Laboratoire d'Annecy de Physique des Particules

Vacuum Tube Design for the Einstein Telescope

Alexandre Lacroix (CNRS LAPP)

CE-ET Beamtube workshop III

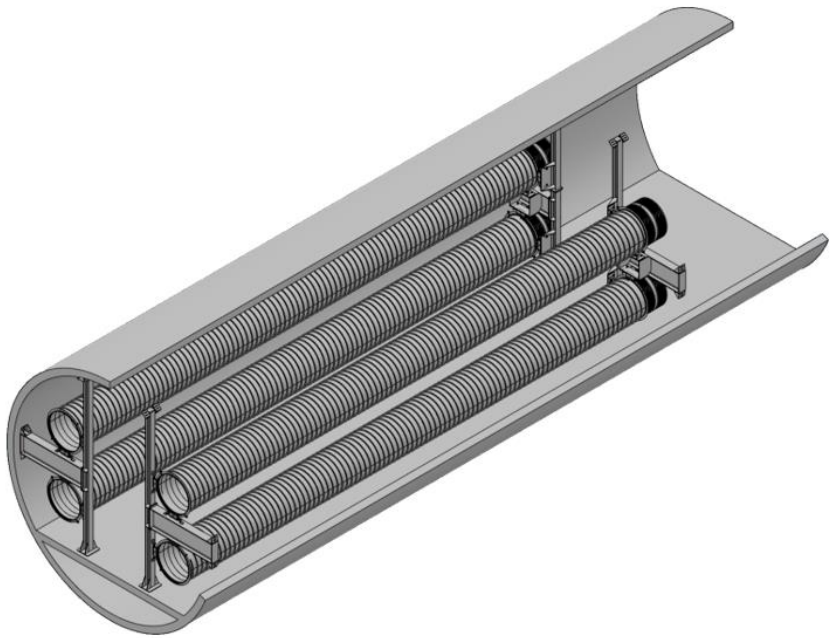
01/02/2025

cnrs

Université Savoie Mont Blanc

SUMMARY

- TUBE DESIGN
- SUPPORT
- SIMULATION

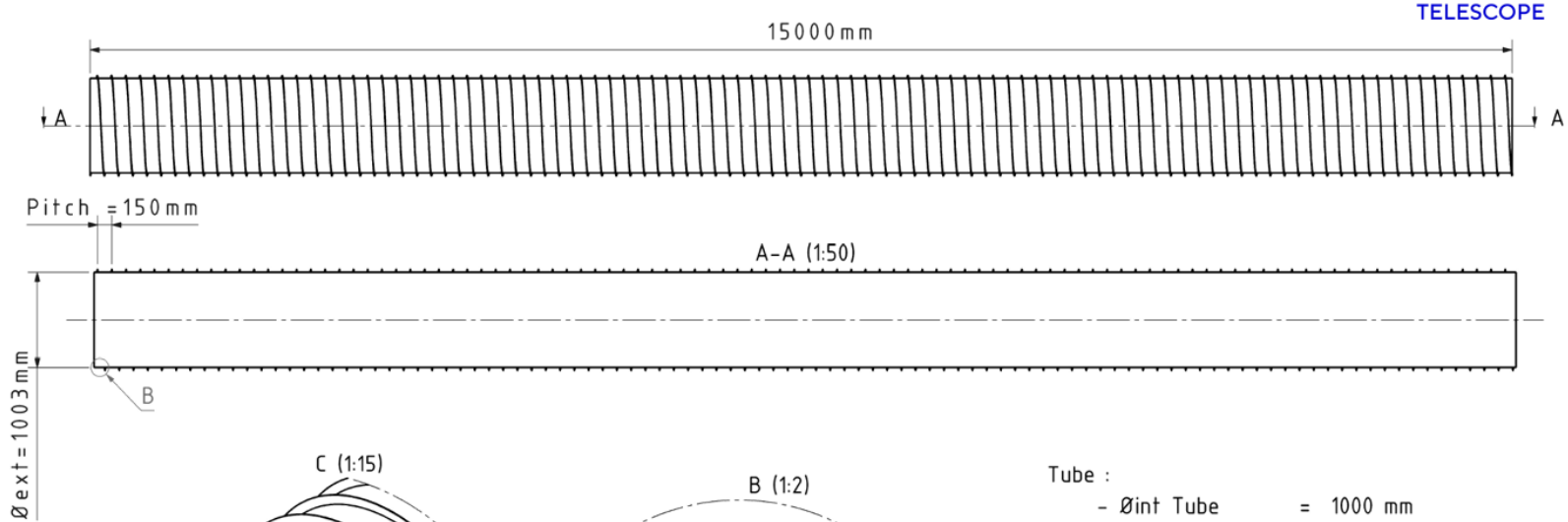


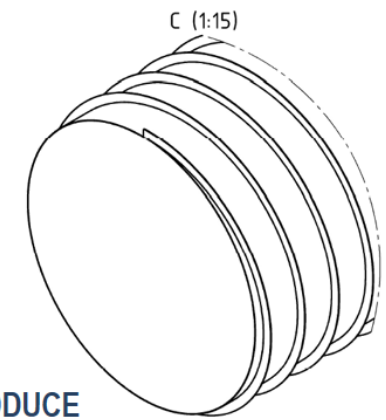
- ACTION IN PROGRESS AND TO BE CONTINUED

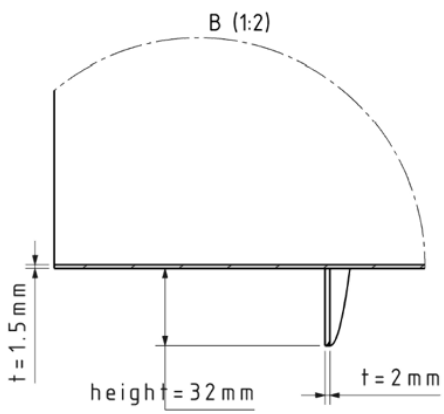
Tube Design – Lightweight and Optimized

EINSTEIN TELESCOPE

- **Length :**
  - 15 m,
  - Φint : 1 m,
  - wall thickness: 1.5 mm
- **External spiral stiffener :**
  - 2 mm thickness,
  - pitch 150 mm







