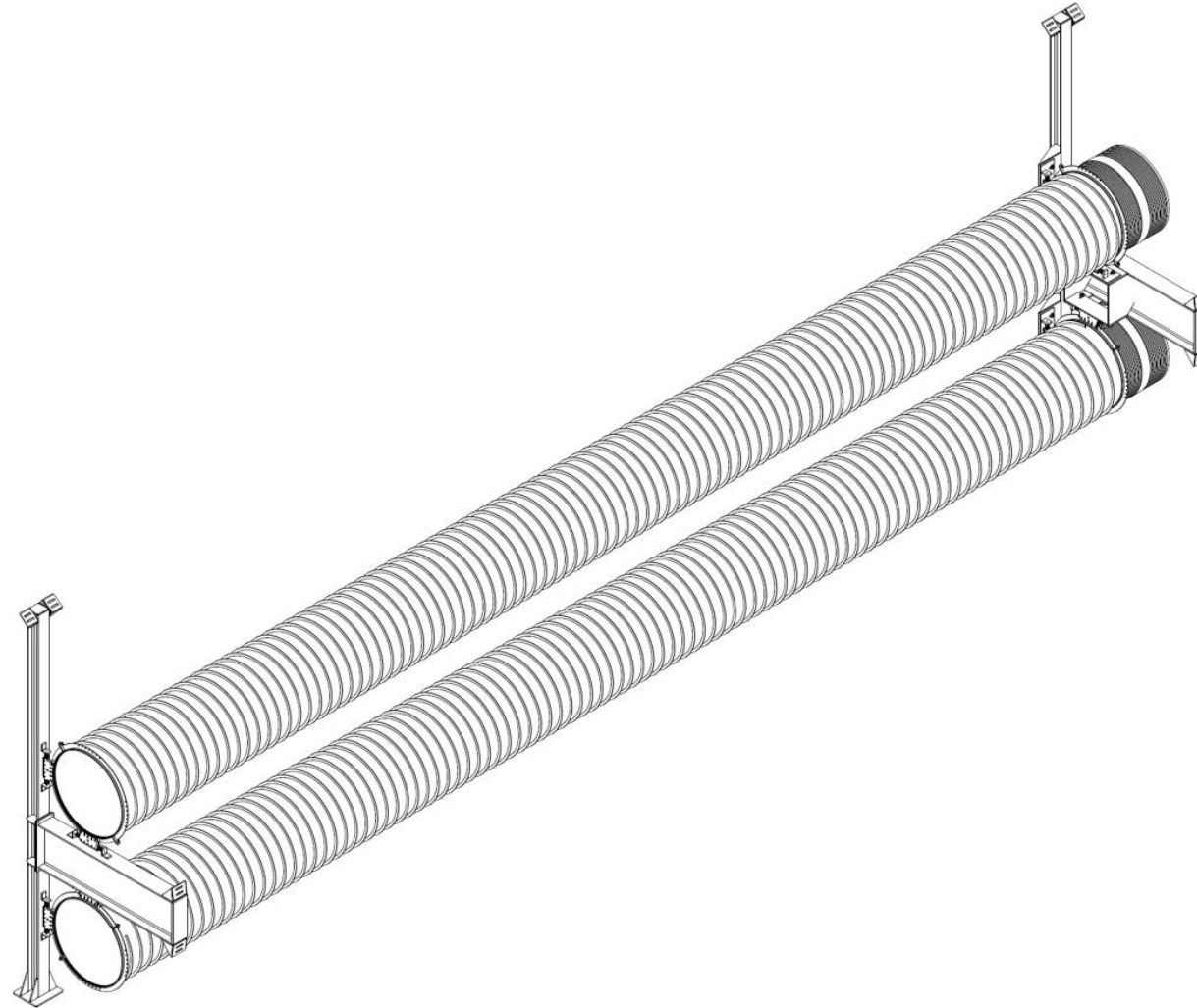
Stiffener :

- height = 32 mm
- Thickness = 2 mm
- Step = 150 mm

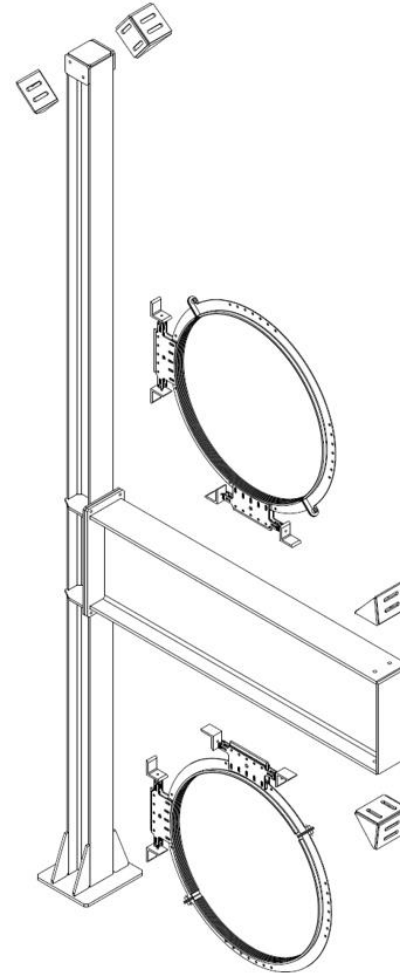
Material :

- Steel 441 (EN 1.4509 – X2CrTiNb 18)

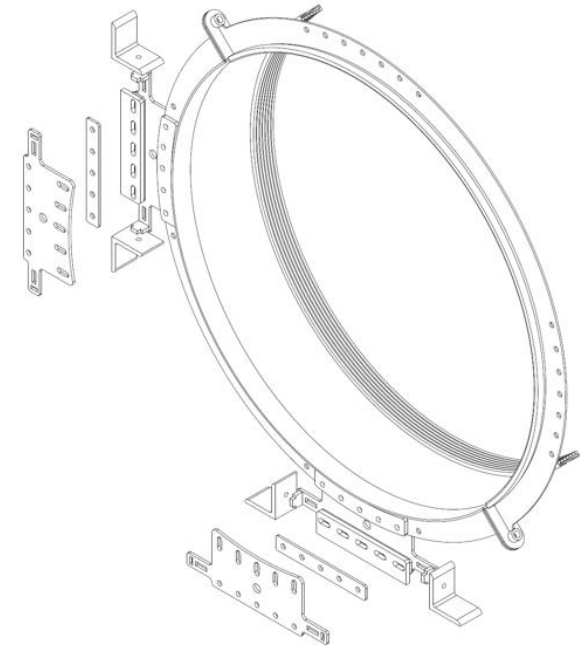
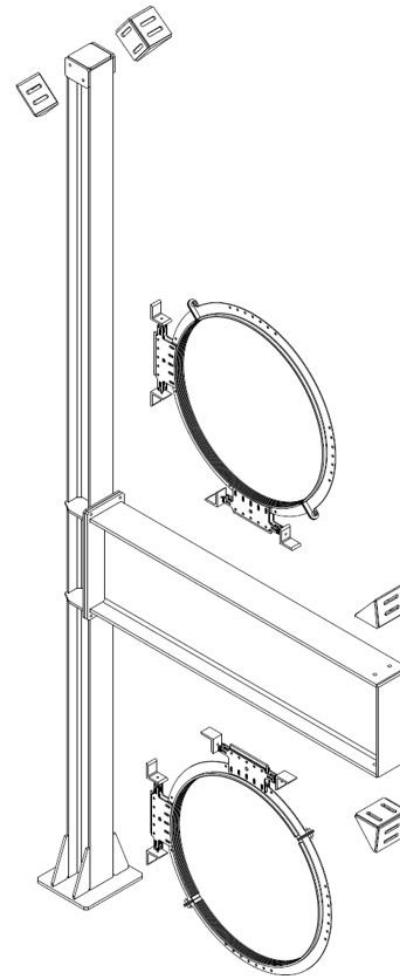




