Laboratoire d'Annecy de Physique des Particules

Design of beam pipes for GWT

Status report of WP1 contributions

Monday 27 March 2023

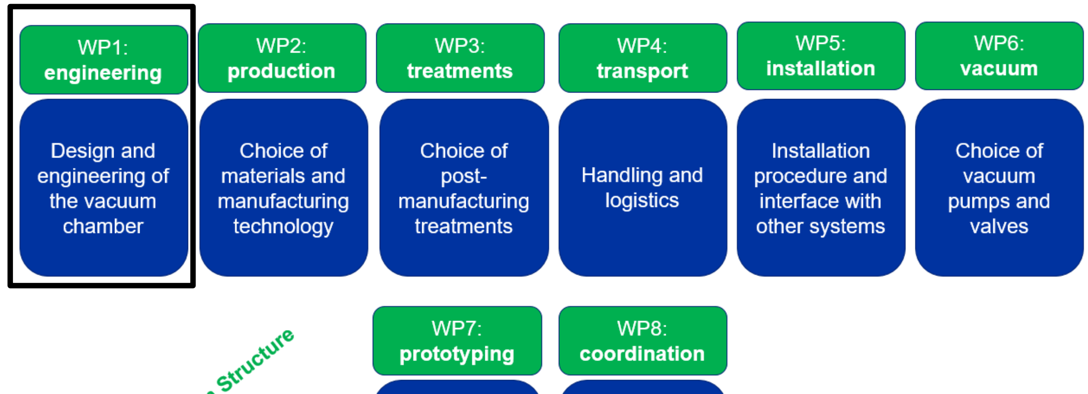
Co-funded by the European Union

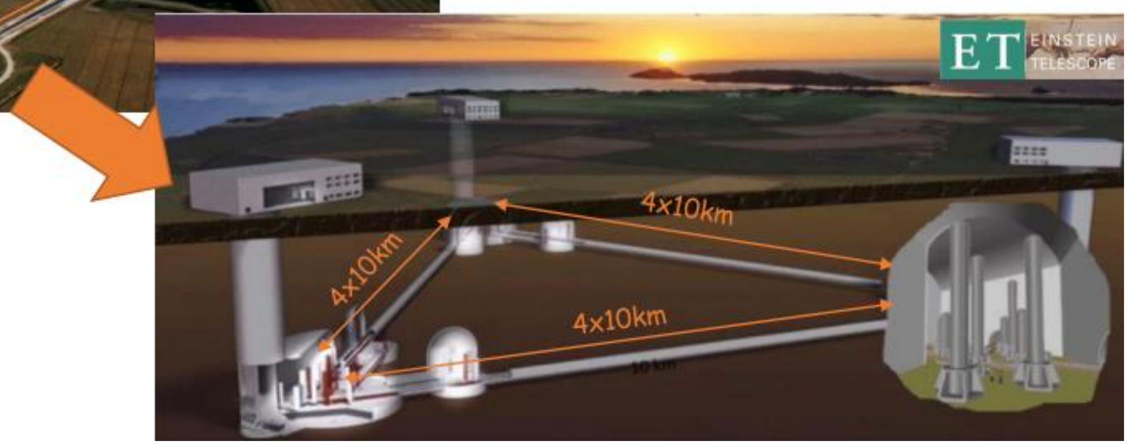
Project: 101079696 — ET-PP — HORIZON-INFRA-2021-DEV-02

UNIVERSITÉ SAVOIE MONT BLANC

Summary of contributions of WP1 members :

- CERN
- LAPP
- IJCLAB
- IFAE





IJCLAB
VIRGO SOLUTION SCALING

"Thick" 304 stainless steel tube with circumferential stiffeners & bellow

ET EINSTEIN TELESCOPE

Module Standard

cnrs · université PARIS-SACLAY · FACULTÉ DES SCIENCES D'ORSAY · Université de Paris

- Ø tubes : Ø1200 mm
- Longueur : 14,370m
- Epaisseur : 4mm
- Raidisseurs espacés de 1200mm – épaisseur : 8mm
- 2 Raidisseurs aux extrémités – épaisseur : 16mm
- 2 Lèvres de soudure aux extrémités
- Matière : Inox 304L – A2 (1,4307 - X2CrNi18-9)
- *Tôles laminées à froid*
- Essai en traction pour mesure de la limite élastique à 0,2% et 1% 20°C pour tôle d'épaisseur 4mm
- Traitement thermique
  - 20°C et 160°C pour tôle d'épaisseur 2mm
  - Chauffé à 400°C dans l'air pour décharger l'hydrogene de l'Inox
    1. 20°C à 400°C en 24hrs minimum
    2. 400°C à ±10°C pendant 72hrs
    3. 400°C à 20°C en 24hrs minimum
  - Prévoir un flux d'air pour extraire l'Hydrogene

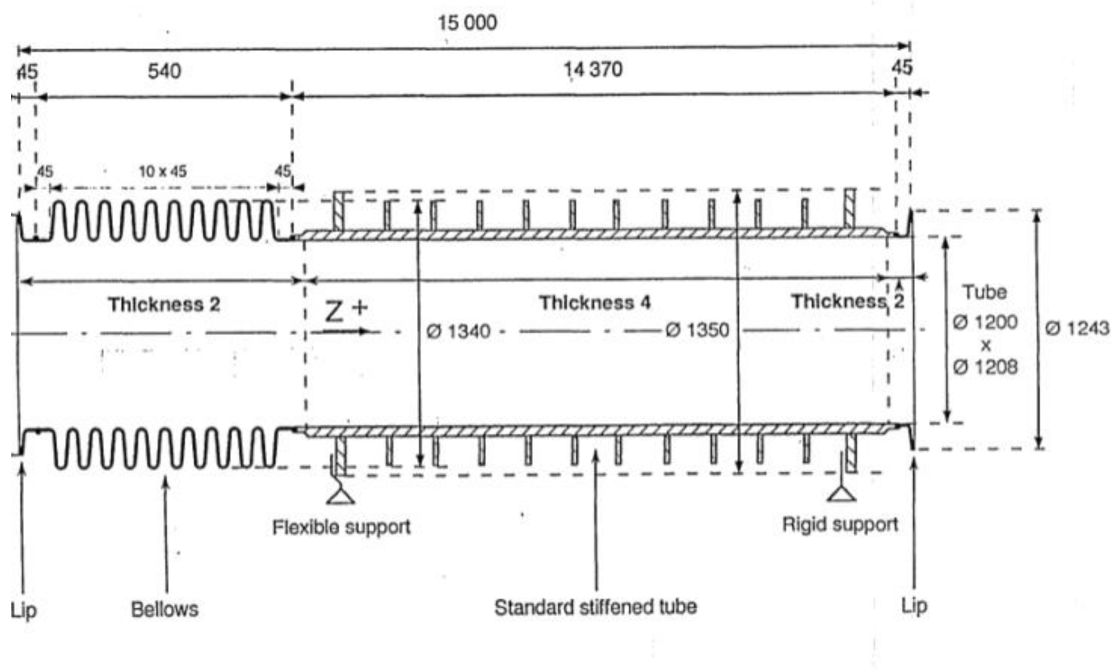


Fig. 3100.1 Standard module

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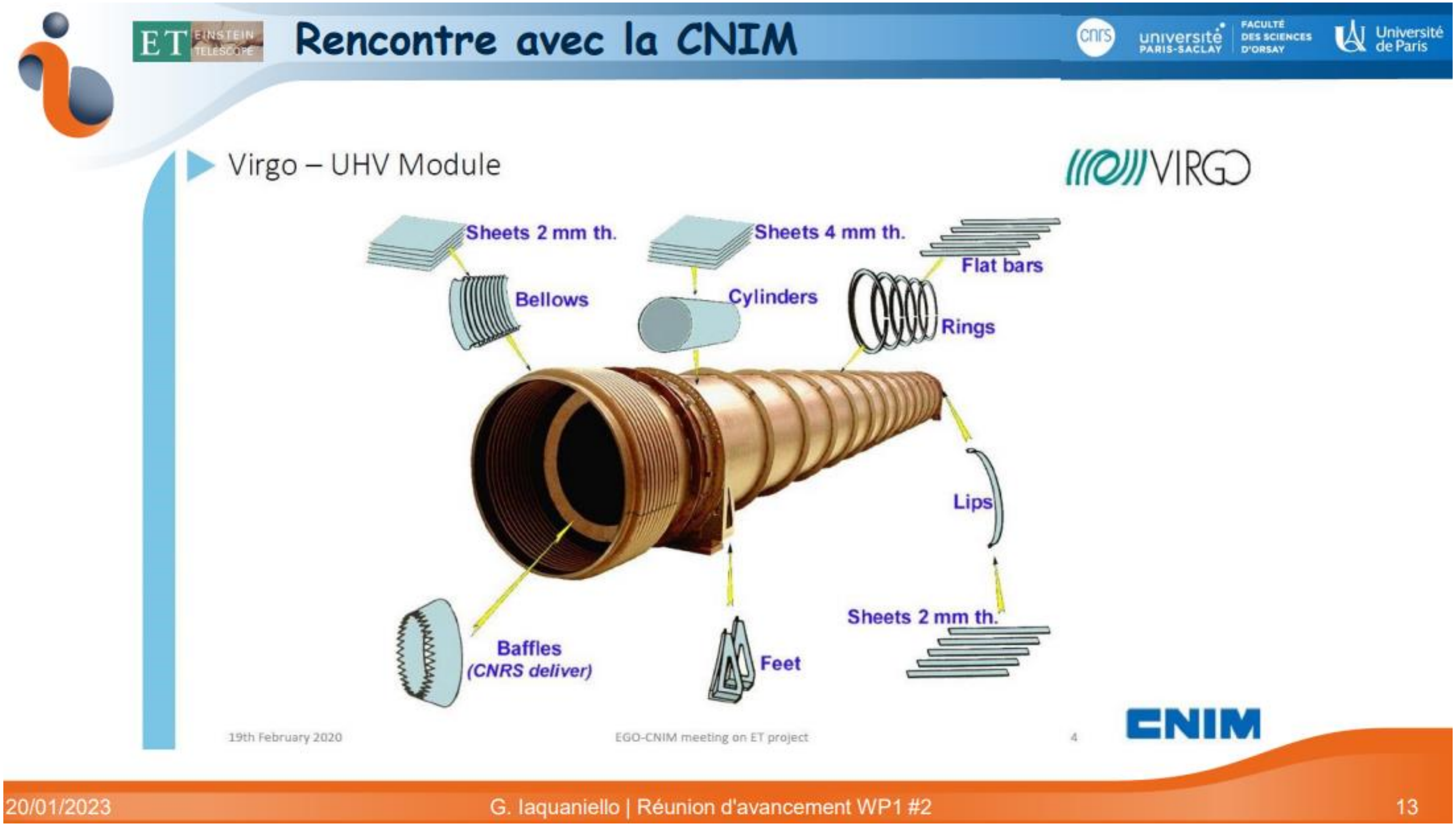
Rencontre avec la CNIM
ET EINSTEIN TELESCOPE
cnrs
université PARIS-SACLAY
FACULTÉ DES SCIENCES D'ORSAY
Université de Paris
Virgo – UHV Module
VIRGO
Sheets 2 mm th.
Bellows
Sheets 4 mm th.
Cylinders
Flat bars
Rings
Lips
Sheets 2 mm th.
Baffles
(CNRS deliver)
Feet
CNIM
19th February 2020
EGO-CNIM meeting on ET project
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20/01/2023
G. Iaquaniello | Réunion d'avancement WP1 #2
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VIRGO :

- Excluding workshop preparation 13 month to produce 2 x 3km tubes (~1tube / day)

Einstein Telescope :

- To scale to 120km (considering 1 Tube/day)

~ 8080 days ⇔ ~ 22 / 31 years (calendar days / working days)

To speed up this production time :

- Hire several companies
- New fabrication process
- Increased productivity

VIRGO actualized cost :

- In **January 2020** CNIM estimated that VIRGO cost would be actualized from 11,8M€ to **18M€**

ET – Input data for cost estimate

If we had to do the same now:

404 UHV modules 15m x Ø1.2m	1997-2002	RoM price 2020
Manpower	66000 hours	5.3m€
Raw material		10.1m€
Other procurements		2.4m€
Transport	0.14m€	0.2m€
Contract price	**11.8m€**	**18.0m€**

Rough estimate
No commitment

Excluded:
- Validation mock-ups & Prototype
- Tooling
- Workshop equipment
- Any new requirement

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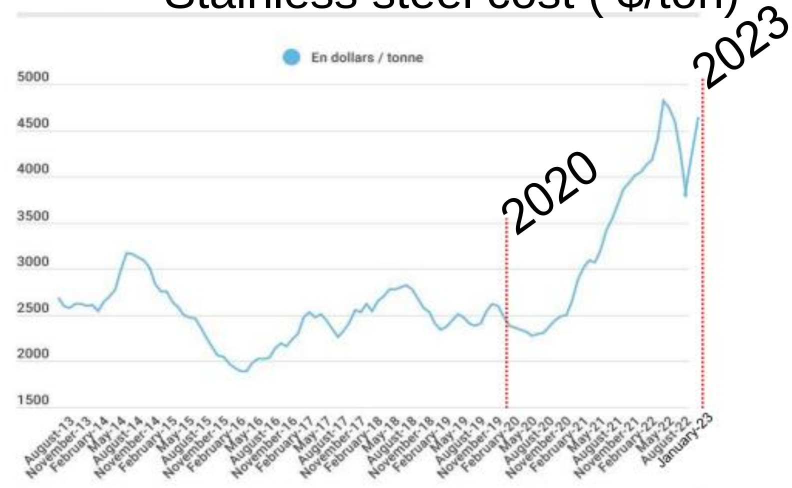
Stainless steel cost ($/ton)



Source : https://www.depery-dufour.fr/cours-metaux/

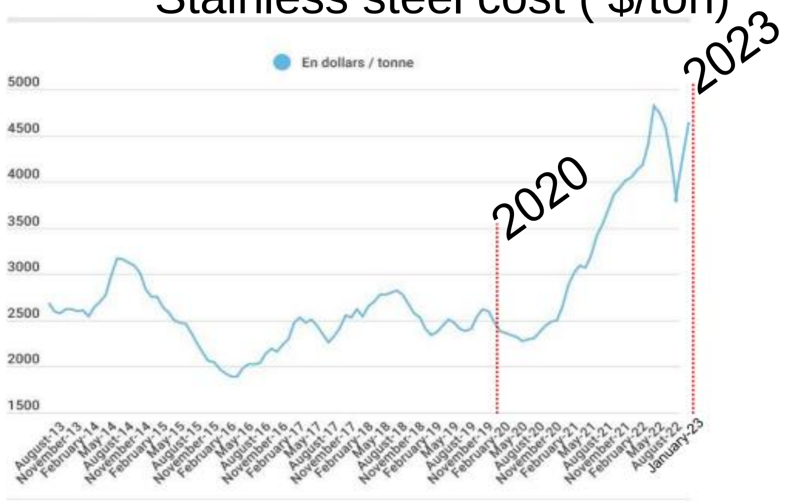
404 UHV modules 15m x Ø1.2m	RoM price 2023
Manpower	5.3m€
Raw material	~~10.1m€~~ 20.2m€
Other procurements	2.4m€
Transport	0.2m€
Contract price	~~18.0m€~~ 28.0m€

Einstein Telescope 's tubes cost estimation in 2023 :

By extrapolation :

- Based on Virgo like design
- without tooling investments
- Without design variation
- …

Stainless steel cost ($/ton)



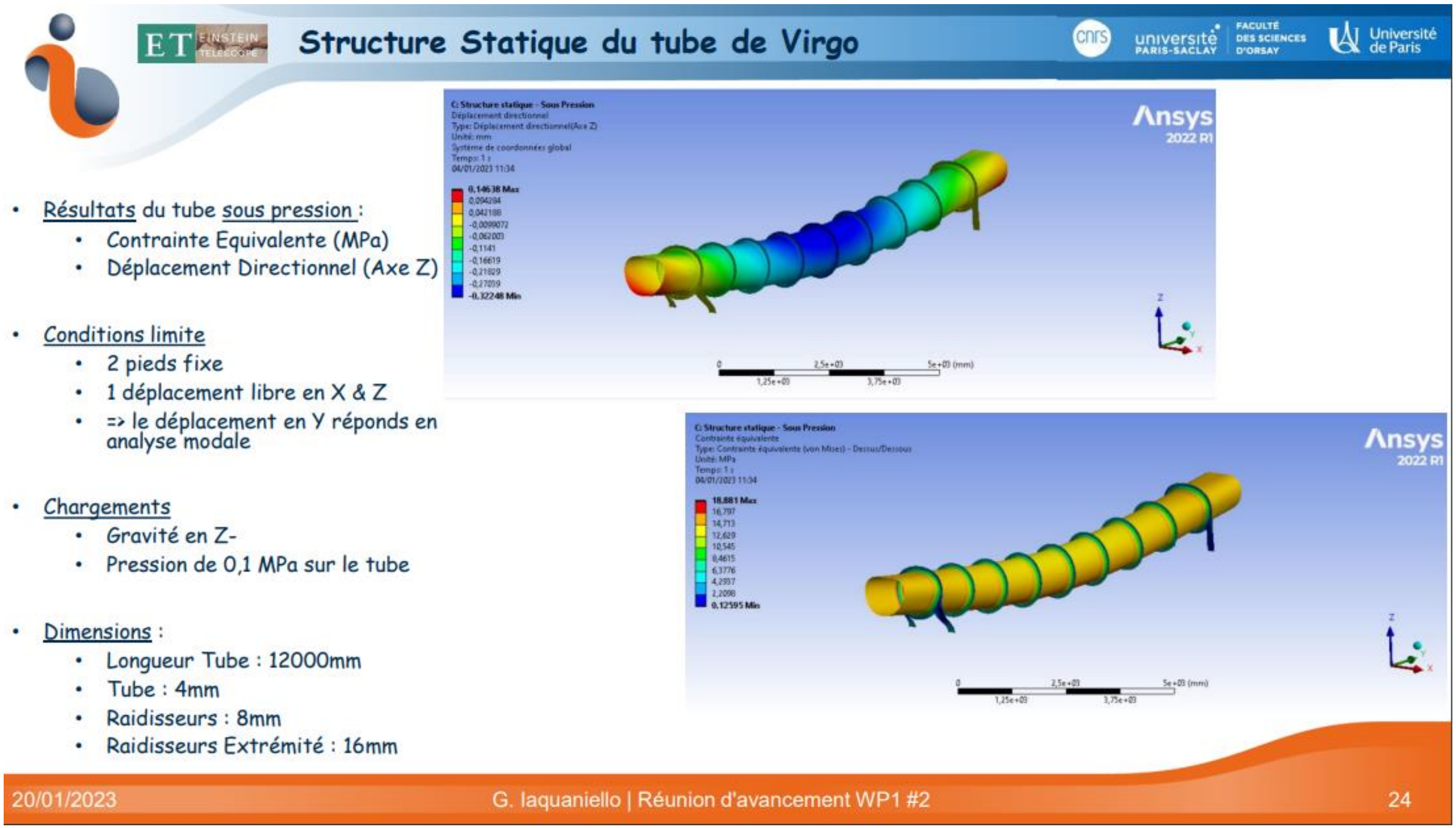
Source : https://www.depery-dufour.fr/cours-metaux/

Cost around **560M€**

Production time : **8080 days ⇔ ~ 22 / 31 years**

Pipe ready to install, no supports, no insulation

Starting point of scaling study

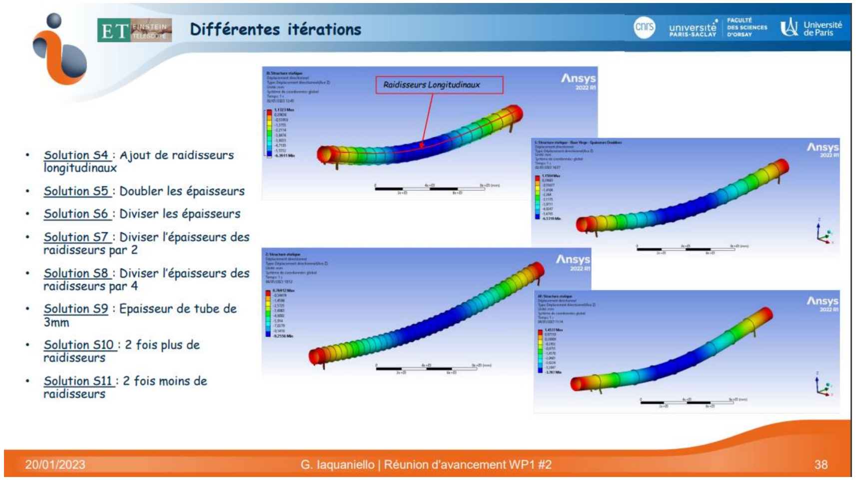


Buckling factor ~= 3

Main idea was to produce longer tubes to speed up production time

Several configuration tested :
- Thickness
- Length
- Stiffeners (circumferential & / or longitudinal)

- Has implication in terms of transport



	Longueur	Largeur	Poids
1re catégorie	Entre 16,6 et 20 m	Entre 2,6 et 3 m	Entre 44 et 48 tonnes
2e catégorie	Entre 20 et 25 m	Entre 3 et 4 m	Entre 48 et 72 tonnes
3e catégorie	Au-delà de 25 m	Au-delà de 4 m	Au-delà de 72 tonnes

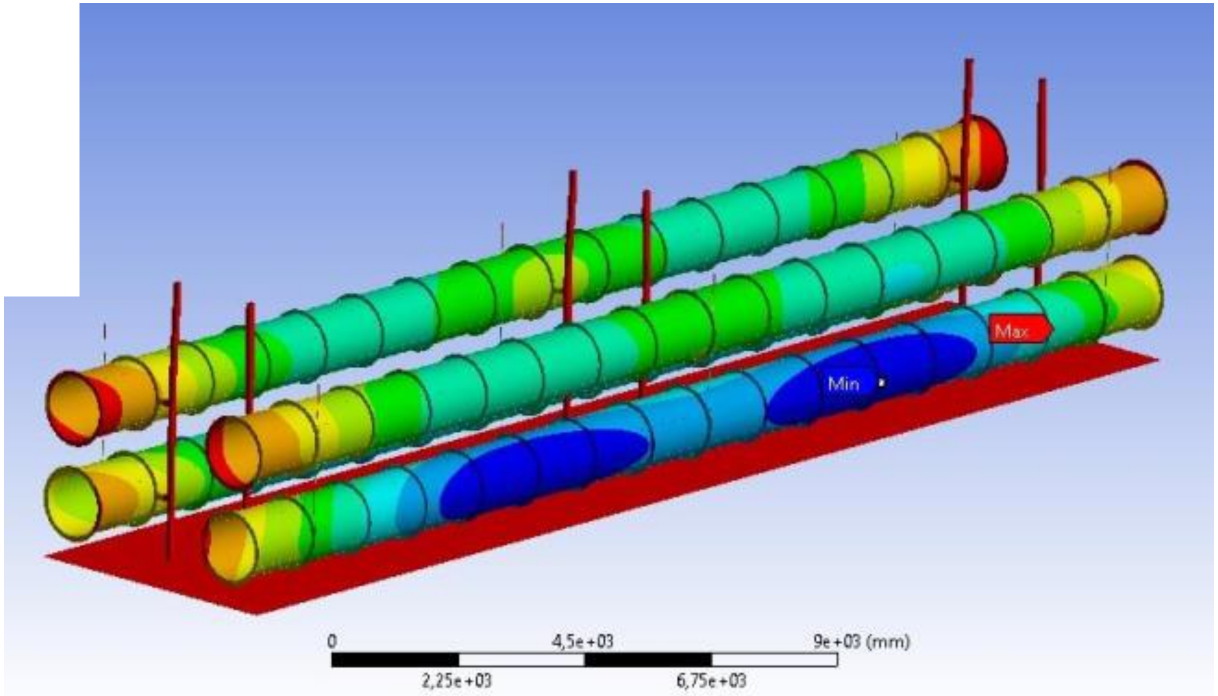
After having computed 14 different configurations