Tube :
- Øint Tube = 1000 mm
- Sheet Thickness = 1.5 mm

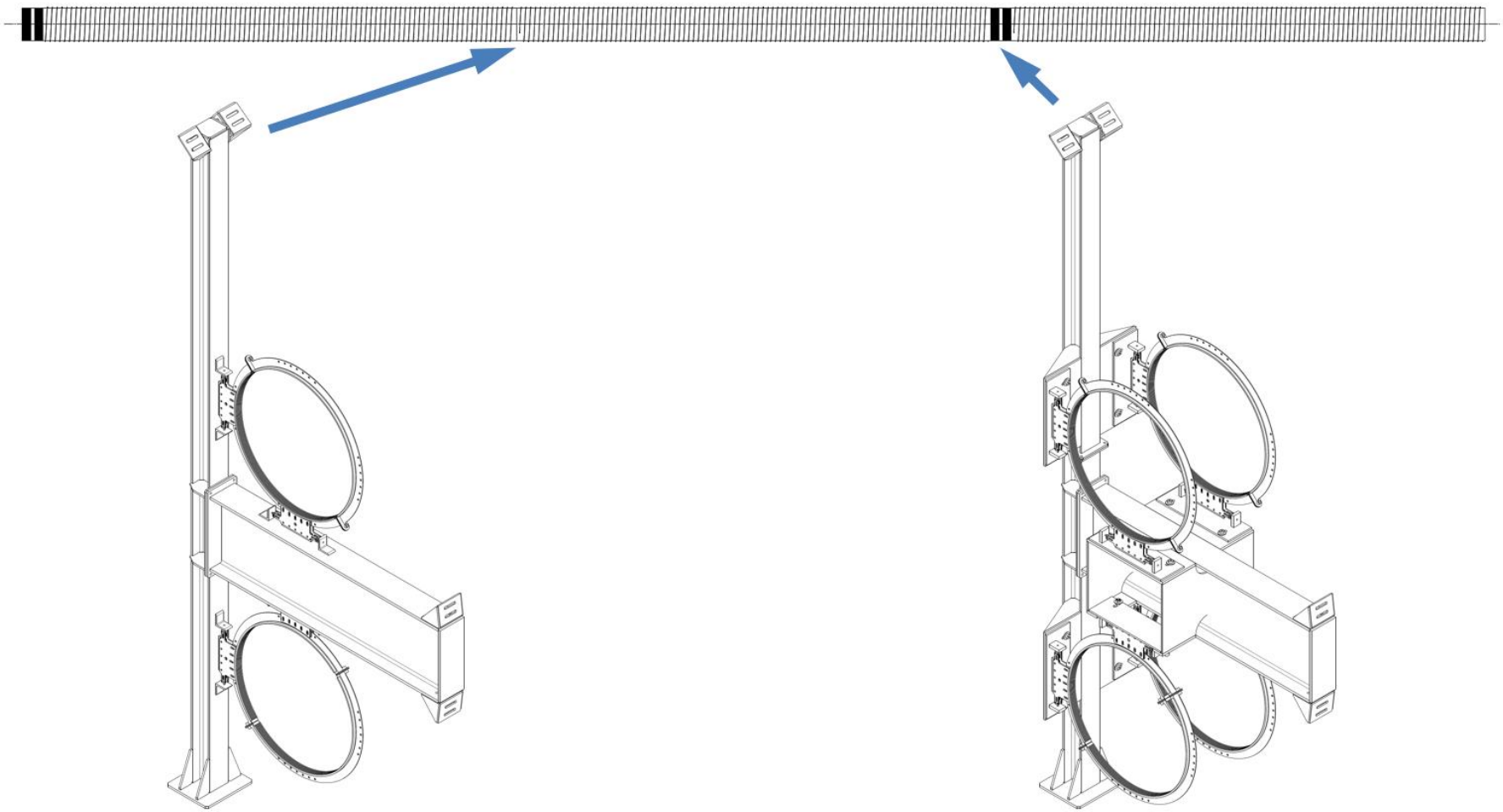
Stiffener :
- height = 32 mm
- Thickness = 2 mm
- Step = 150 mm

Material :
- Steel 441 (EN 1.4509 – X2CrTiNb 18)

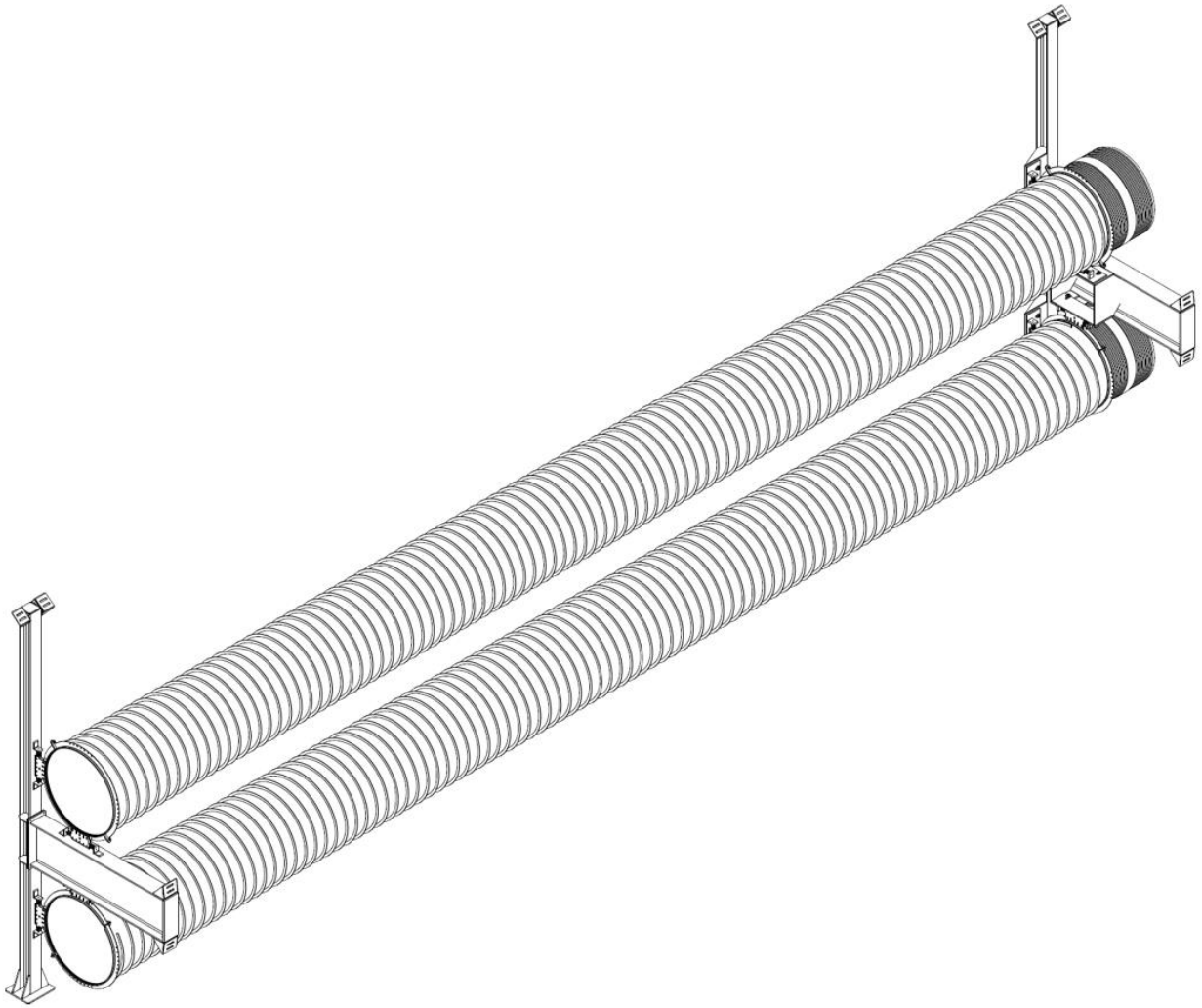
- **Total weight: ~750 kg → lightweight, reduced steel usage**
- **Cost-effective for medium-series production (120 km of tube planned)**
- **Exploits automation/robotization to produce slightly more complex geometry than Virgo**