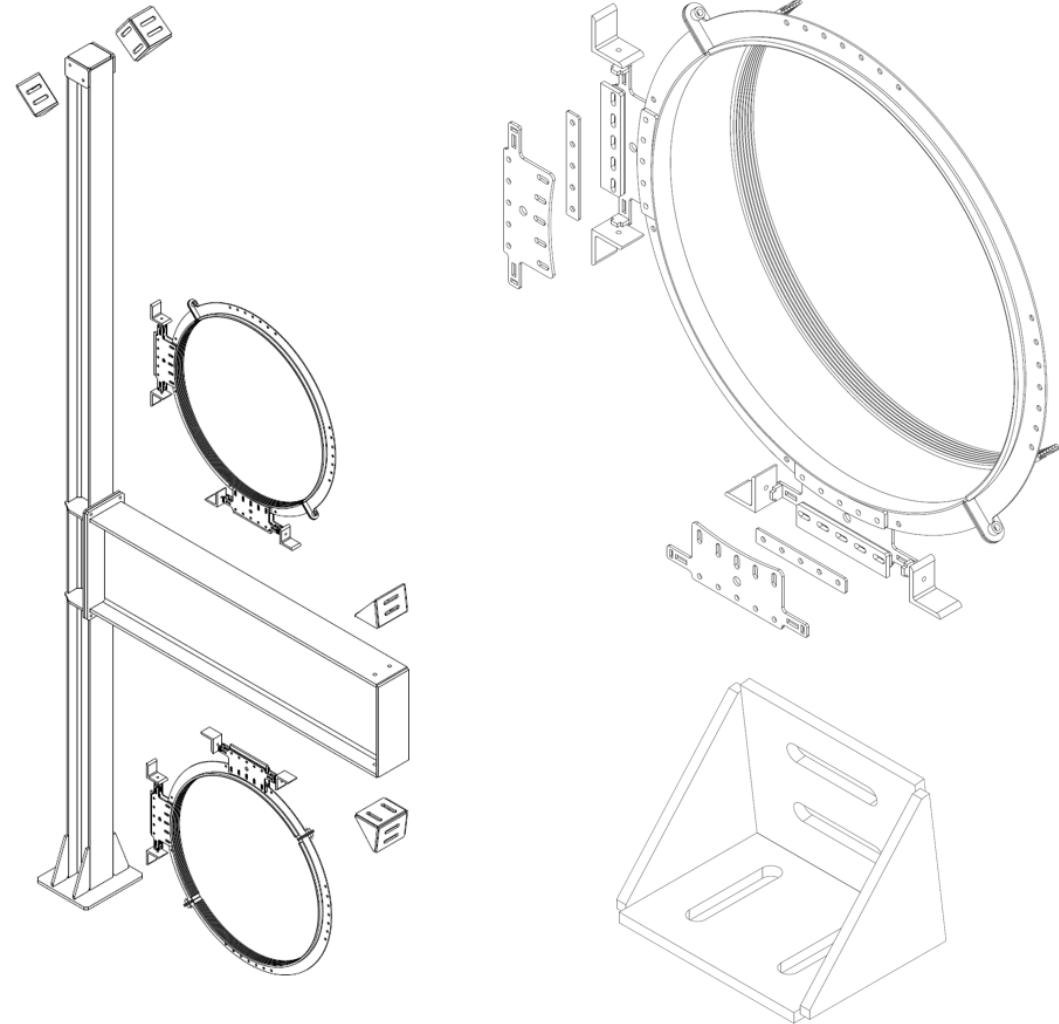
- **H-BEAMS: VERTICAL + HORIZONTAL → CARRY 2 TUBES (TOP/BOTTOM)**

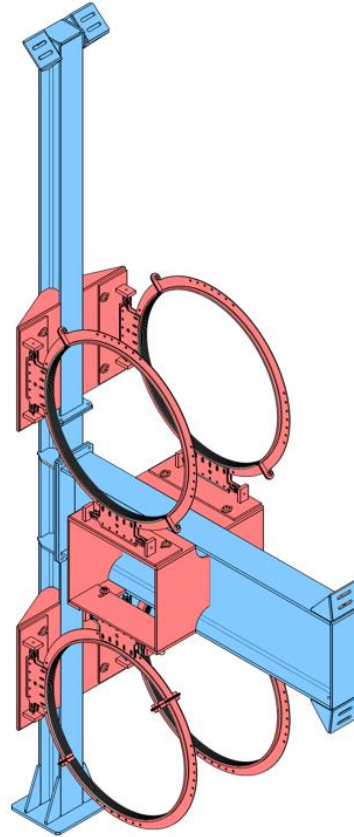


- **H-BEAMS: VERTICAL + HORIZONTAL → CARRY 2 TUBES (TOP/BOTTOM)**
- **RINGS CLAMP THE TUBE, WITH ADJUSTABLE JAWS → ENSURE ALIGNMENT & TOLERANCES**
- **ELECTRICAL + MECHANICAL ISOLATION DURING BAKE-OUT (UP TO 200 °C)**

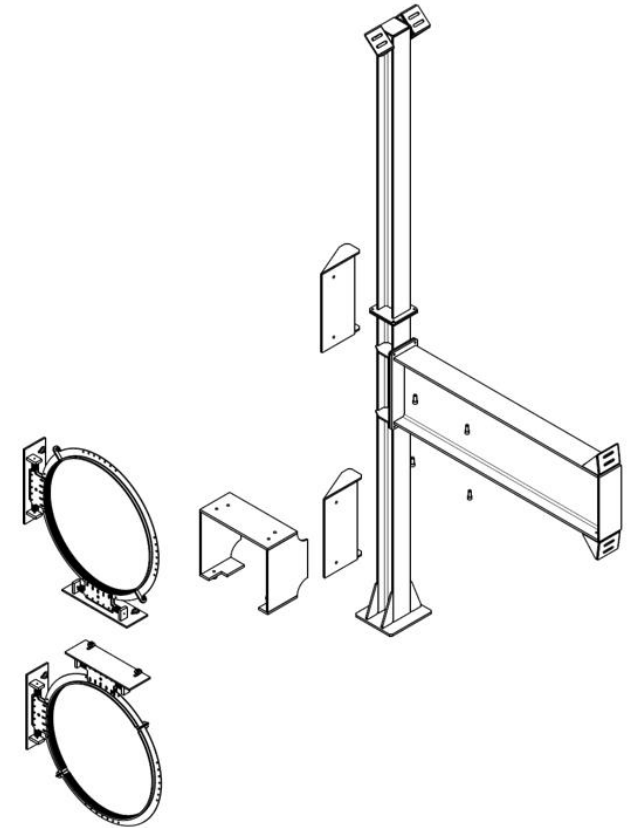
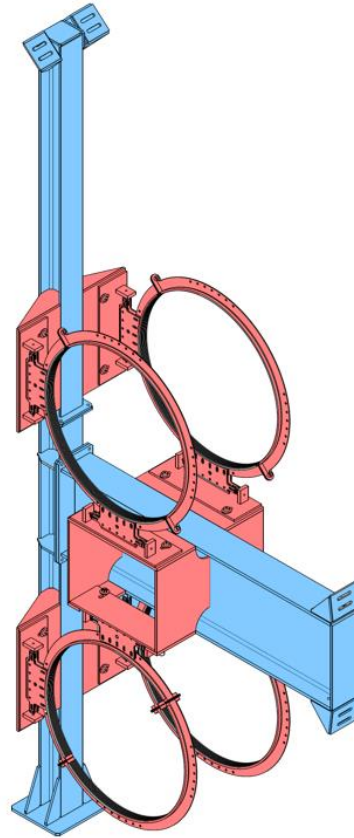