IJCLAB is now entering in more refined simulations for best candidate :

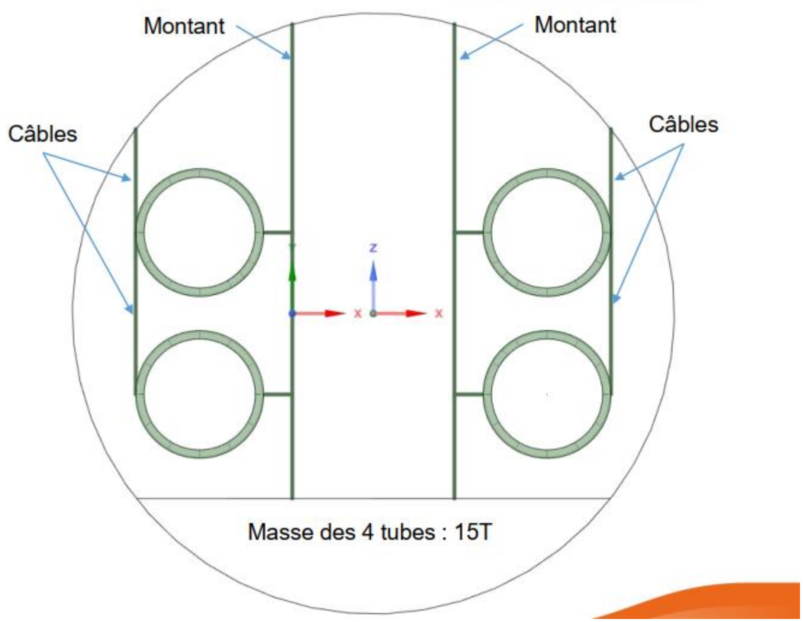
- Influence of supporting system
- Ground to baffle transfer function estimations

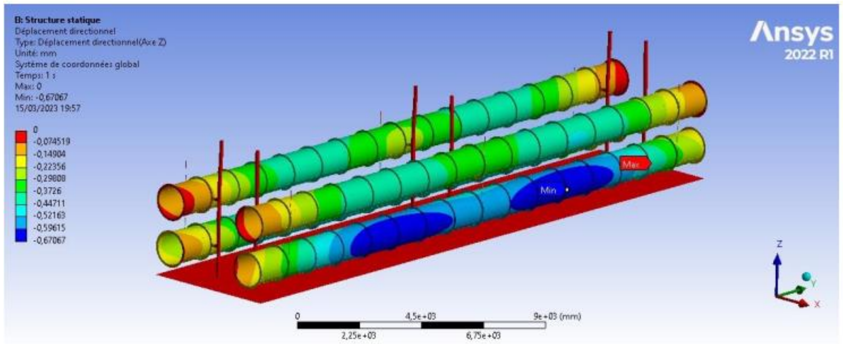
Dimensions :

- Longueur Tube : 24'000mm
- Tube : 4mm
- Raidisseurs : 8mm
- Raidisseurs Extrémité : 16mm

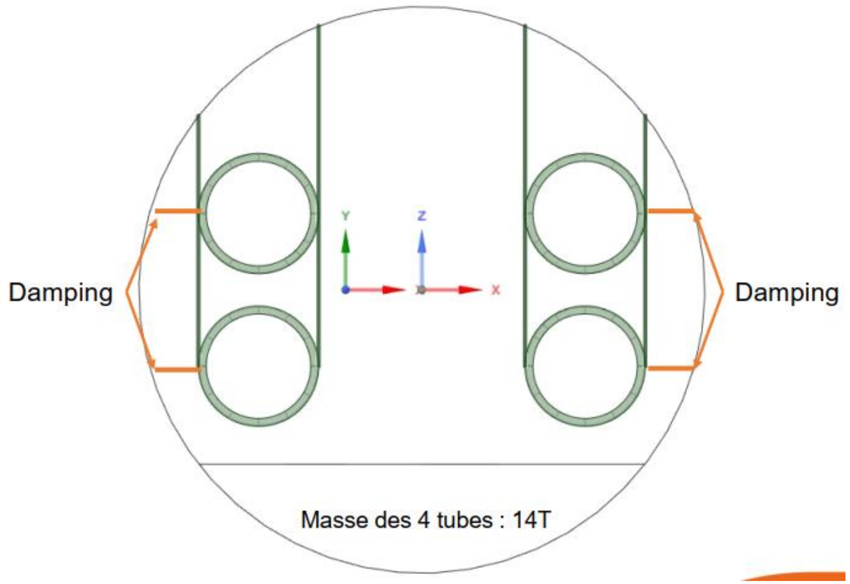


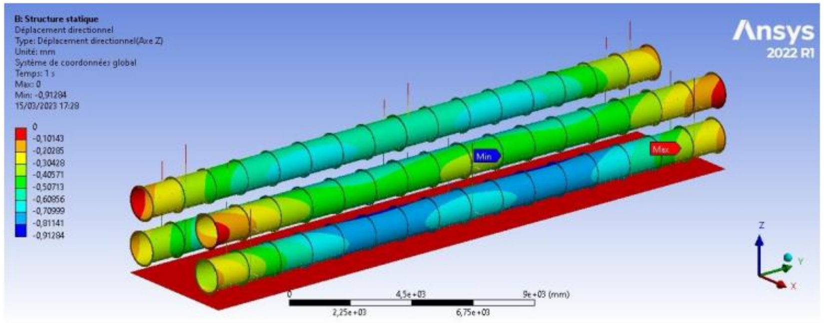
Semi rigid configuration





Suspended configuration

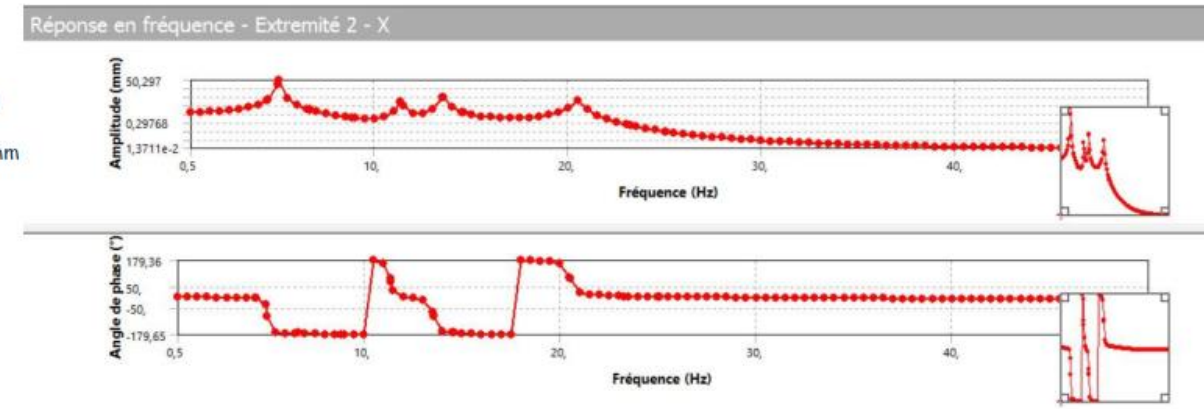




System frequency response

Solution Semi-Suspendue - Réponse en Fréquence Harmonique - Axe X - Extrémité 2

- Résultats des tubes sous leurs propre poids :
  - Déplacement Directionnel (Axe X) - Intensité : 1 mm
- Conditions limite
  - 2 paires de tubes suspendues en 3 points par des câbles de Ø20mm en acier standard et fixe sur montant vertical 100x100 creux, épaisseur 10mm
  - Taux d'amortissement : 1%
- Chargements
  - Gravité en Z-
- Dimensions :
  - Longueur Tube : 24'000mm
  - Tube : 4mm
  - Raidisseurs : 8mm
  - Raidisseurs Extrémité : 16mm

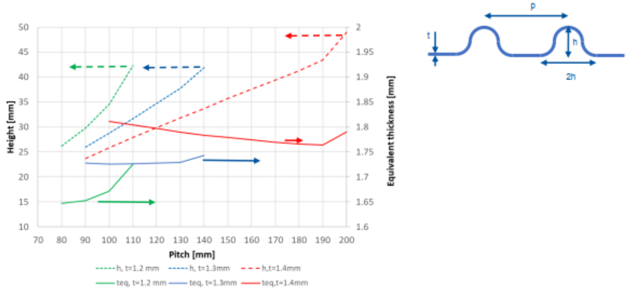


More details concerning TF @end of this presentation

CERN
CORRUGATED SOLUTION

Mechanical aspects

Wall thickness in the range 1.2-1.5 mm can be considered for a buckling differential pressure of 3 bars.



1.3 mm thick wall chamber is a good compromise with a 120 mm pitch and 35 mm corrugation height. Possible optimisation with other constraints.

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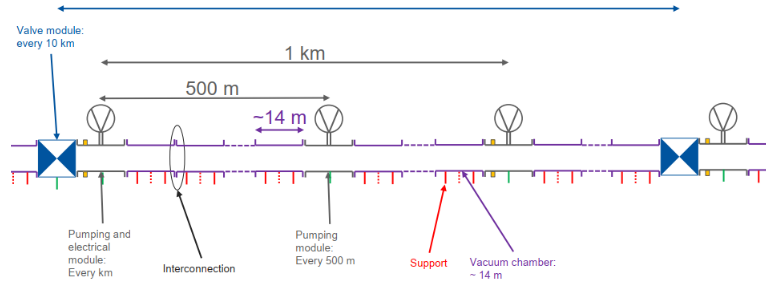
System layout

Solution #1



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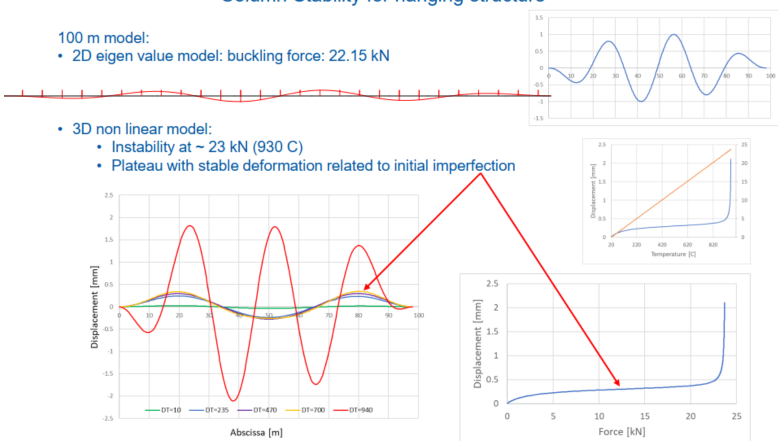
Mechanical aspects

Column Stability for hanging structure

100 m model:
- 2D eigen value model: buckling force: 22.15 kN

- 3D non linear model:
  - Instability at ~ 23 kN (930 C)
  - Plateau with stable deformation related to initial imperfection



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Mechanical aspects

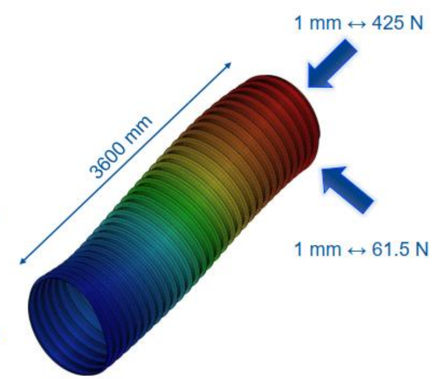
Specific stiffness:
- Axial (E.S): 1.53E6 N
- Transversal (E.I): 2.4E11 N.mm²

Specific weight: 48 kg/m

Bakeout induced axial force: -3.3 kN (< 95 kN thrust force)

Euler buckling force (in case of accidental venting during bakeout), assuming simple supports distanced by 7.5 m : -42 kN

→ Global column instability not expected.