SUPPORTS DESIGN

EINSTEIN TELESCOPE

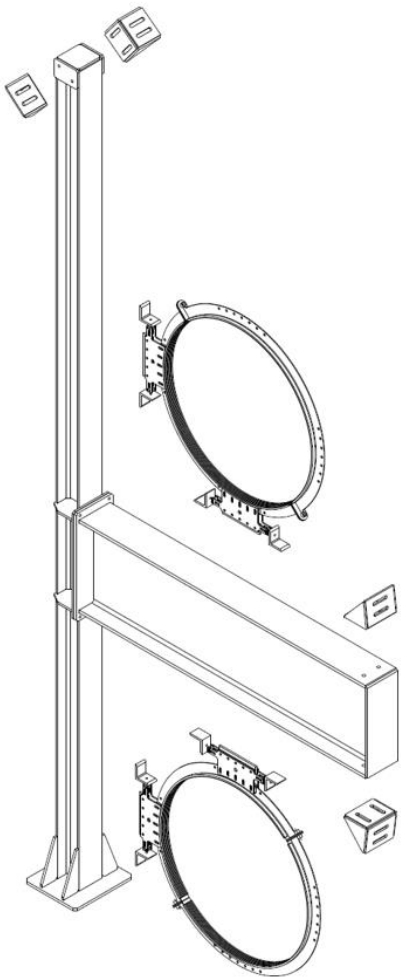


SUPPORTS DESIGN



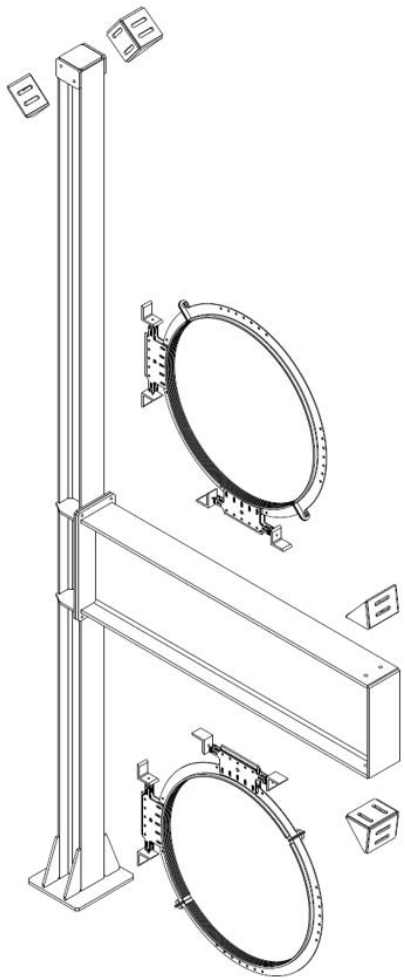
SUPPORT DESIGN – STRUCTURE & MOUNTING

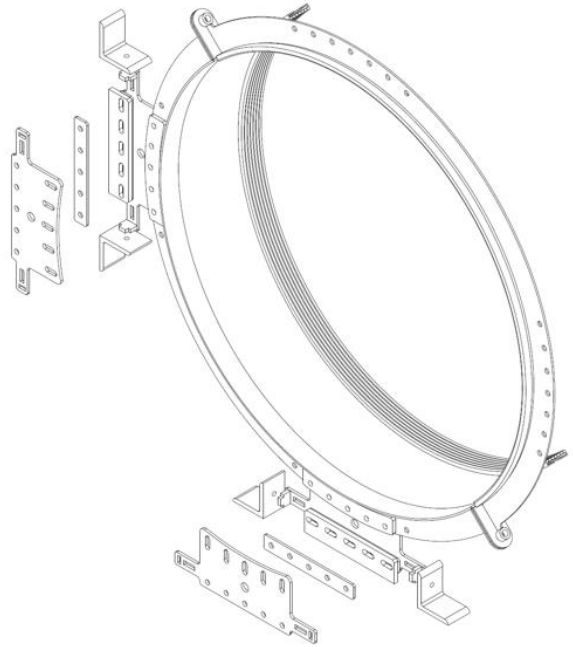
- H-BEAMS: VERTICAL + HORIZONTAL ⟶ CARRY 2 TUBES (TOP/BOTTOM)



Support Design – Structure & Mounting

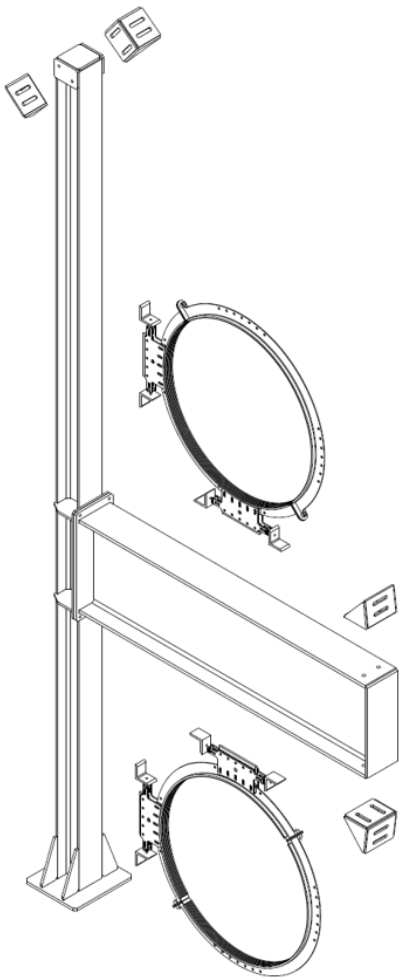
- H-beams: vertical + horizontal → carry 2 tubes (top/bottom)
- Rings clamp the tube, with adjustable jaws → ensure alignment & tolerances
- Electrical + mechanical isolation during bake-out (up to 200 °C)

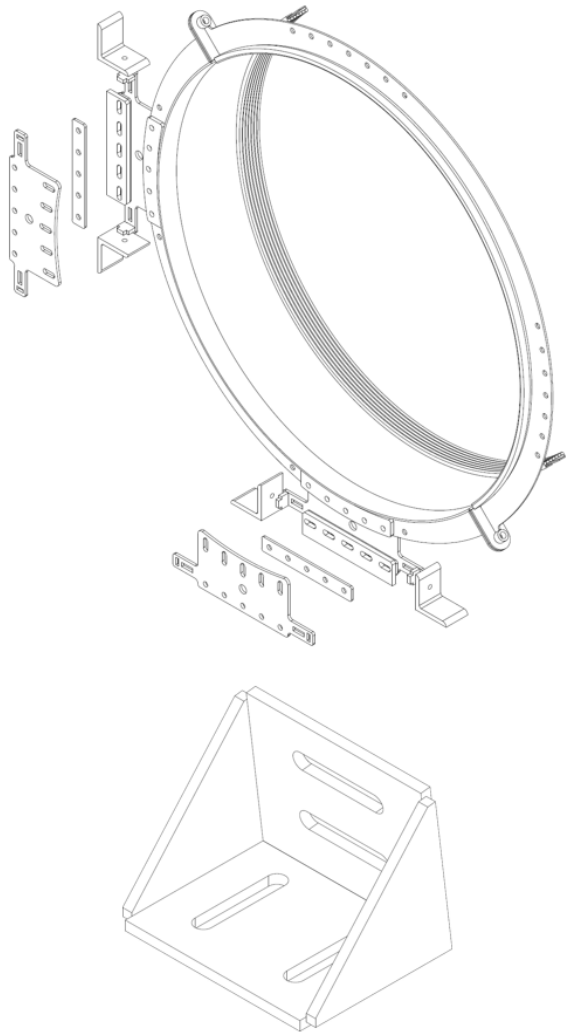




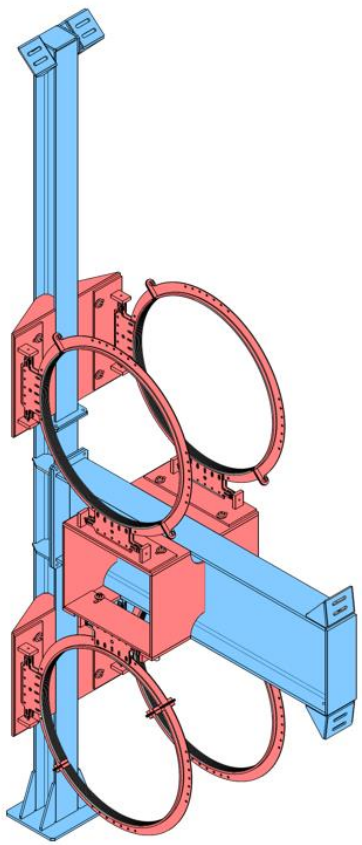
Support Design – Structure & Mounting

- 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)
- Anchored at floor (base plate) and tunnel wall (sliding brackets) → compensate tunnel irregularities