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- **ANCHORED AT FLOOR (BASE PLATE) AND TUNNEL WALL (SLIDING BRACKETS) → COMPENSATE TUNNEL IRREGULARITIES**

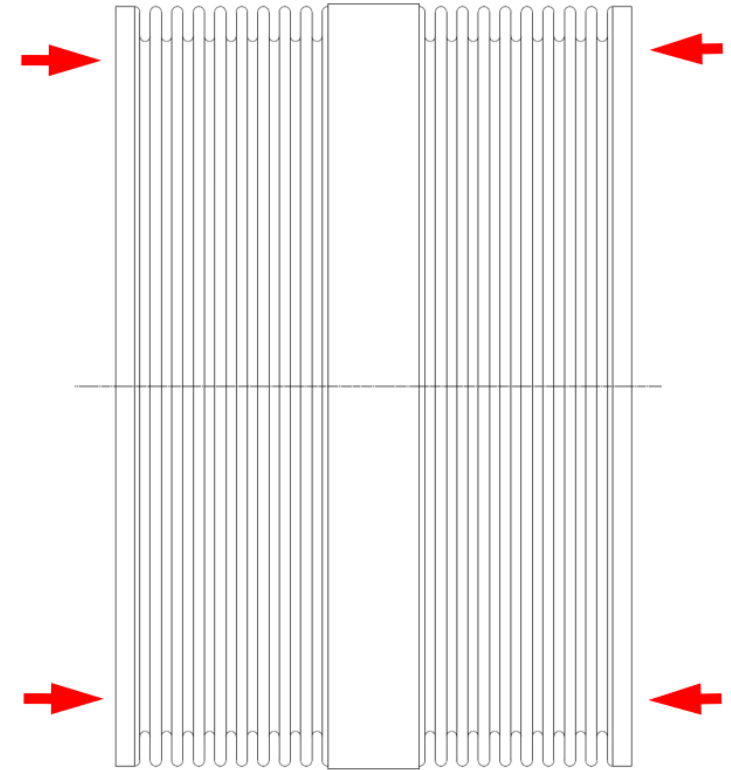
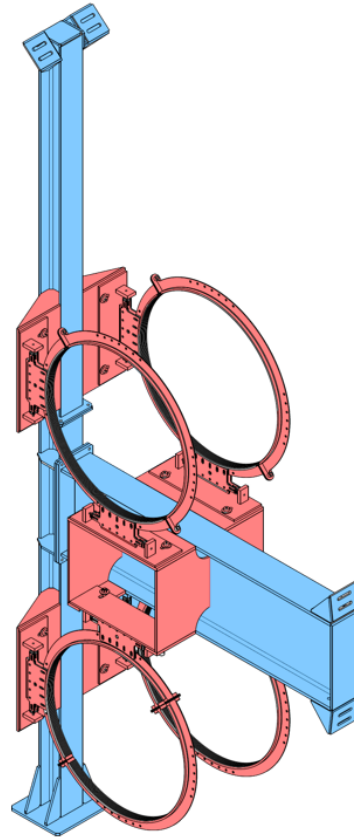




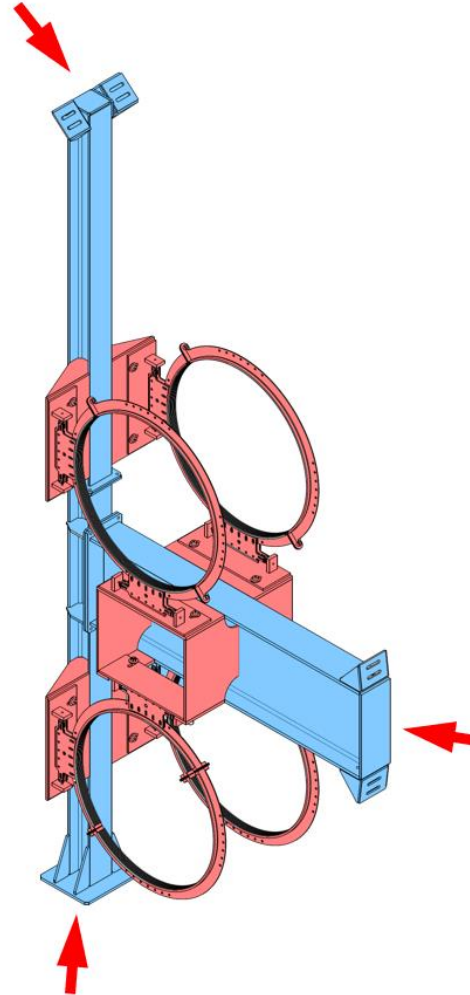
- SLIDING SUPPORT ALLOWS TUBE EXPANSION
(~20 MM DURING BAKE-OUT)



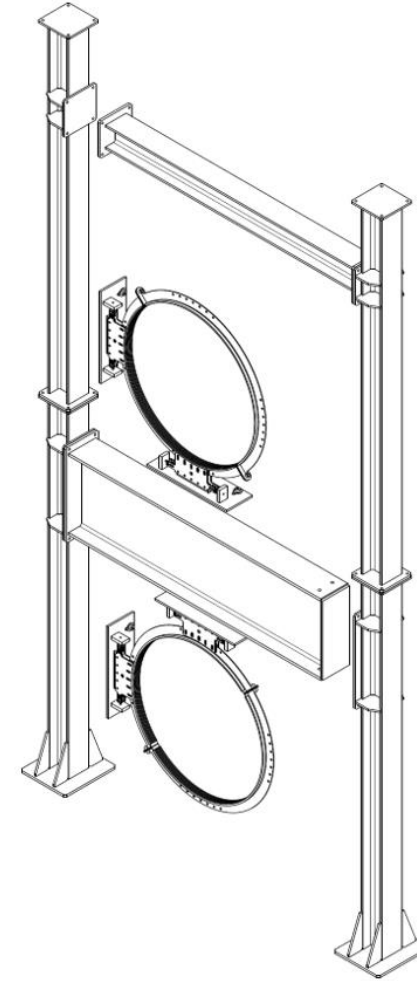
- **SLIDING SUPPORT ALLOWS TUBE EXPANSION**
(~20 MM DURING BAKE-OUT)
- **HELPS BELLOWS COMPRESS UNDER THERMAL DILATION**
- **DESIGN INDEPENDENT FROM BELLOWS →**
AVOIDS EXCESSIVE TORQUE (WEIGHT
DEFLECTION + SPIRAL STIFFENER TORSION)