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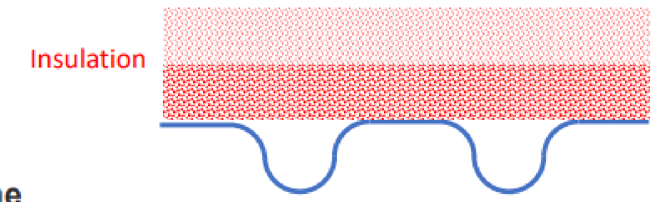
Proposed solution :

Solution proposée



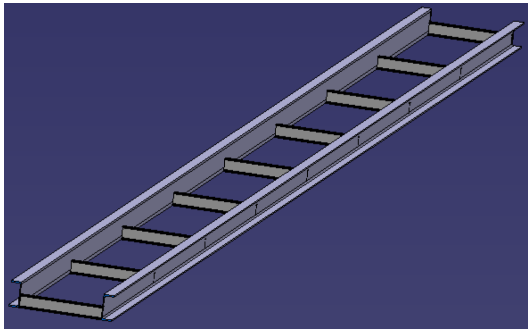
Concept:

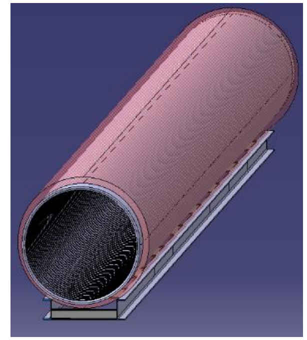
- Aspects mécaniques: **tube corruguée à paroi fine**
  - Diamètre : 1.1m
  - Epaisseur de paroi du chambre: 1.3mm
  - Longueur du secteur: 14m
  - Insulation thermique basée sur la mouse phénolique et/ou polyuréthane
    - Moins de poussière
    - Installation plus facile par rapport aux autres solutions proposées
    - Solution standard de fournisseur
    - Compatibilité avec le vacuum bake-out jusqu'à ~150°C

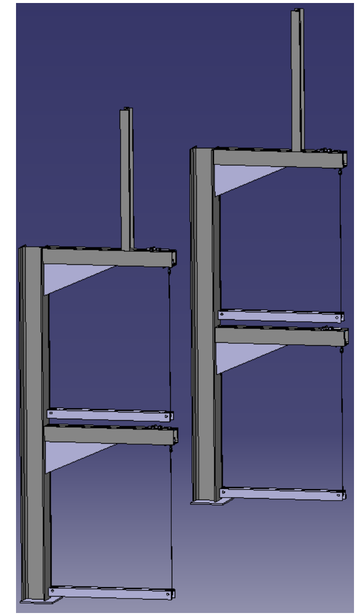
23 November 2022 Hana HAVLIKOVA, Cedric GARION | Conception, intégration et fabrication du prototype 5

Numbers are to be considered as working assumptions

Associated supporting concept

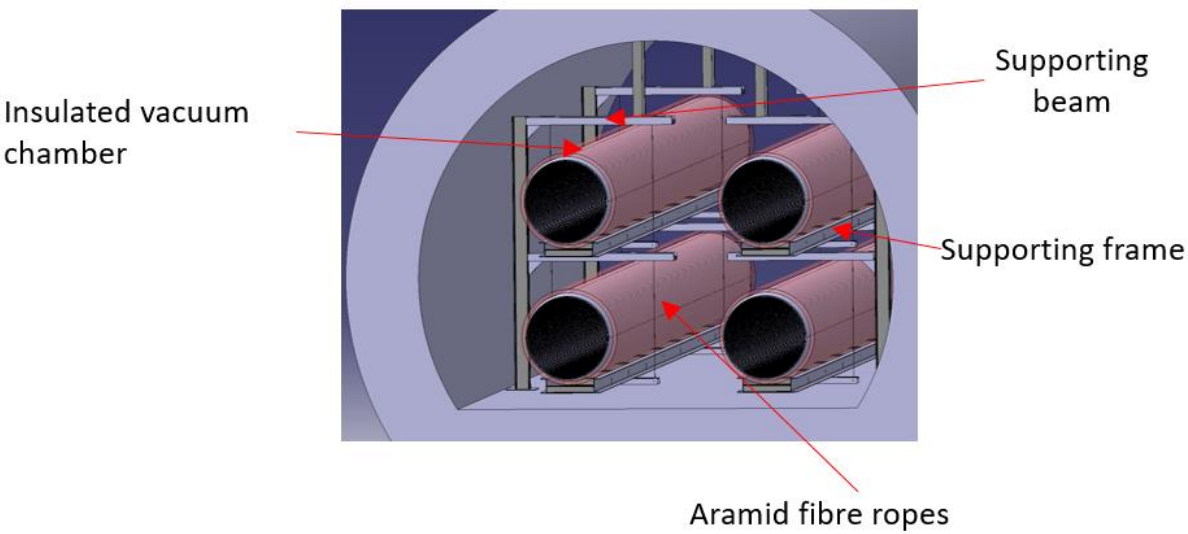




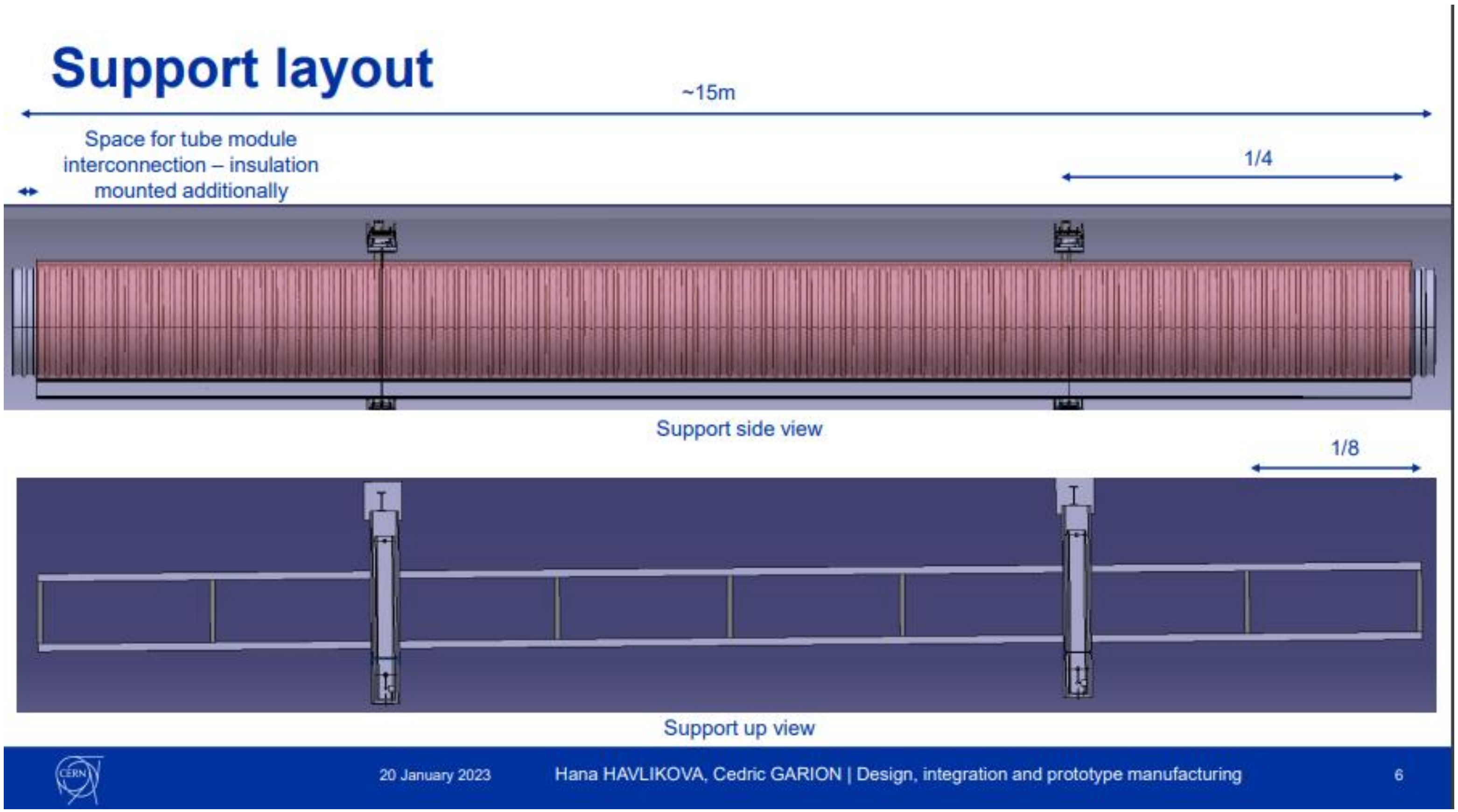


The proposed design, based on a suspended vacuum chamber, aims at reducing vibrations on the baffles.

Basic concept is based on harmonic oscillator and aims at lowering the first eigen frequencies.



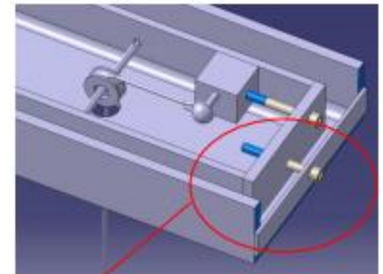
Associated supporting concept

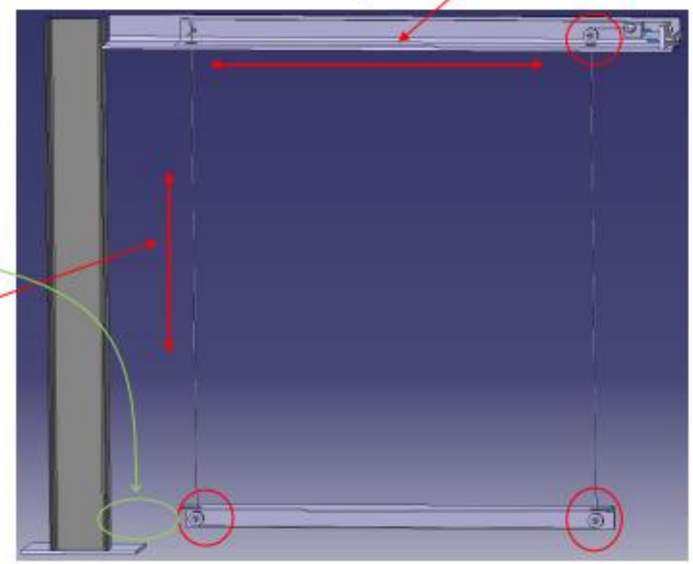


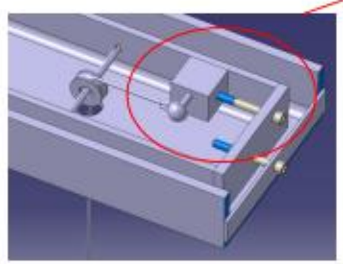
Suspension system

- **TECHNORA rope** (already used in CERN)
- **System of 3 pulleys**
- **2 adjustments by screws**
  - Rope length: ~ ± 5 cm (vertical position)
  - Horizontal position: ~ ± 1 cm