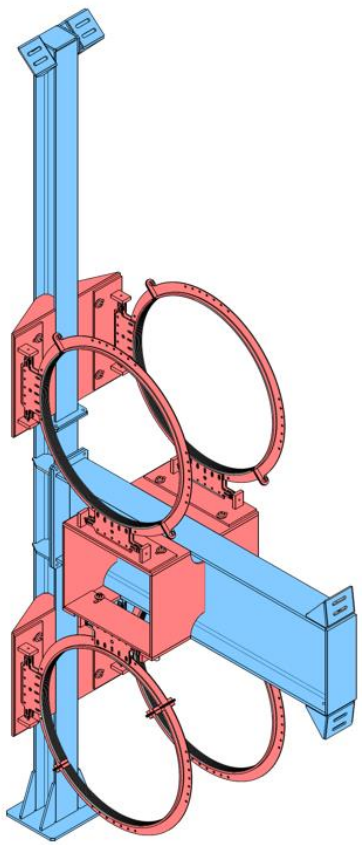
SUPPORT DESIGN – FUNCTIONAL FEATURES

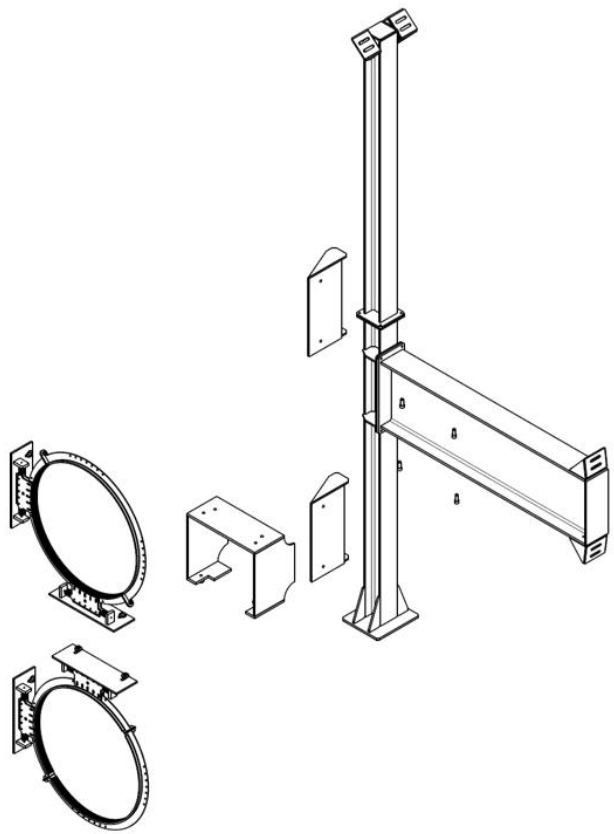


SUPPORT DESIGN – FUNCTIONAL FEATURES

EINSTEIN TELESCOPE

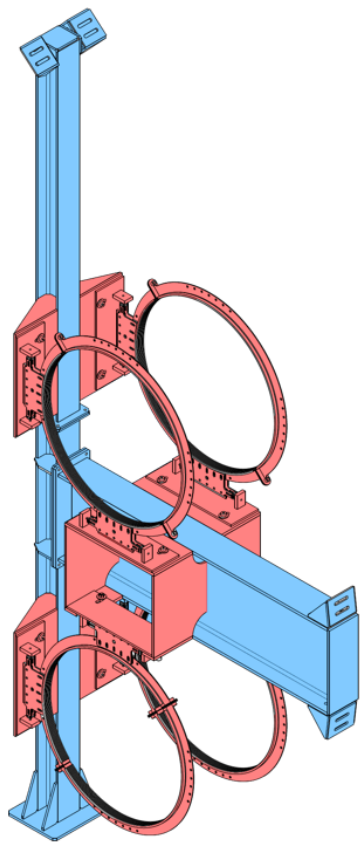
- SLIDING SUPPORT ALLOWS TUBE EXPANSION (~20 MM DURING BAKE-OUT)

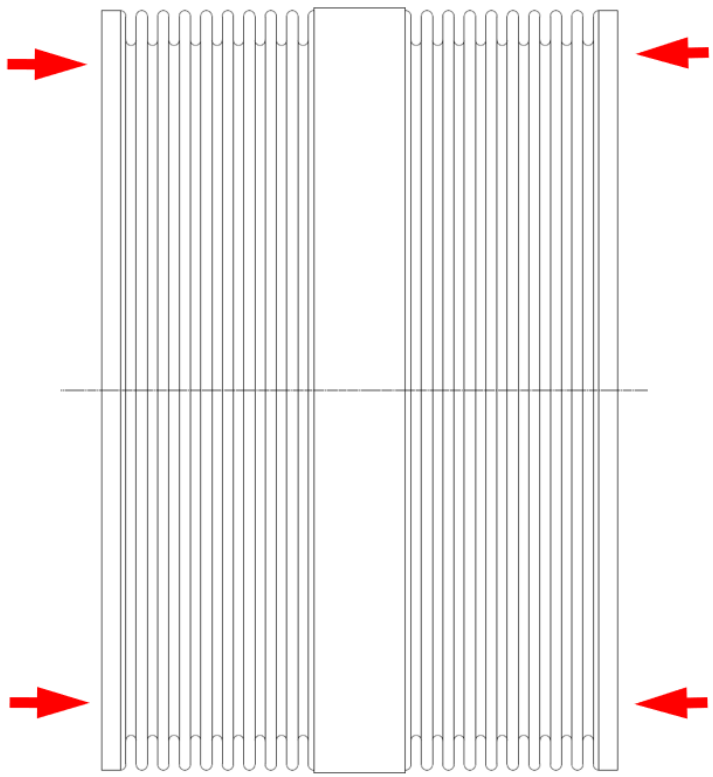




Support Design – Functional Features

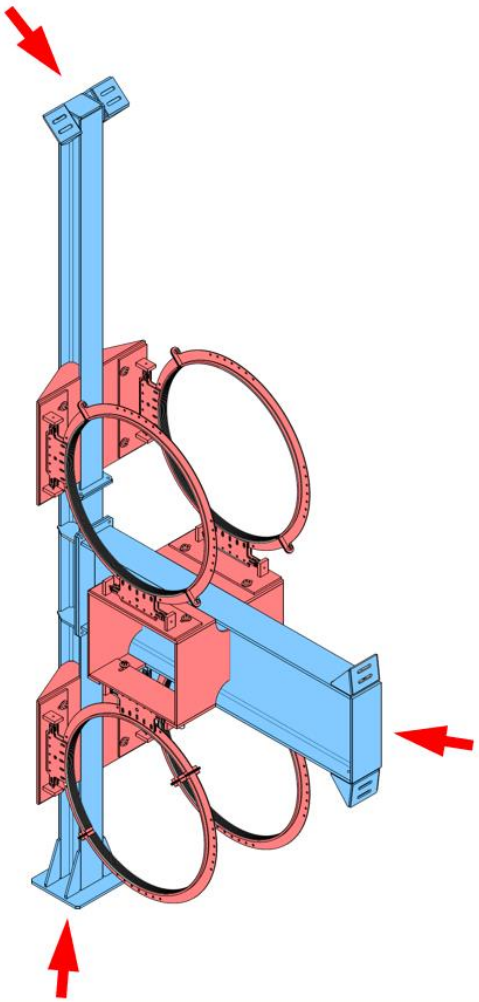
- Sliding support allows tube expansion (~20 mm during bake-out)
- Helps bellows compress under thermal dilation
- Design independent from bellows → avoids excessive torque (weight deflection + spiral stiffener torsion)