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- DESIGN INDEPENDENT FROM BELLOWS → AVOIDS EXCESSIVE TORQUE (WEIGHT DEFLECTION + SPIRAL STIFFENER TORSION)
- OPTIONAL DAMPING PLATES → REDUCE VIBRATIONS AND TUBE DISPLACEMENT

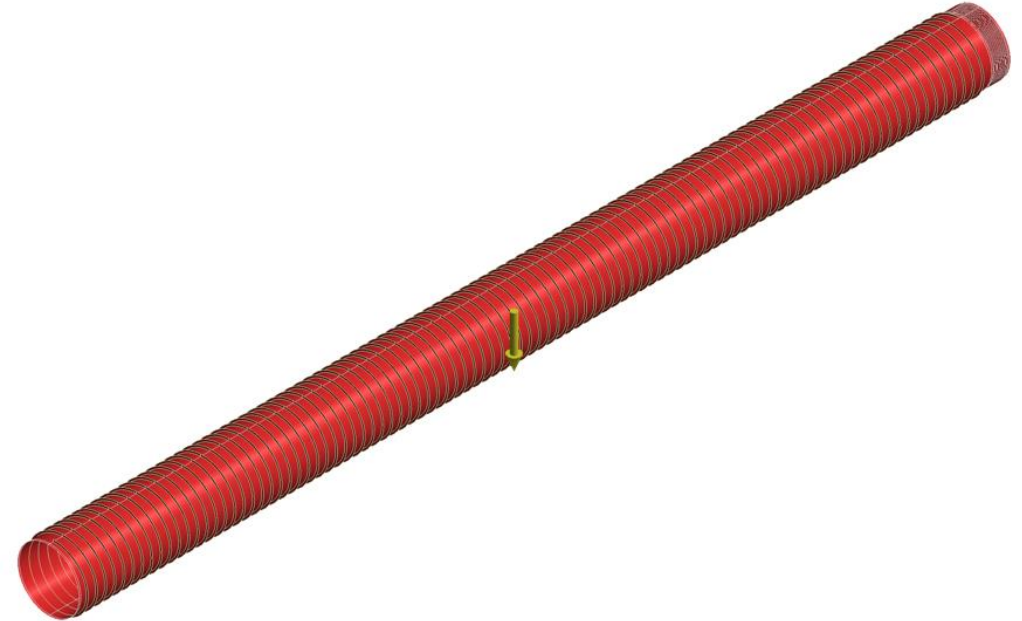


- **MODULAR DESIGN:** COMPONENTS CAN BE REUSED IN NEW CONFIGURATIONS (*“LIKE LEGO BRICKS”*)
- **CAD SKELETON METHOD** → EASY DIMENSIONAL CHANGES, AUTOMATIC UPDATES OF ASSEMBLIES
- **ENABLES ADAPTATION TO FUTURE PILOT SECTOR AT CERN (2026)**



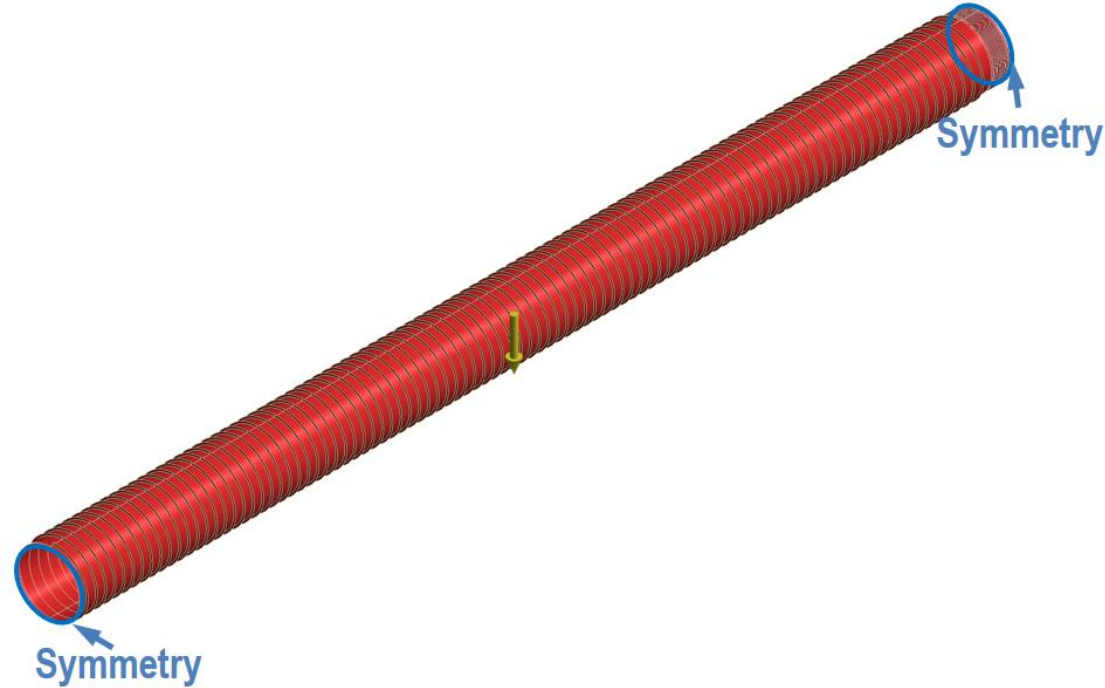
THERMAL EXPANSION & DEFORMATION MODEL

- TUBE WITH BELLOWS (ONE END) + 80 KG DISTRIBUTED LOAD (THERMAL INSULATION)



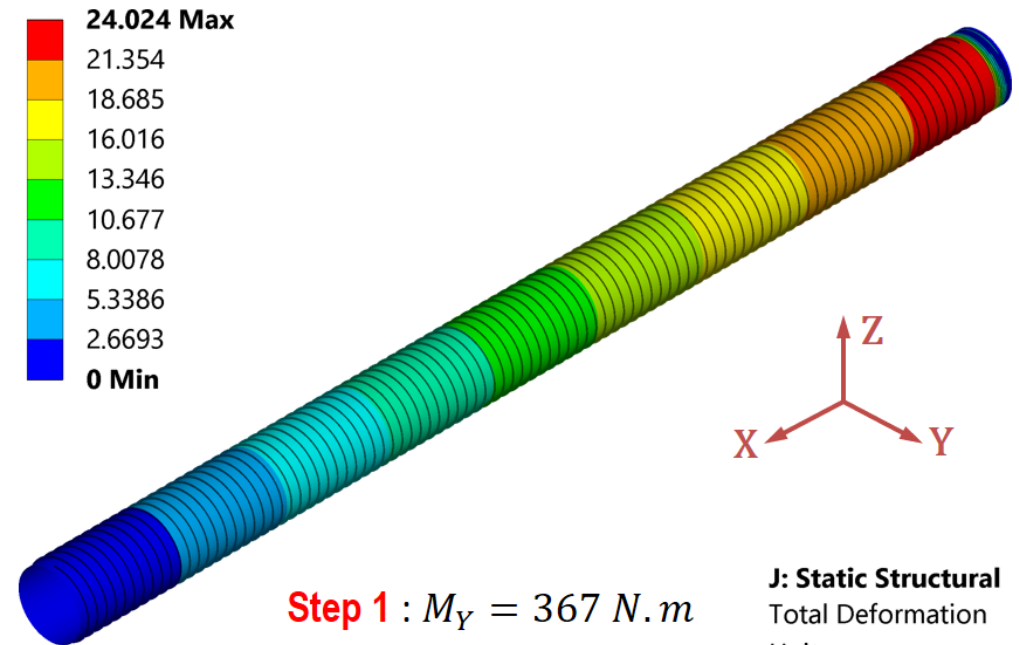
THERMAL EXPANSION & DEFORMATION MODEL

- TUBE WITH BELLOWS (ONE END) + 80 KG DISTRIBUTED LOAD (THERMAL INSULATION)
- SYMMETRY CONDITIONS AT BOTH ENDS + RINGS BLOCKING RADIAL EXPANSION
- SEQUENTIAL LOAD STEPS: GRAVITY $\rightarrow$ $+150\text{ }^{\circ}\text{C}$ $\rightarrow$ VACUUM (-1 BAR)