  - Transversal damping device can be easily implemented if required

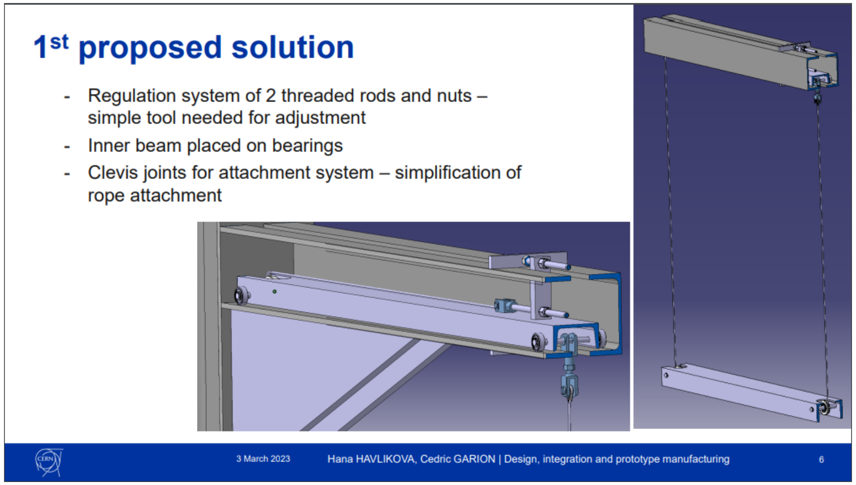


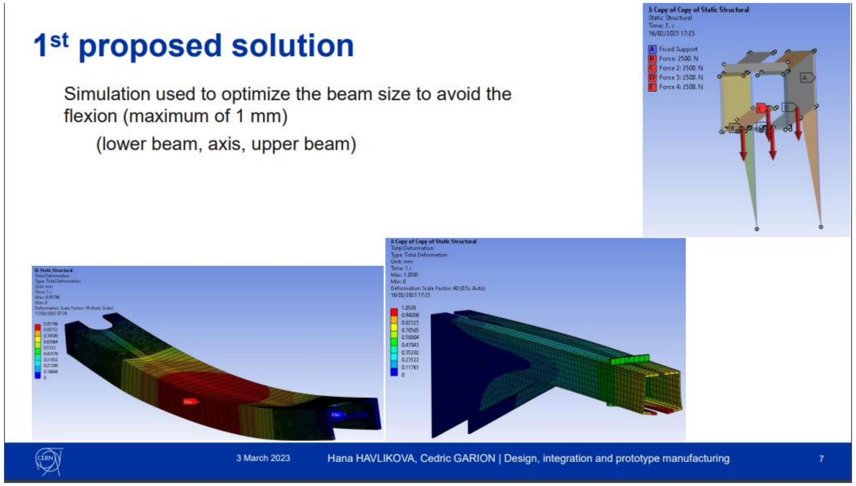




20 January 2023 Hana HAVLIKOVA, Cedric GARION | Design, integration and prototype manufacturing 7

Work is going on to develop in further details this concept



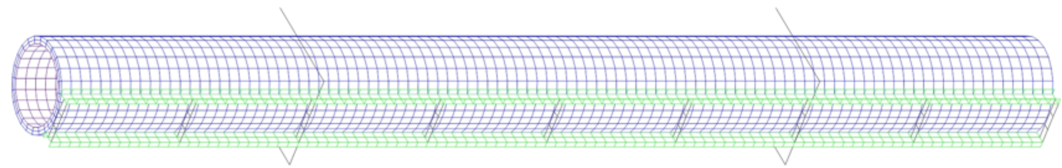


Optimize supporting system sizing :

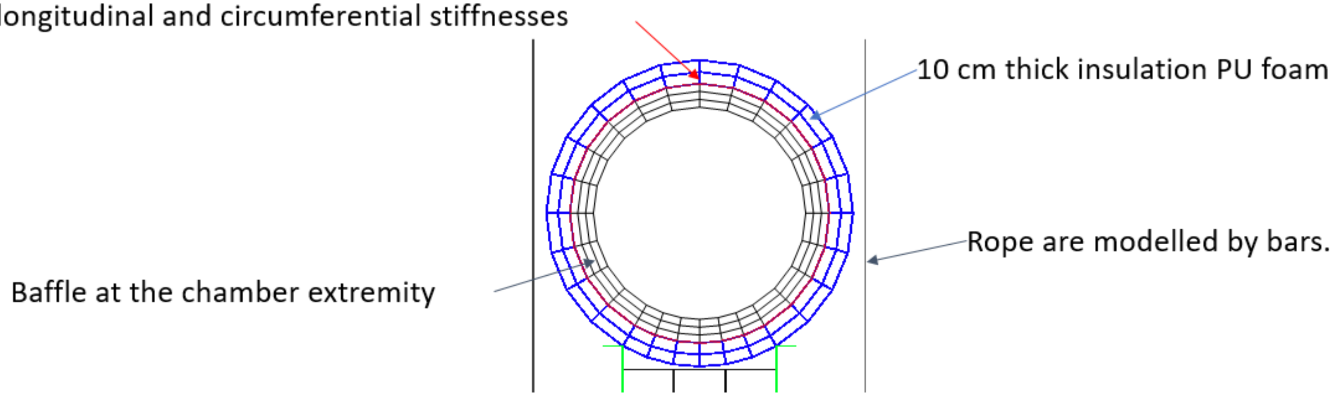
- Sag mitigation
- Introduce realistic representative stiffness in FEM

Vibration analysis

Finite element model:



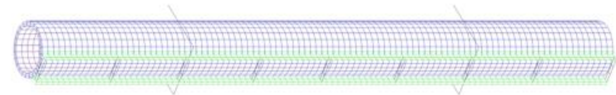
Corrugated chamber modelled by an equivalent smooth chamber with shell elements:
- Same mass distribution
- Equivalent longitudinal and circumferential stiffnesses



The influence of vacuum on the chamber stiffness is considered in the model.

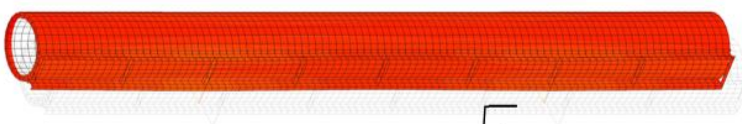
Vibration analysis

Eigen modes and frequencies:



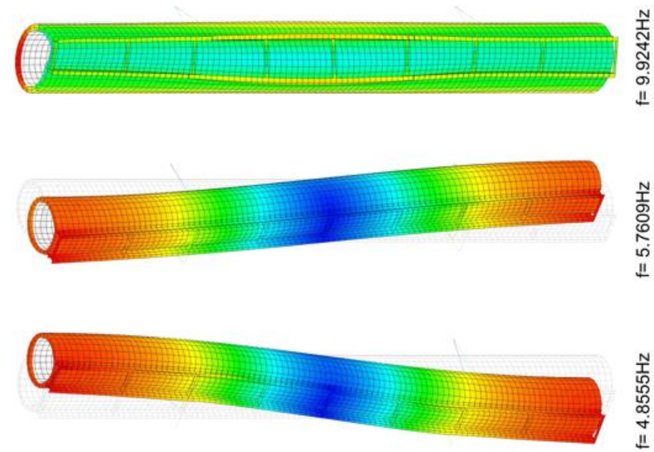
$$f \sim 0.4\,Hz \quad \omega = \sqrt{\frac{g}{h}}$$

First mode corresponds to a pendulum (horizontal displacement).



$$f \sim 3.4\,Hz \quad \omega = \sqrt{\frac{k}{M}}$$

Second mode corresponds to a spring/mass system (vertical displacement).



0,4Hz pendulum mode close to wave induced seismic ground motion (0,1 to 0,3Hz)

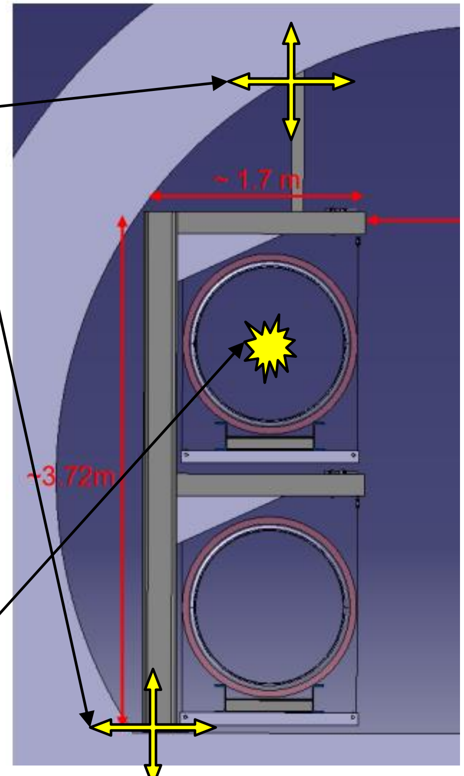
Oscillator frequency can be easily tuned if needed

Ground to baffle transfer function

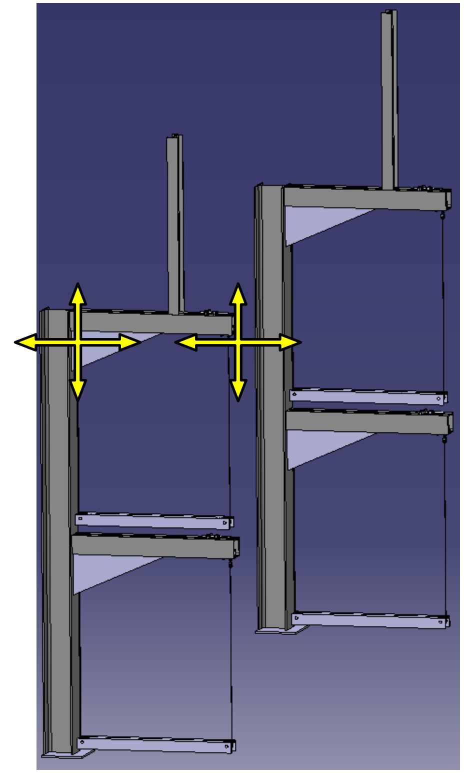
Imposed ground motion :
- Arbitrary
- Flat over frequency span
- Coherent motion

Transfer function

Baffle displacements

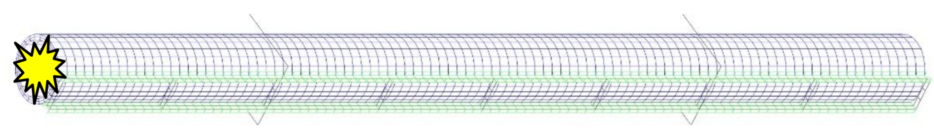


Should be considered



Considered in current FEM

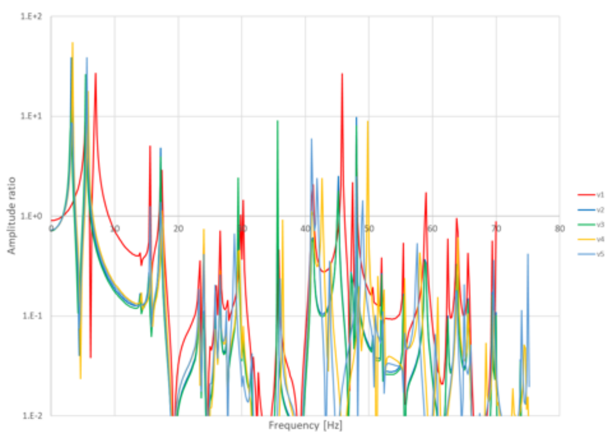
Considered baffle location



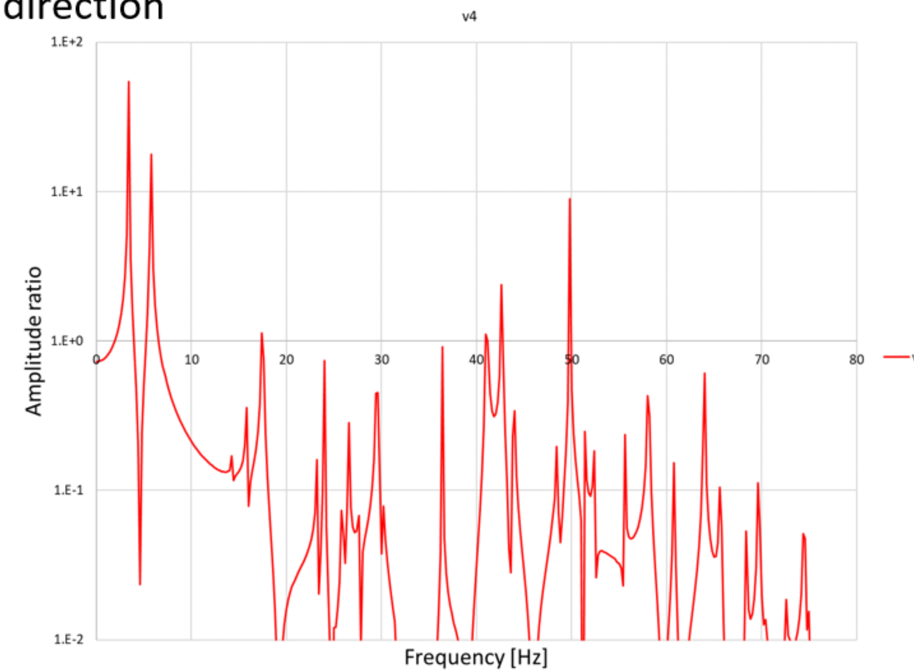
Vibration analysis

Transfer function: Ground motion in vertical direction

Displacements applied at the rope extremities and observed at the baffle location.