Support Design – Functional Features

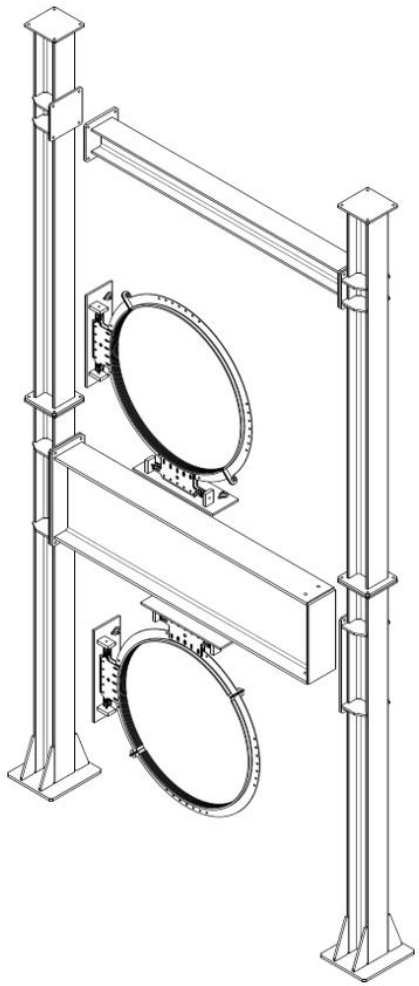
- Sliding support allows tube expansion (~20 mm during bake-out)
- Helps bellows compress under thermal dilation
- Design independent from bellows → avoids excessive torque (weight deflection + spiral stiffener torsion)
- Optional damping plates → reduce vibrations and tube displacement



SUPPORT ADAPTABILITY

EINSTEIN TELESCOPE

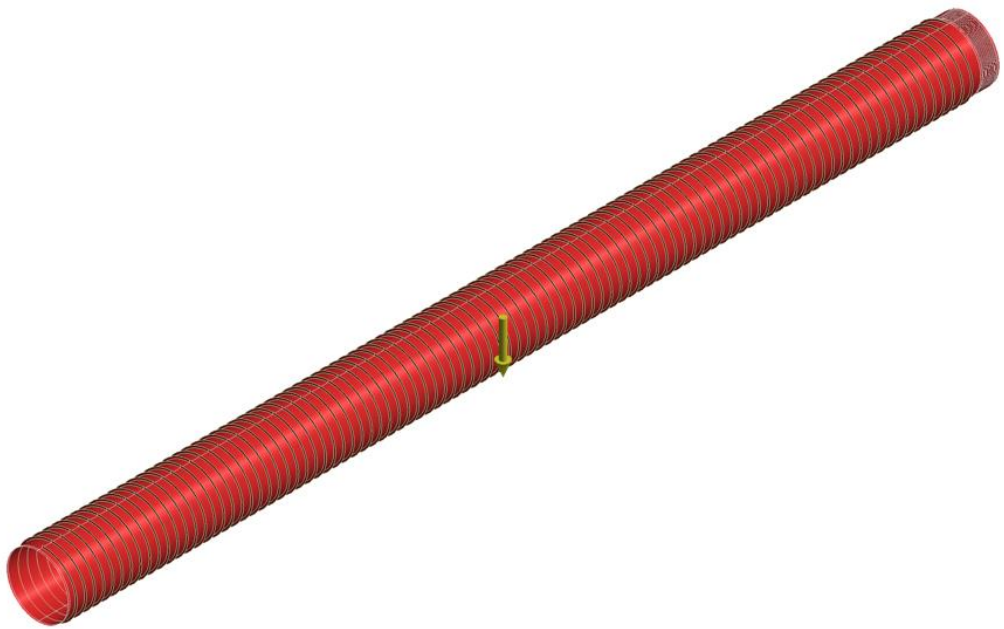
- MODULAR DESIGN: COMPONENTS CAN BE REUSED IN NEW CONFIGURATIONS (*"LIKE LEGO BRICKS"*)
- CAD SKELETON METHOD ⟶ EASY DIMENSIONAL CHANGES, AUTOMATIC UPDATES OF ASSEMBLIES
- ENABLES ADAPTATION TO FUTURE PILOT SECTOR AT CERN (2026)



EINSTEIN TELESCOPE

THERMAL EXPANSION & DEFORMATION MODEL

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



EINSTEIN TELESCOPE

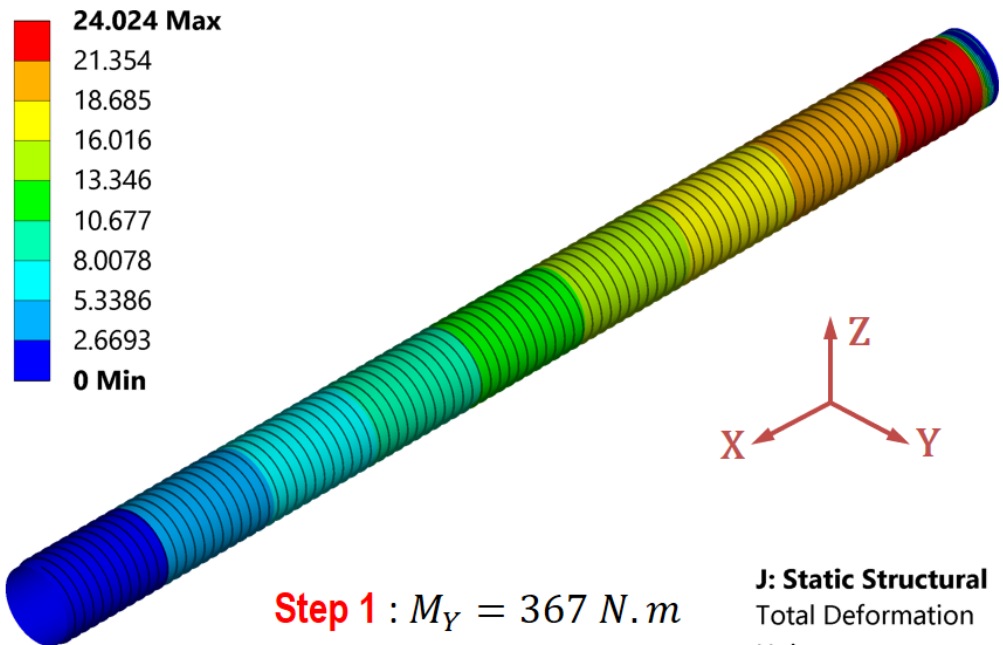
THERMAL EXPANSION & DEFORMATION MODEL

- TUBE WITH BELLOWS (ONE END) + 80 KG DISTRIBUTED LOAD (THERMAL INSULATION)
- SYMMETRY CONDITIONS AT BOTH ENDS + RINGS BLOCKING RADIAL EXPANSION
- SEQUENTIAL LOAD STEPS: GRAVITY → +150 °C → VACUUM (-1 BAR)

THERMAL EXPANSION MODEL

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 ⟶ +150 °C ⟶ 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 : $M_Y = 367\ N.m$