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- SEQUENTIAL LOAD STEPS: GRAVITY $\rightarrow$ +150 °C $\rightarrow$ VACUUM (-1 BAR)
- OUTPUTS:
 - TUBE ELONGATION & BELLOW COMPRESSION
 - TORQUE ON THE BELLOW (WEIGHT + THERMAL + STIFFENING SPIRAL)
-  LED TO DESIGN CHANGE: SUPPORT WITH SLIDING SYSTEM



Step 1 : $M_Y = 367 \text{ N.m}$

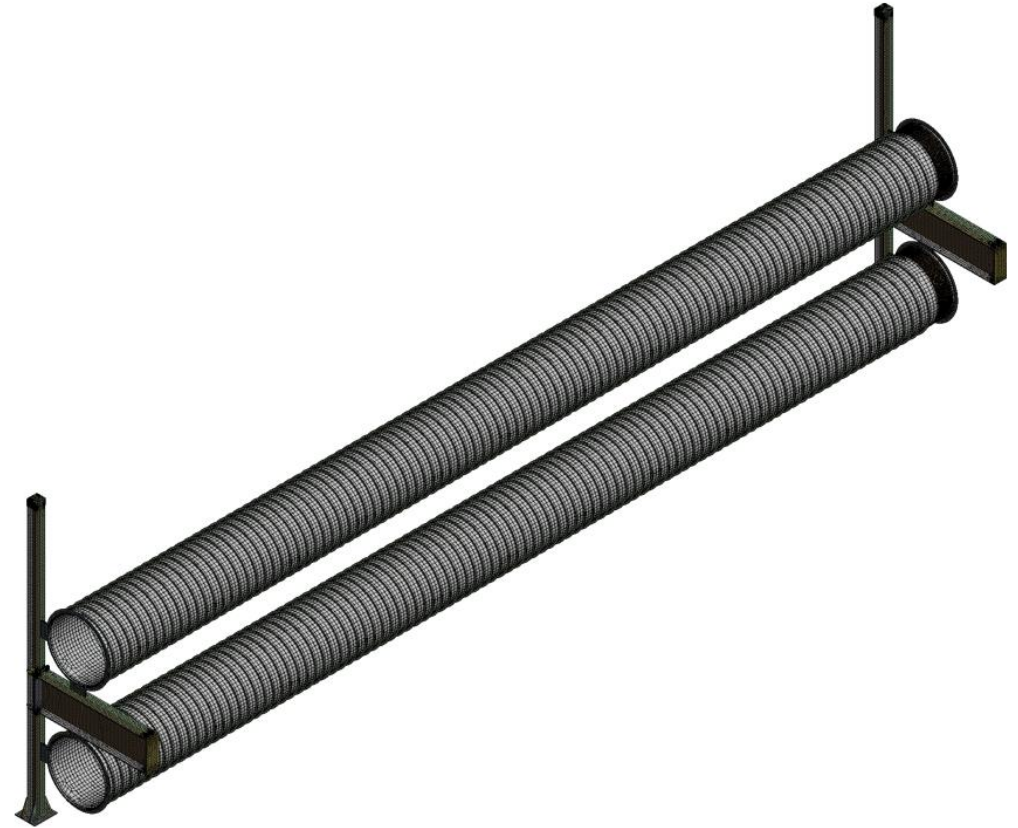
Step 2 : $M_Y = 347 \text{ N.m}$

Step 3 : $M_X = 413 \text{ N.m}$
 $M_Y = 259 \text{ N.m}$

J: Static Structural
Total Deformation
Unit: mm
Time: 3 s

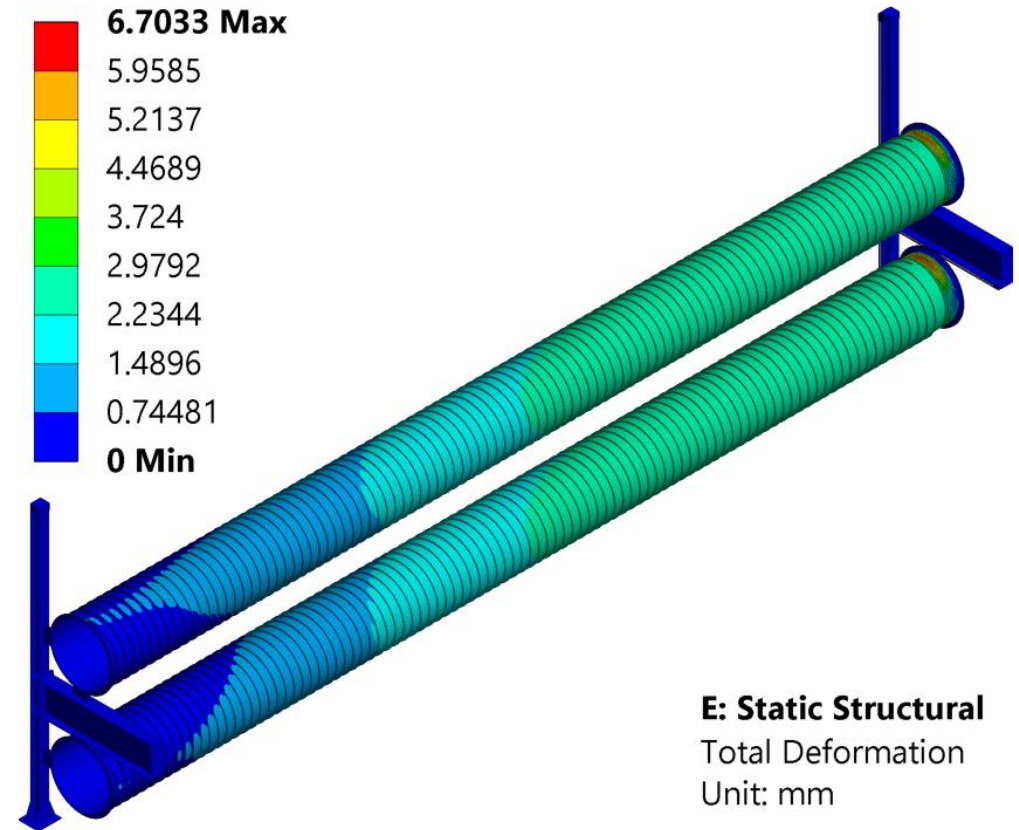
STATIC DEFORMATION & BUCKLING ANALYSIS

- TWO TUBES WITH SUPPORTS (OLD DESIGN, CONNECTED THROUGH BELLOWS).
- LOADS: GRAVITY + VACUUM