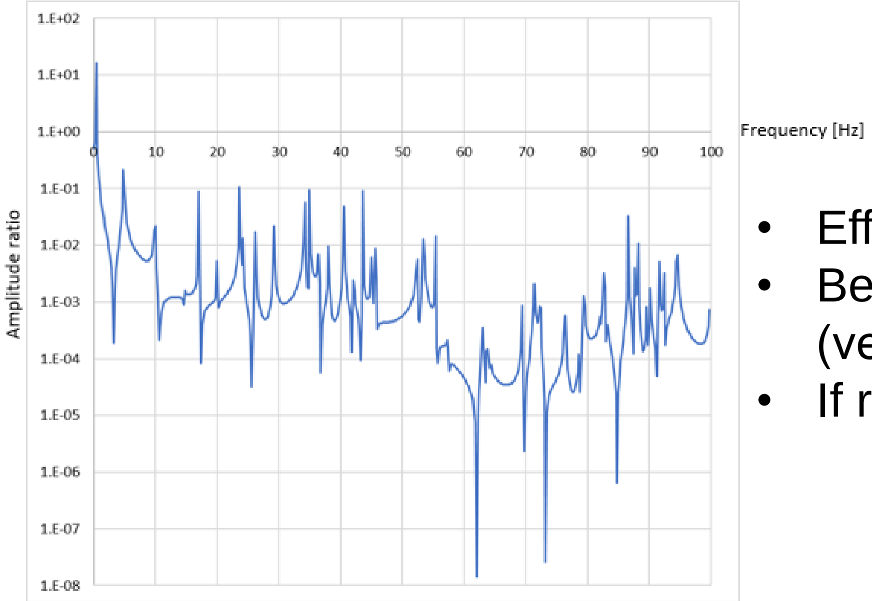


Different ropes/supporting frames have been considered



Transfer function for the retained solution

Transfer function: Ground motion in horizontal direction



Transfer function for the retained solution in horizontal direction

- Efficient reduction of horizontal ground motion.
- Behaviour under direct force excitation (ventilation?, …) needs to be assessed.
- If required, dampers may be easily implemented.

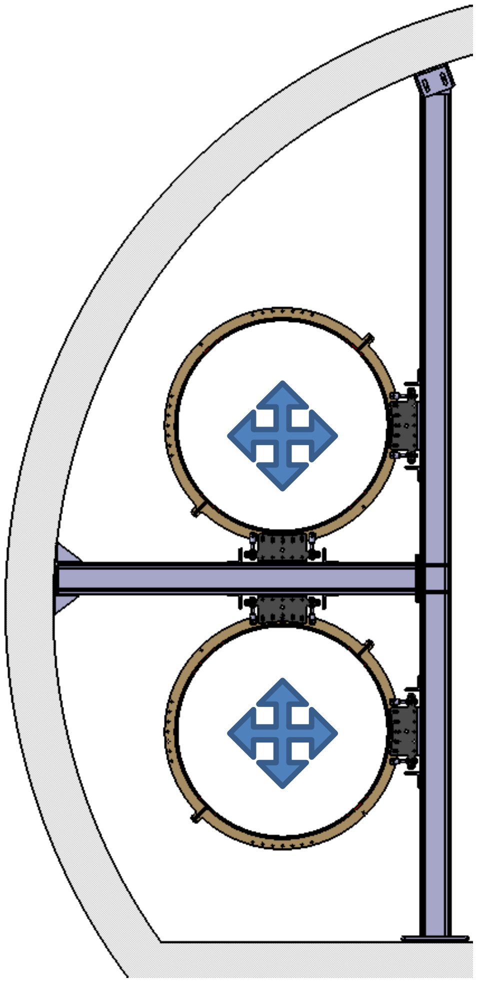
Recent developments consisting in simplified FEM of a 315 m long sector not presented in details

LAPP

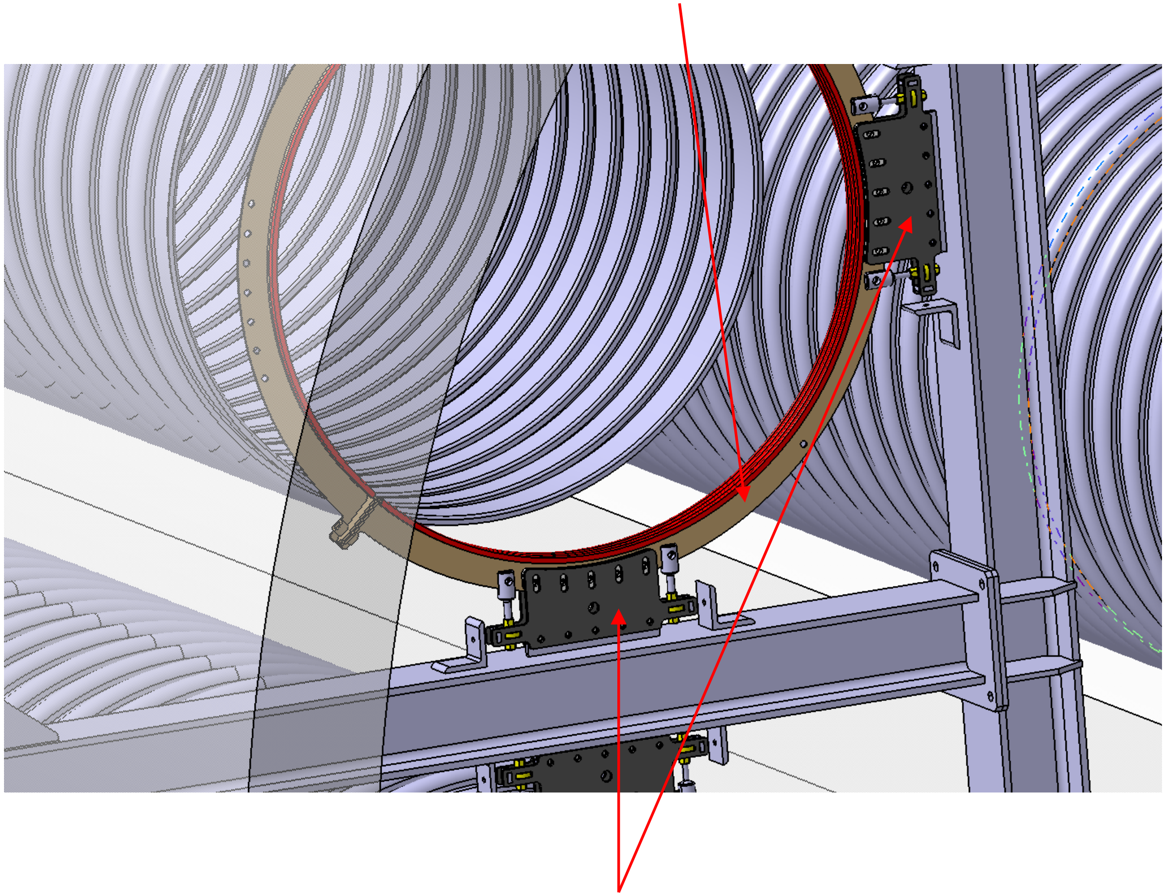
CORRUGATED SOLUTION VIBRATION ANALYSIS

ALTERNATIVE TUBE CONCEPT PROPOSAL

Second solution family : Collars squeezing tube



Collar (between two corrugations)



Positioning and fixing devices

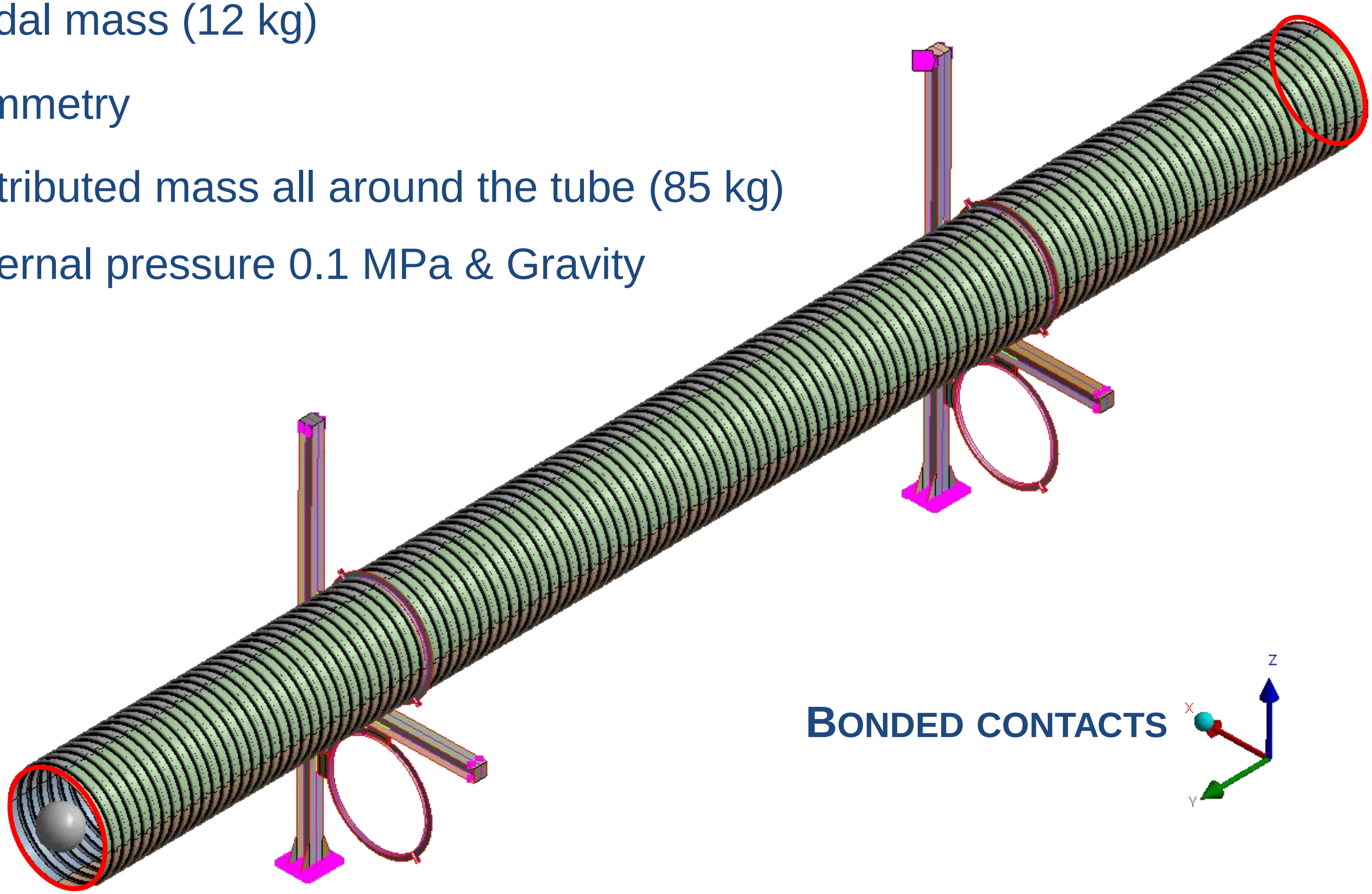
Fixed Nodes

Modal mass (12 kg)

Symmetry

Distributed mass all around the tube (85 kg)