Step 2 : $M_Y = 347\ N.m$

Step 3 : $M_X = 413\ N.m$, $M_Y = 259\ N.m$

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

SUPPORT MODEL – STATIC & BUCKLING

EINSTEIN TELESCOPE

STATIC DEFORMATION & BUCKLING ANALYSIS

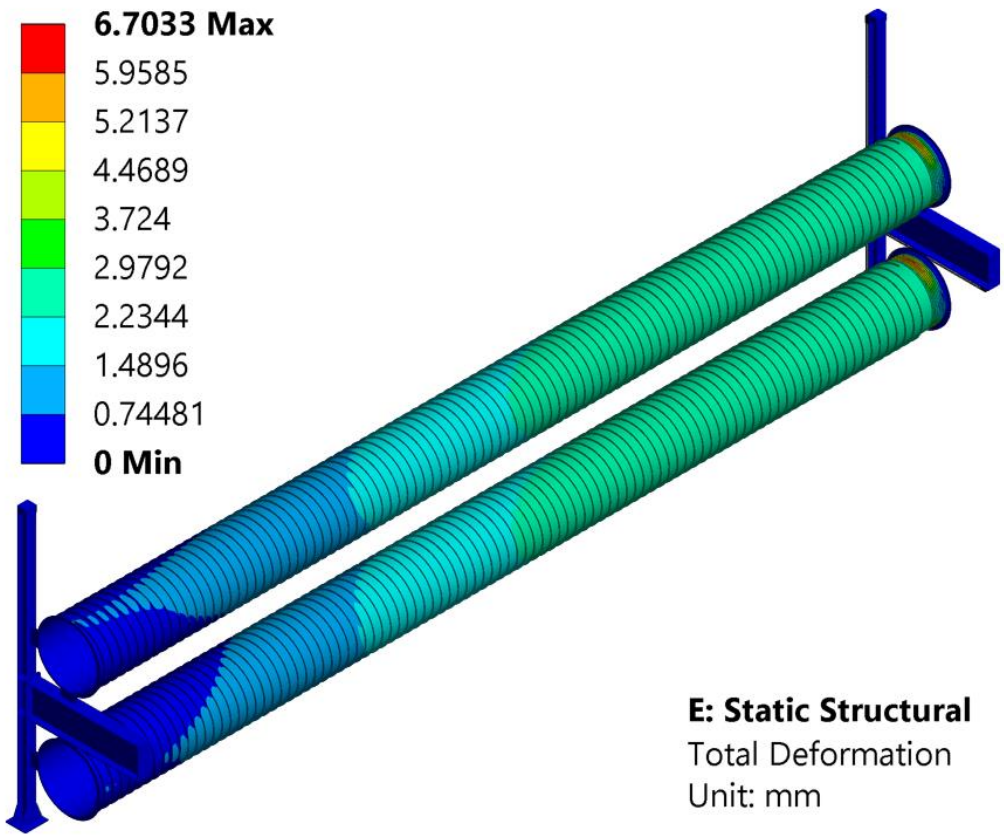
- TWO TUBES WITH SUPPORTS (OLD DESIGN, CONNECTED THROUGH BELLOWS).
- LOADS: GRAVITY + VACUUM

SUPPORT MODEL – STATIC & BUCKLING

EINSTEIN TELESCOPE

STATIC DEFORMATION & BUCKLING ANALYSIS

- TWO TUBES WITH SUPPORTS (OLD DESIGN, CONNECTED THROUGH BELLOWS).
- LOADS: GRAVITY + VACUUM
- MAX DEFLECTION: < 7 MM OVER 15 M (< 3 MM WITHOUT BELLOW)

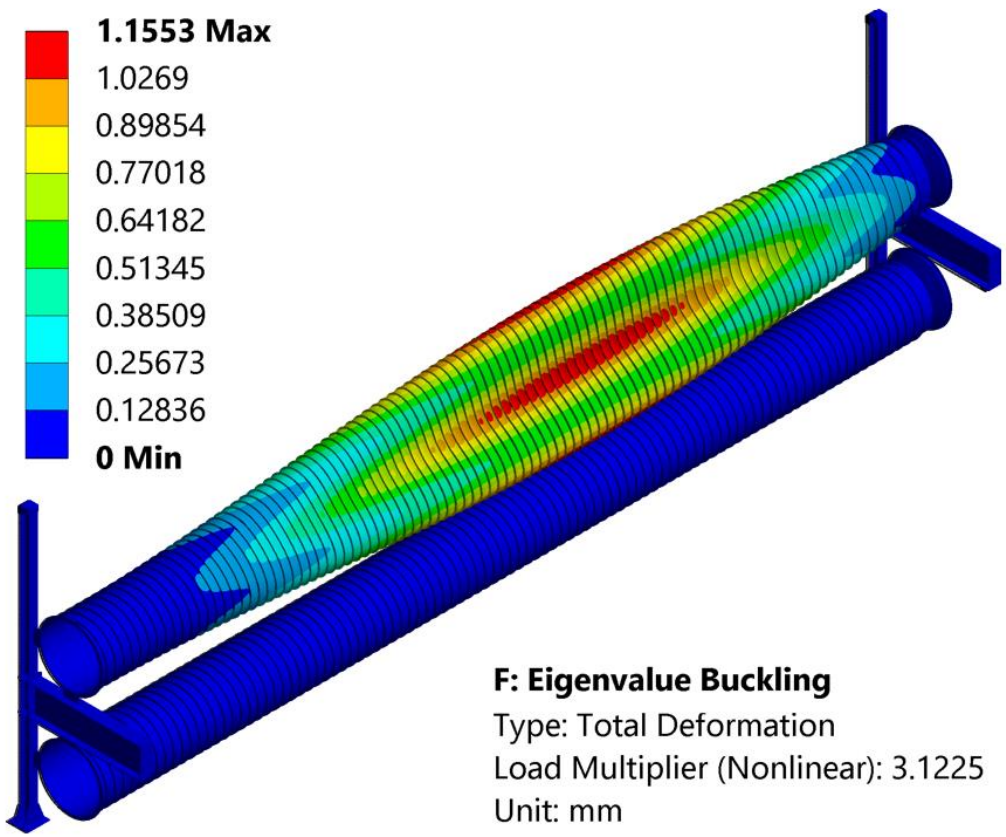


Support Model – Static & Buckling

EINSTEIN TELESCOPE

STATIC DEFORMATION & BUCKLING ANALYSIS

- Two tubes with supports (old design, connected through bellows).
- Loads: gravity + vacuum
- Max deflection: < 7 mm over 15 m (< 3 mm without bellow)
- Buckling analysis performed from static equilibrium (Safety Coef.: 4.1)
- ☞ Design validation choice : no risk of collapse under operating conditions

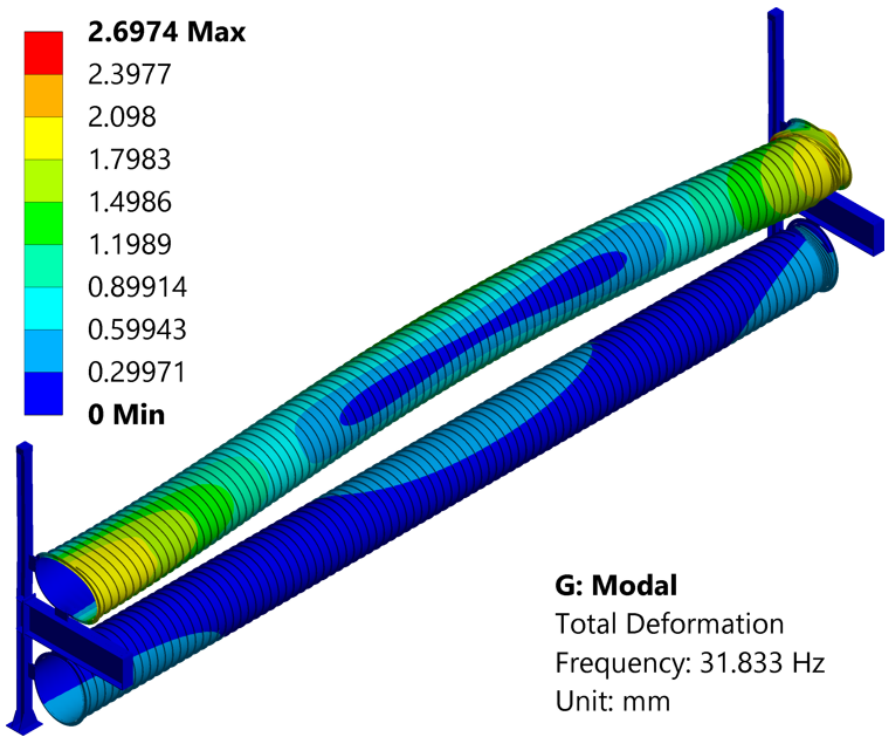


LAPP SUPPORT MODEL – MODAL & TRANSFER FUNCTION

EINSTEIN TELESCOPE

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) :