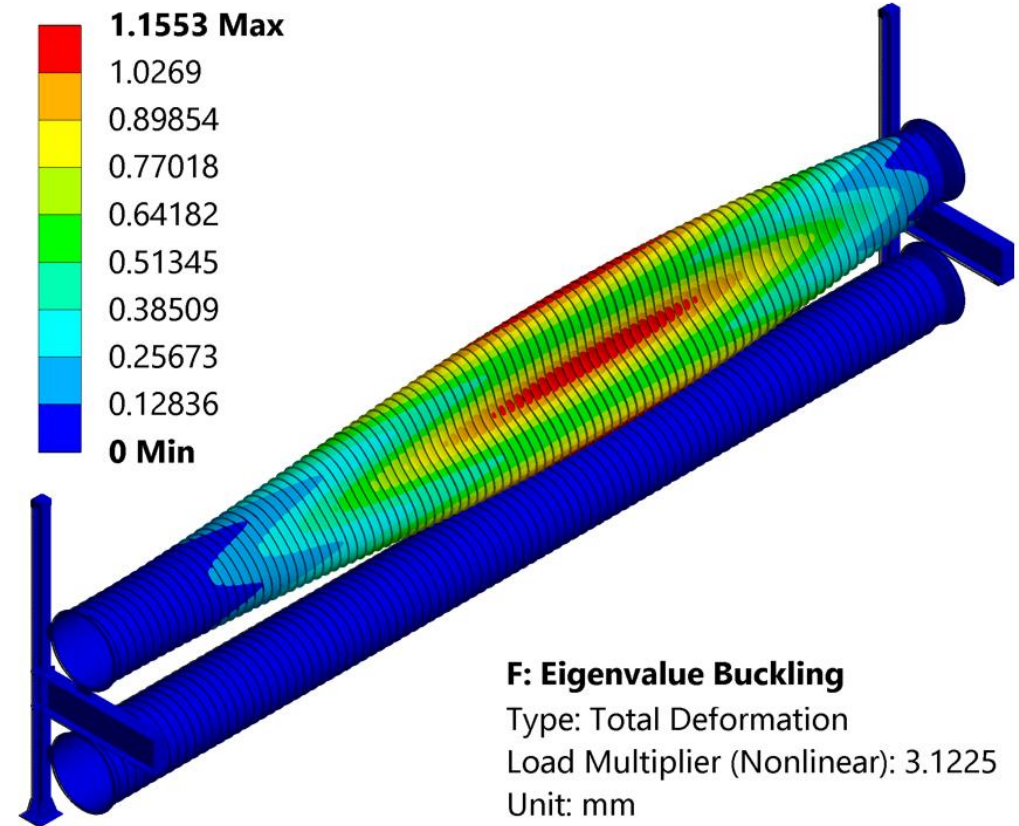
STATIC DEFORMATION & BUCKLING ANALYSIS

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- MAX DEFLECTION: < 7 MM OVER 15 M (< 3 MM WITHOUT BELLOW)



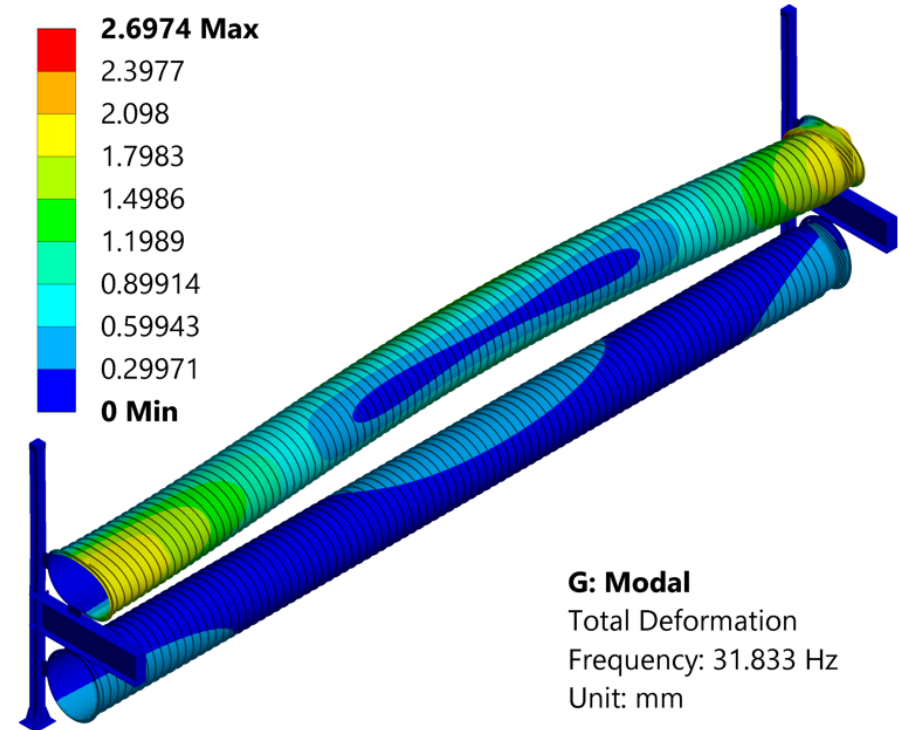
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- BUCKLING ANALYSIS PERFORMED FROM STATIC EQUILIBRIUM (SAFETY COEF.: 4.1)
-  DESIGN VALIDATION CHOICE : NO RISK OF COLLAPSE UNDER OPERATING CONDITIONS



MODAL BEHAVIOUR & HARMONIC RESPONSE

- MODAL ANALYSIS UP TO 100 Hz (2% DAMPING)
- EXCITATIONS APPLIED AT SUPPORT FIXATIONS IN X, Y, Z (1 MM DISPLACEMENT)



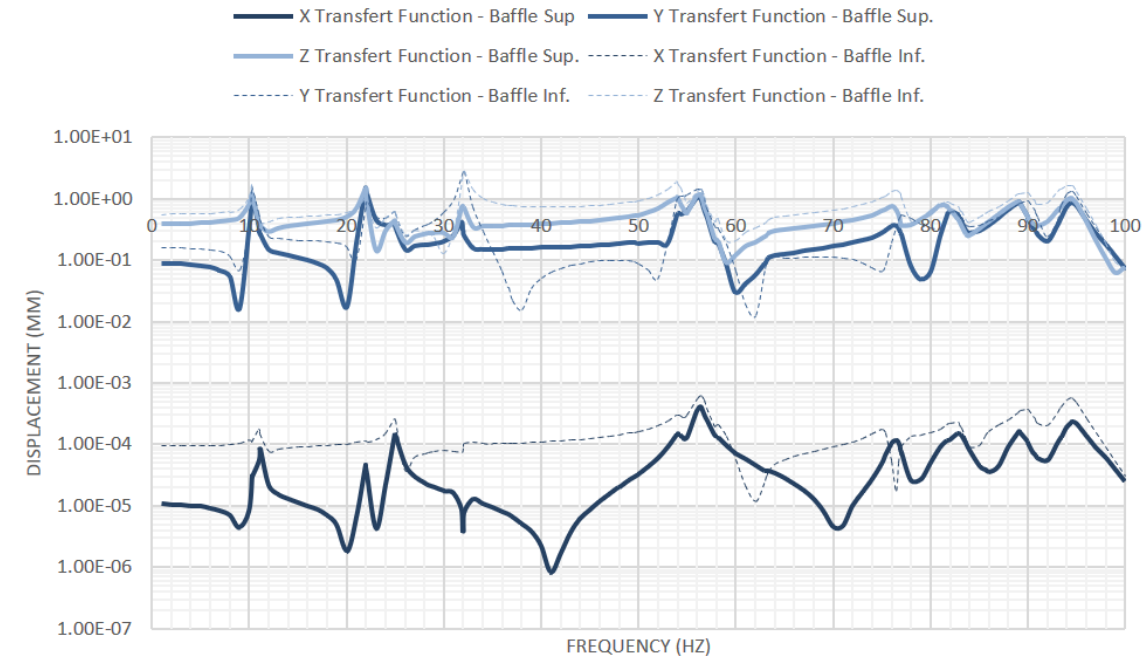
70 FIRST MODES CALCULATED (0 → 100 Hz) :