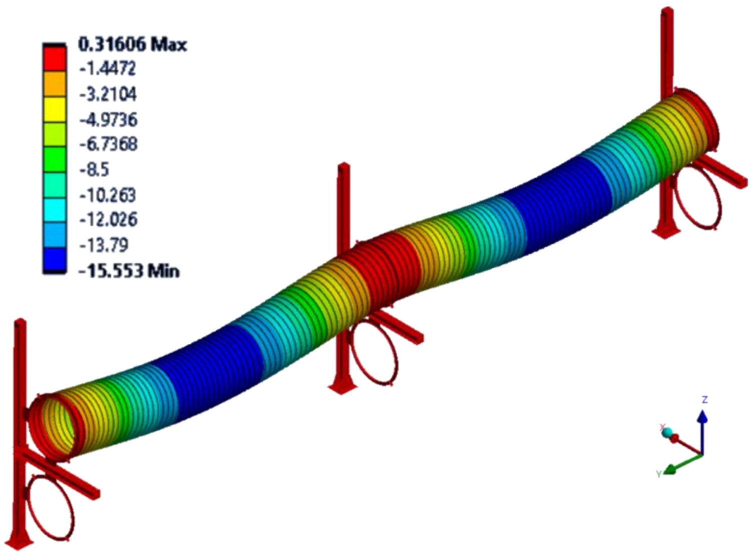
LOADS : External pressure 0.1 MPa & Gravity

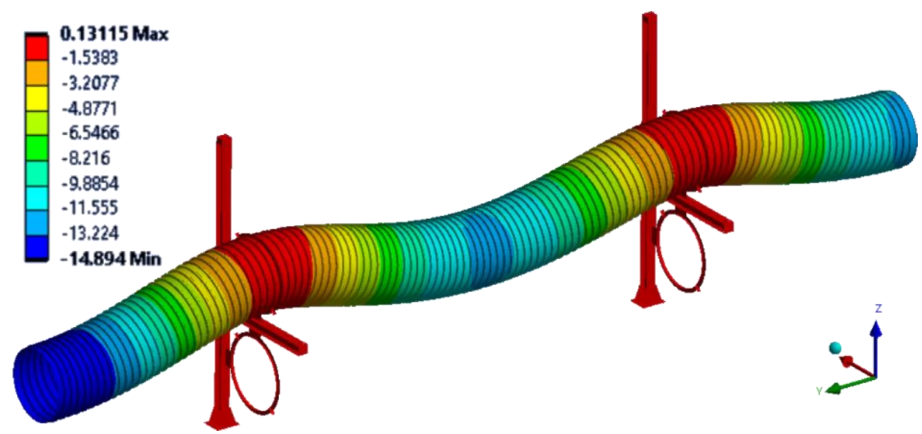


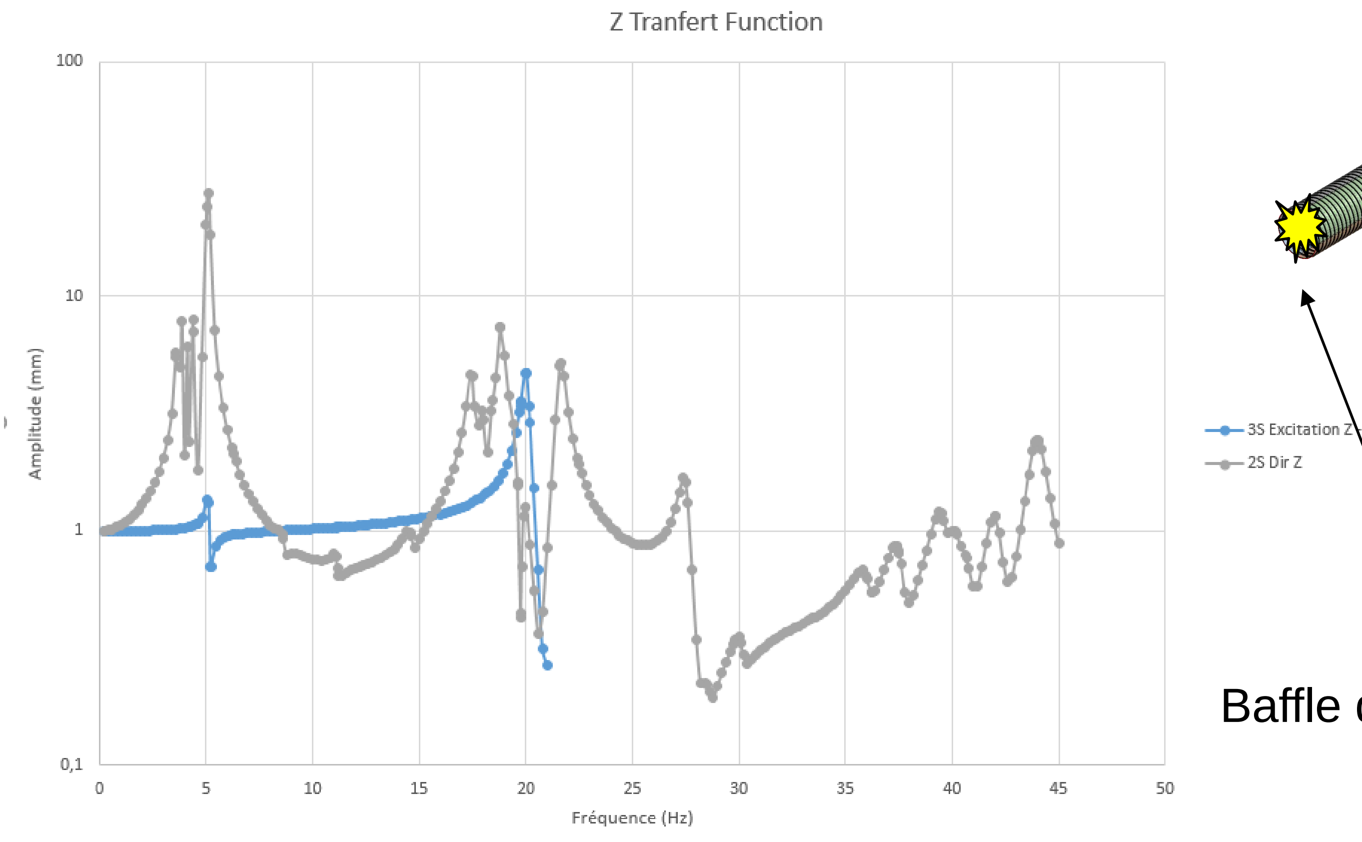
BONDED CONTACTS

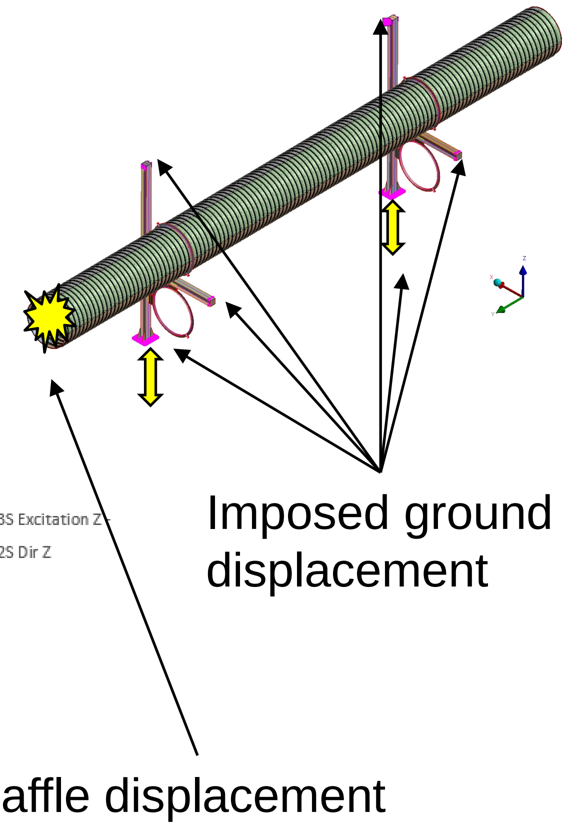
Loads :

- External pressure
- gravity







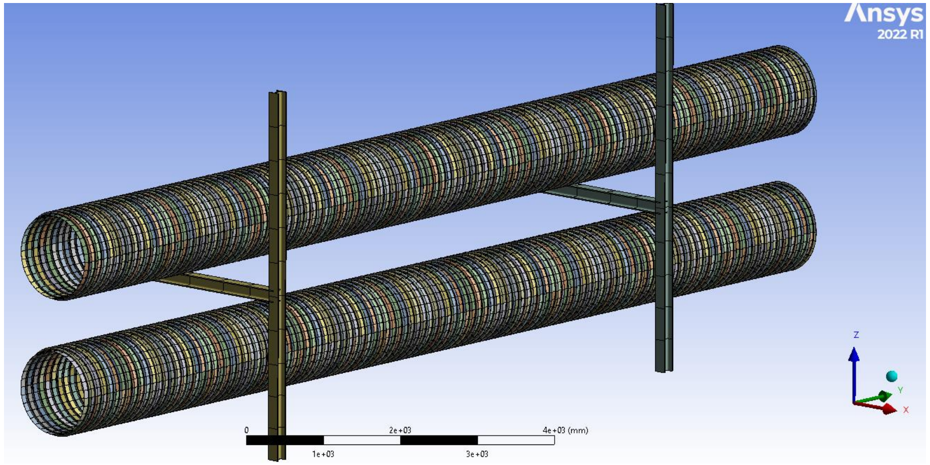


Vertical ground to baffle transfer function

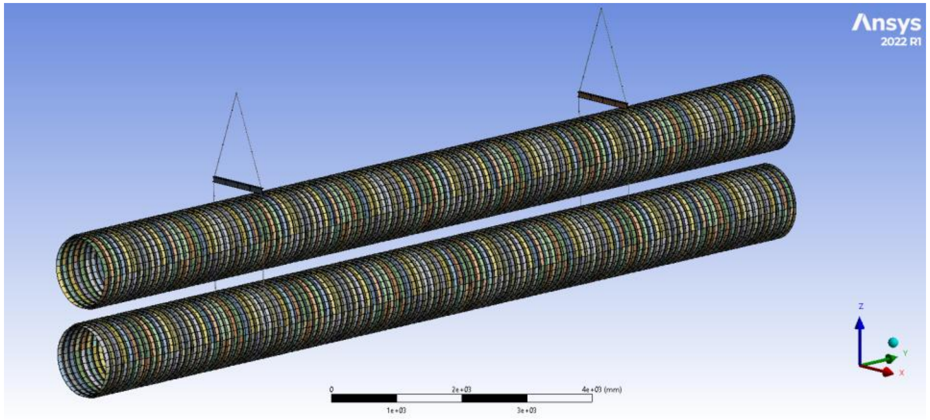
Similar curves in horizontal direction

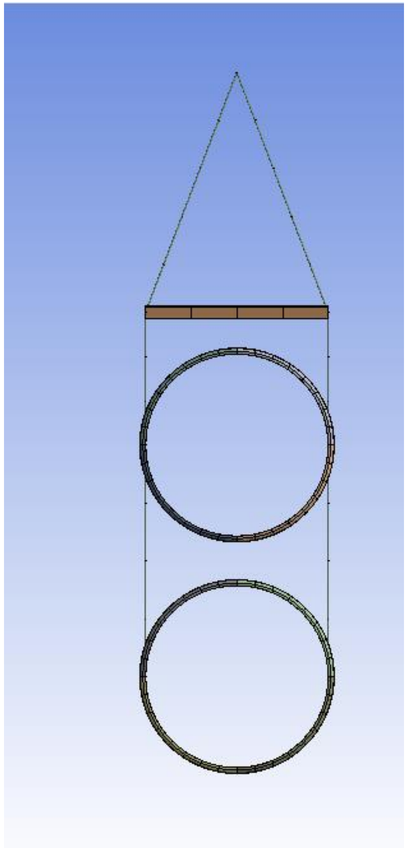
Simplified models, sufficient for comparison purposes