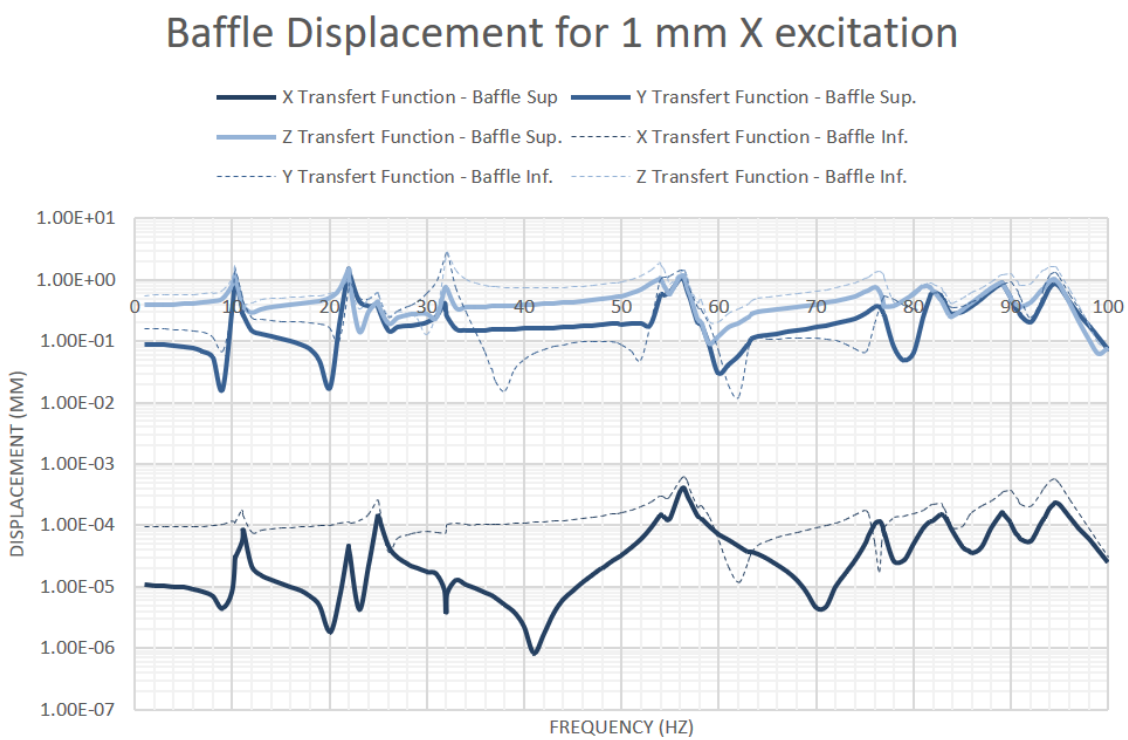
- 37 FROM THE BELLOWS
- 28 FROM THE TUBES
- 5 FROM THE SUPPORTS

LAPP SUPPORT MODEL – MODAL & TRANSFER FUNCTION

EINSTEIN TELESCOPE

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)

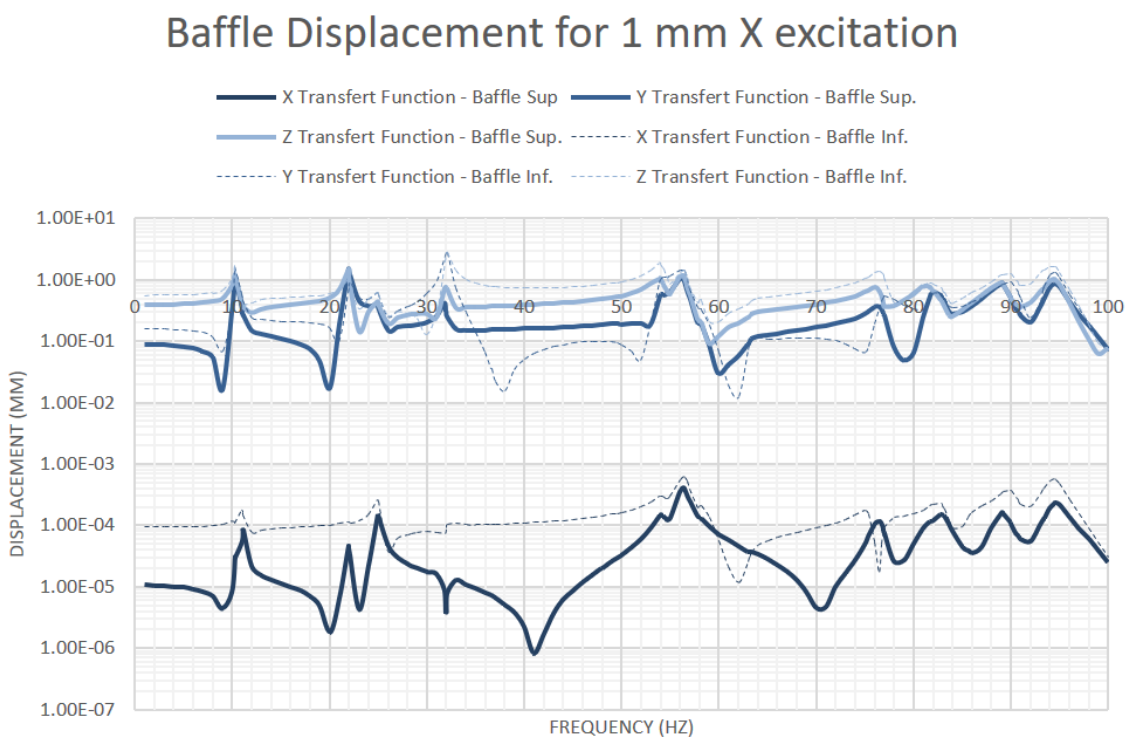


LAPP SUPPORT MODEL – MODAL & TRANSFER FUNCTION

EINSTEIN TELESCOPE

MODAL BEHAVIOUR & HARMONIC RESPONSE

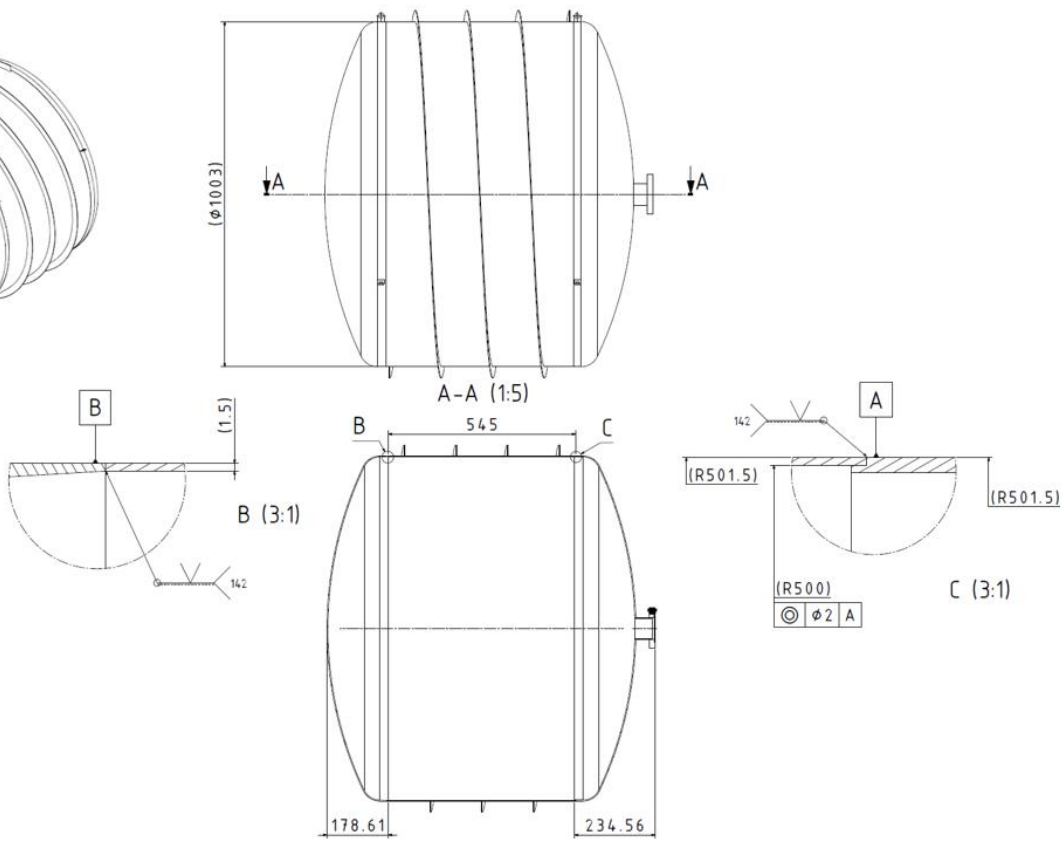
- MODAL ANALYSIS UP TO 100 HZ (2% DAMPING)
- EXCITATIONS APPLIED AT SUPPORT FIXATIONS IN X, Y, Z (1 MM DISPLACEMENT)
- TRANSFER FUNCTIONS COMPUTED AT BAFFLES (END OF TUBES)
- ☞ VALIDATION: THESE PROVISIONAL RESULTS ARE GIVEN FOR A 1 MM EXCITATION. THEY MUST BE MULTIPLIED BY THE SEISMIC SPECTRUM MEASURED AT THE FINAL INSTALLATION SITE TO ENSURE THAT THEY ARE ACCEPTABLE