- 37 FROM THE BELLOWS
- 28 FROM THE TUBES
- 5 FROM THE SUPPORTS

MODAL BEHAVIOUR & HARMONIC RESPONSE

- **MODAL ANALYSIS UP TO 100 Hz (2% DAMPING)**
- **EXCITATIONS APPLIED AT SUPPORT FIXATIONS IN X, Y, Z (1 MM DISPLACEMENT)**
- **TRANSFER FUNCTIONS COMPUTED AT BAFFLES (END OF TUBES)**

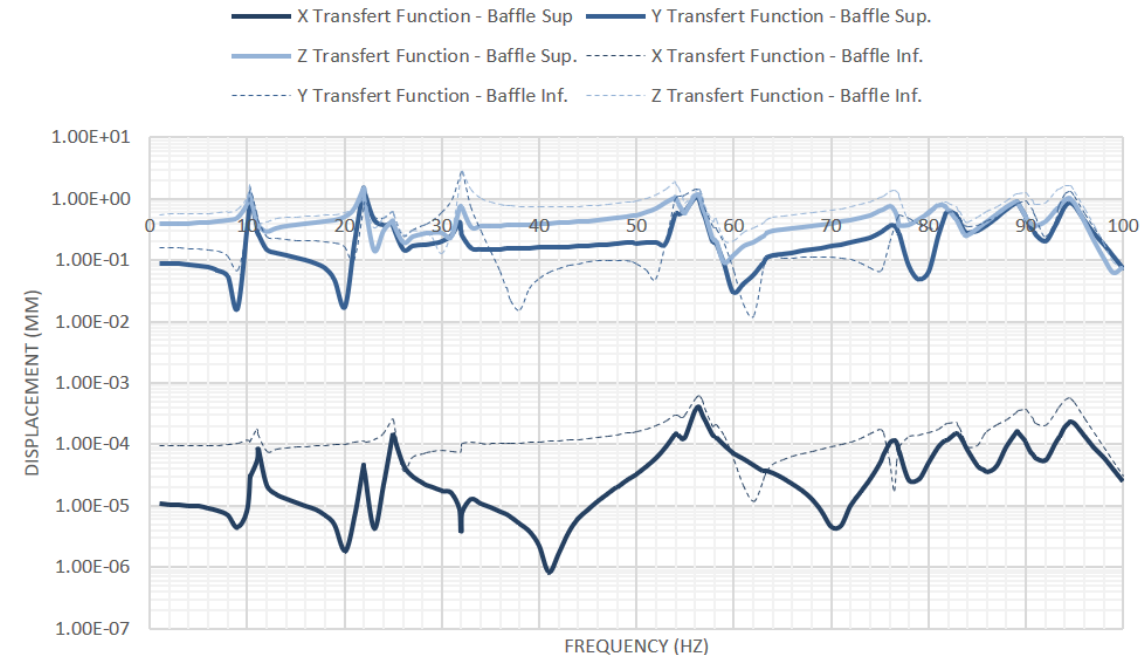
Baffle Displacement for 1 mm X excitation



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- **TRANSFER FUNCTIONS COMPUTED AT BAFFLES (END OF TUBES)**
- **🔗 VALIDATION: THESE PROVISIONAL RESULTS ARE GIVEN FOR A 1 MM EXCITATION. THEY MUST BE MULTIPLIED BY THE SEISMIC SPECTRUM MEASURED AT THE FINAL INSTALLATION SITE TO ENSURE THAT THEY ARE ACCEPTABLE**

Baffle Displacement for 1 mm X excitation



PROTOTYPE TUBE UNDER FABRICATION

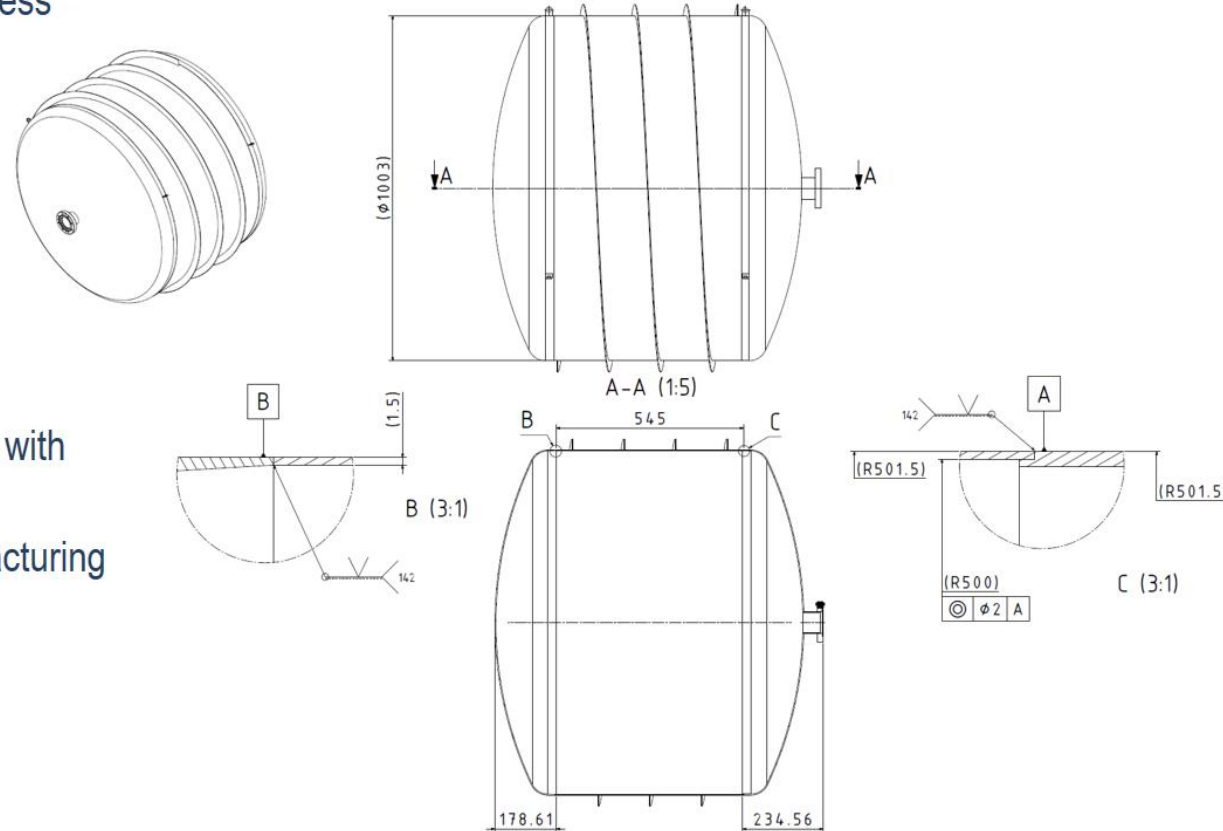
- **Dimensions:** 0.5 m length, $\varnothing 1$ m internal, 1.5 mm thickness
- **Spiral stiffener:** 2 mm, 150 mm pitch
- **Ends:** domed caps, one with pumping port
- **Material:** stainless steel 441

Objectives:

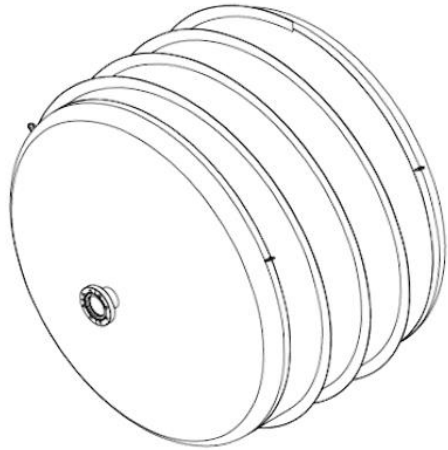
- Validate leak-tightness down to 10^{-8} mbar
- Test feasibility of rolling/soldering thin 1.5 mm sheet with stiffener & domed ends
- Ensure no distortion, cracks, or leaks during manufacturing

Status:

- Sheets delivered, welding procedure written
- Fabrication ongoing during this workshop



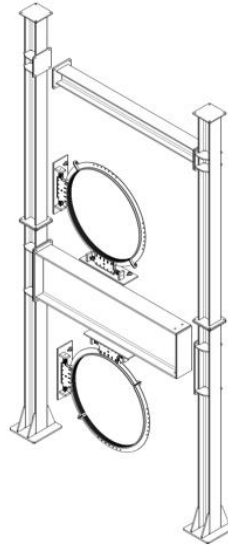
2025 - 2026



PROTOTYPE



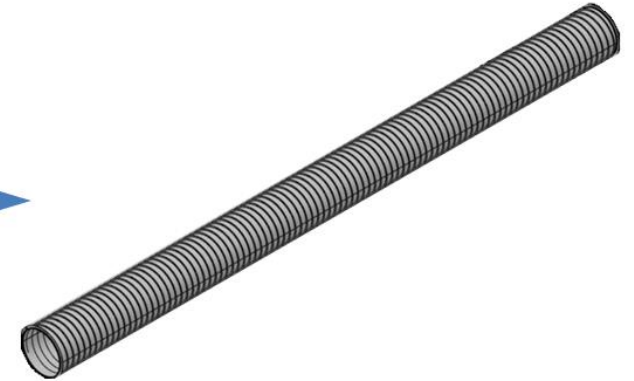
2026



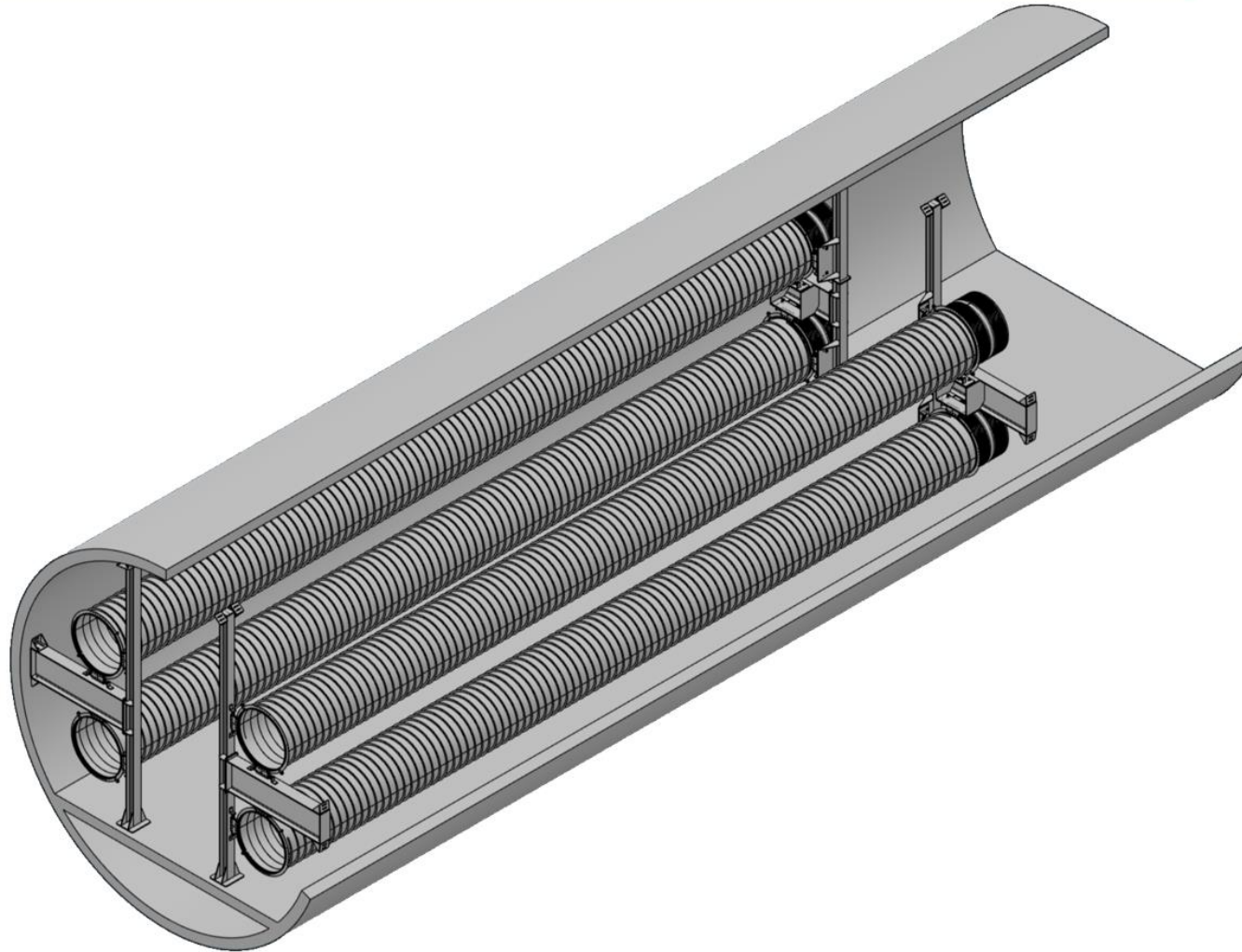
**CERN PILOTE SECTOR
EVOLUTION
+
NEW SUPPORTS**



2027



**NEW PILOT SECTOR
DESIGN**



THANK YOU FOR YOUR ATTENTION