SMALL PROTOTYPE

PROTOTYPE TUBE UNDER FABRICATION

- **Dimensions**: 0.5 m length, Ø1 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

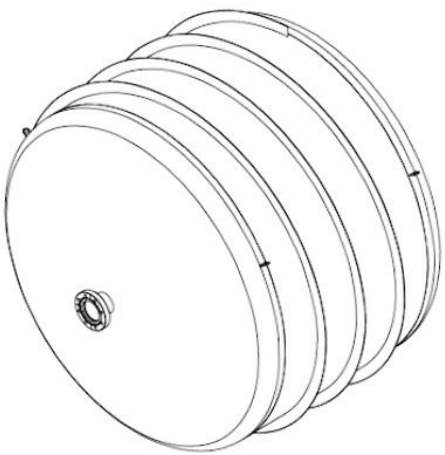
Status:

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

ROADMAP & VISION

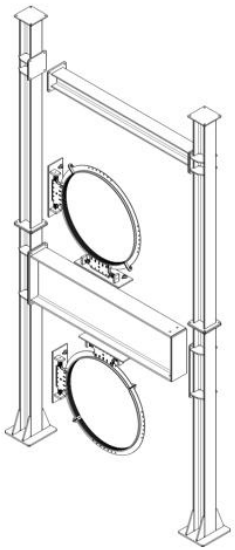
EINSTEIN TELESCOPE

2025 - 2026



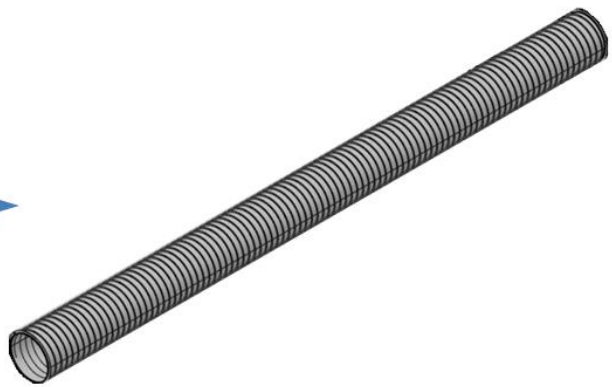
PROTOTYPE

2026



CERN PILOTE SECTOR EVOLUTION + NEW SUPPORTS

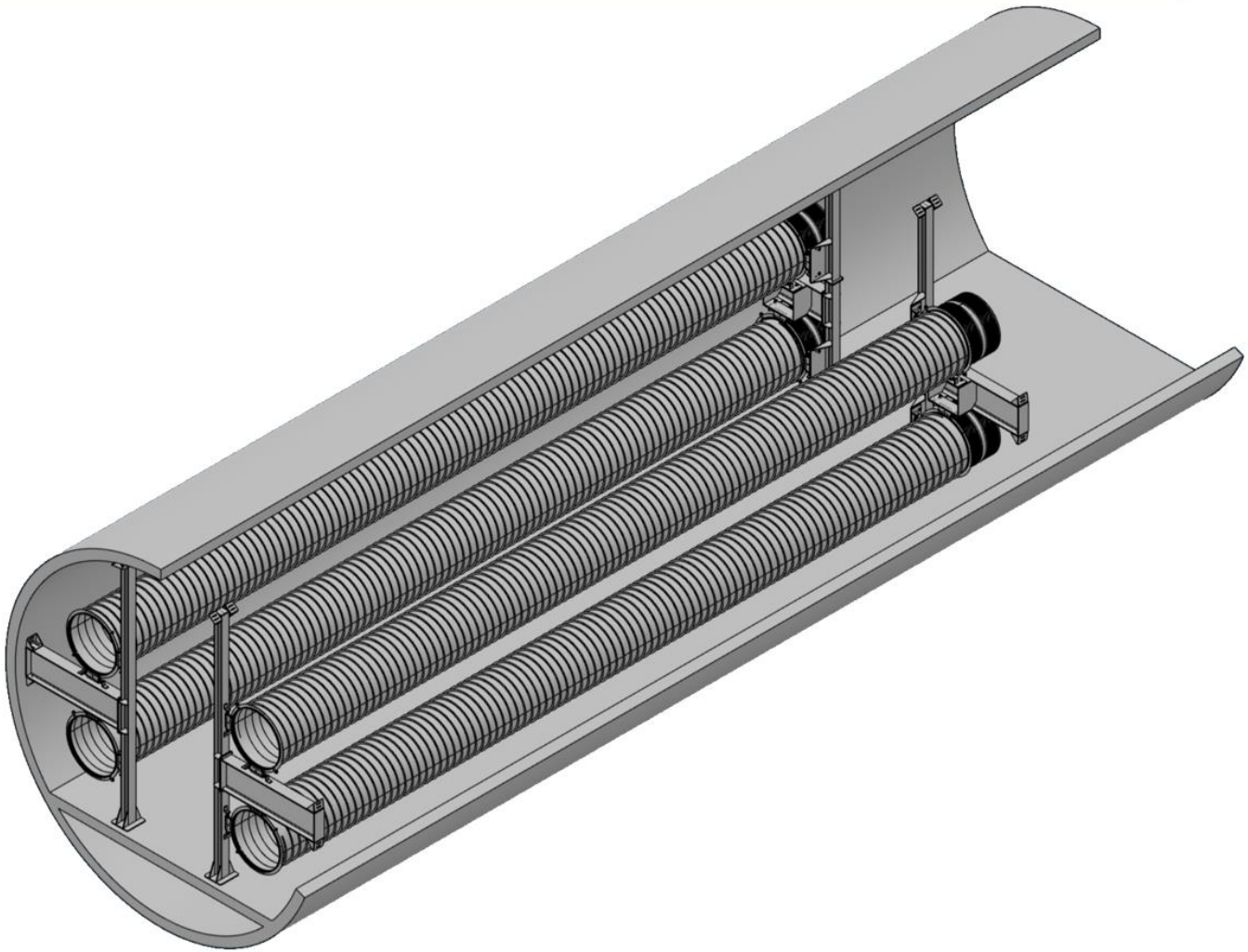
2027



NEW PILOT SECTOR DESIGN

ROADMAP & VISION

EINSTEIN TELESCOPE



THANK YOU FOR YOUR ATTENTION