Rigid supports



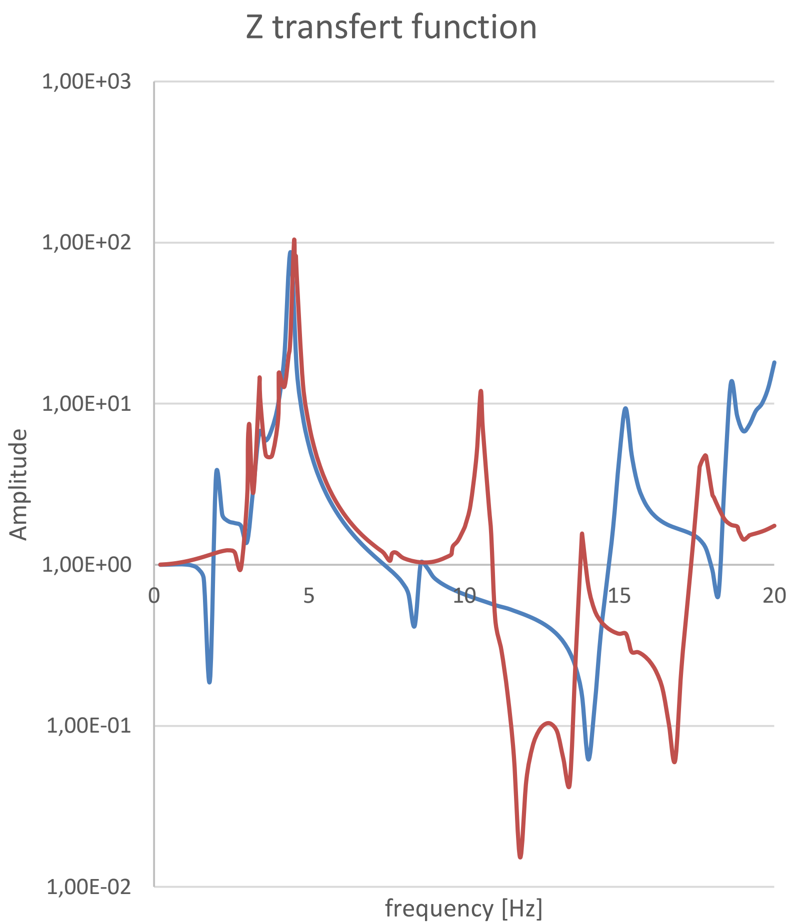
Suspended

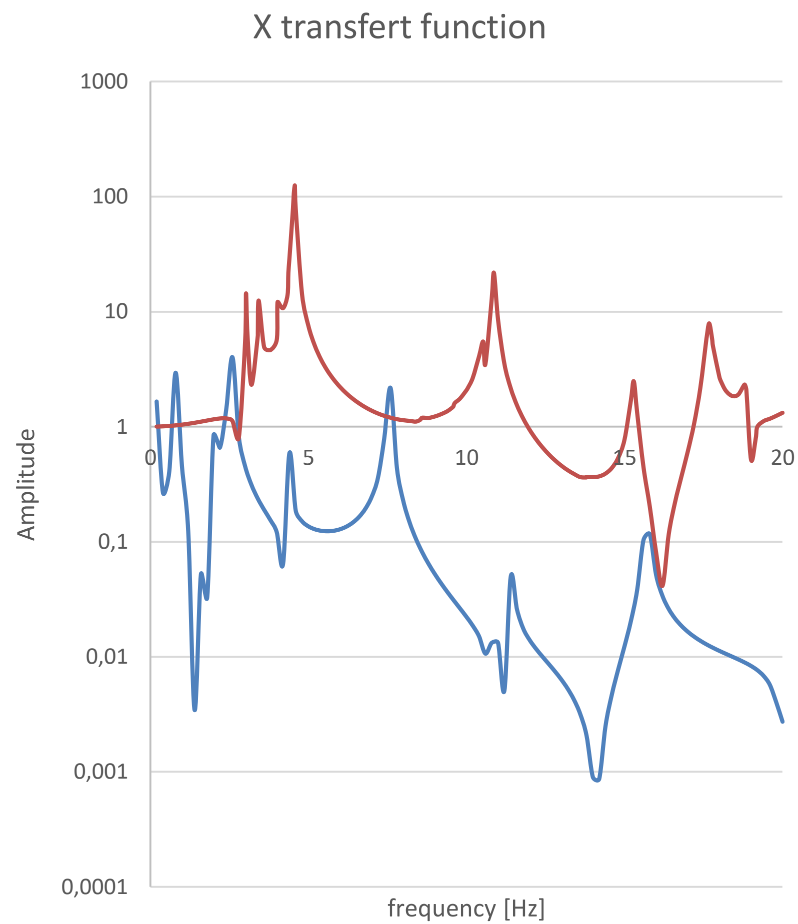




Supports position and tube concept being the same

Beams Vs suspended comparison

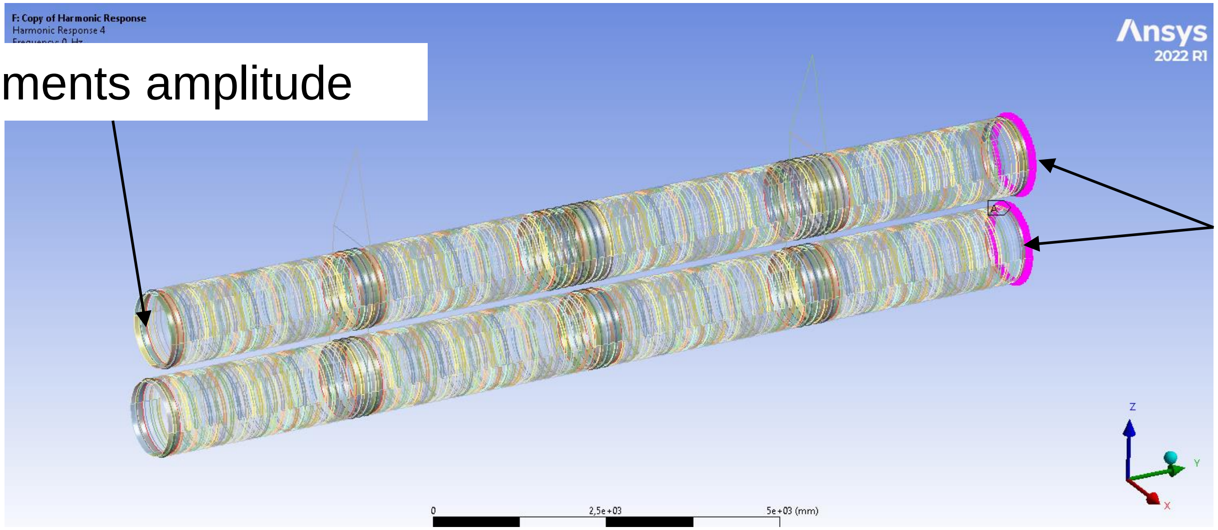




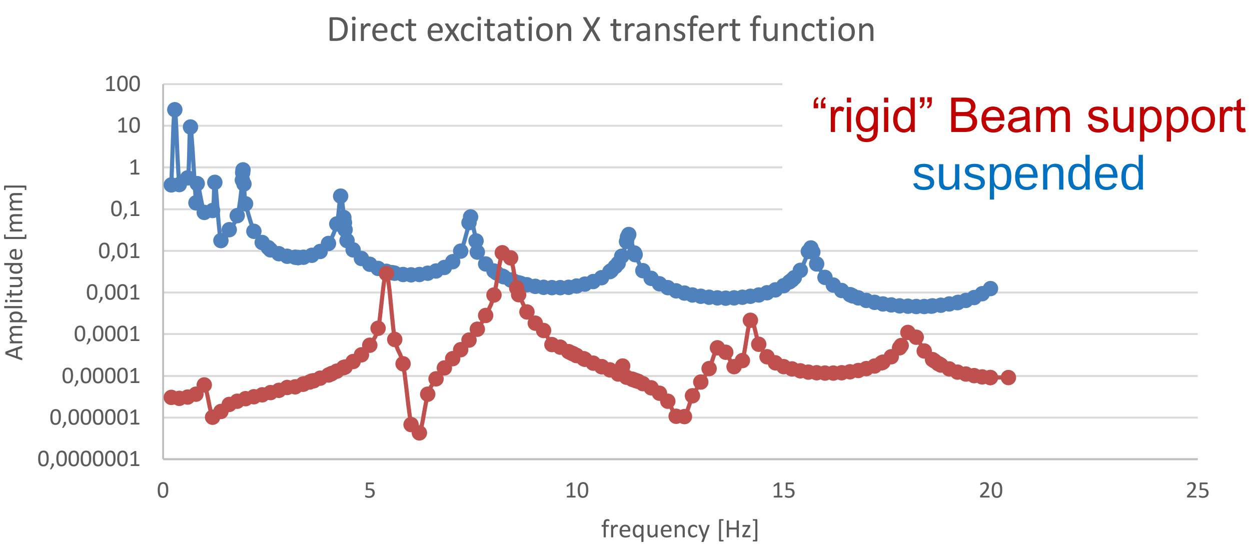
"rigid" Beam support / suspended

Direct force excitation

Displacements amplitude



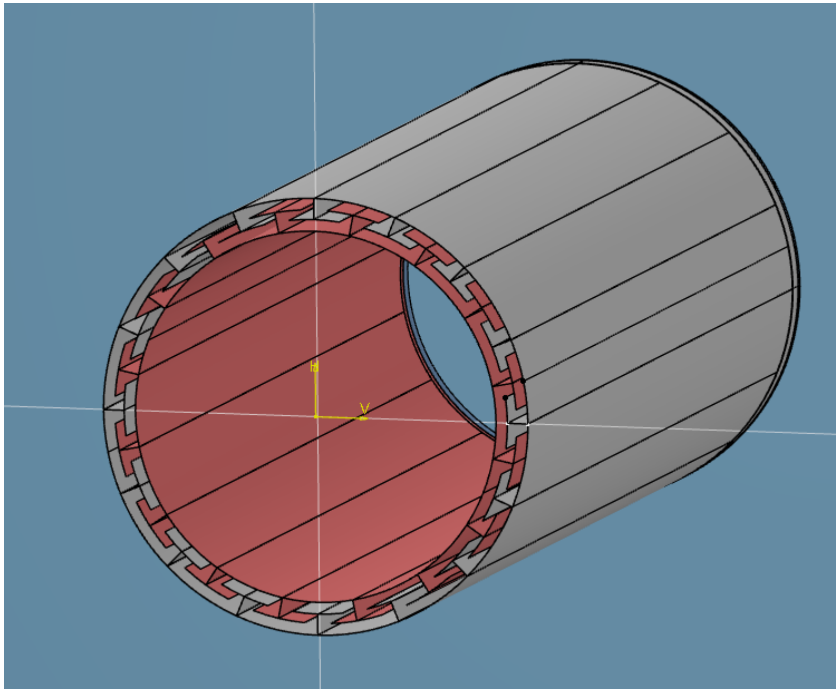
Excitation forces :
X =1N
Z = 1N

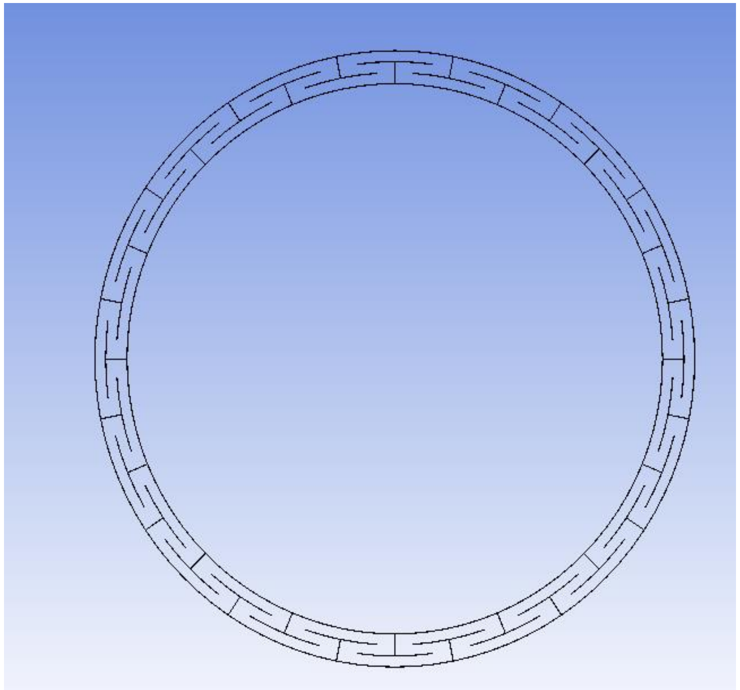


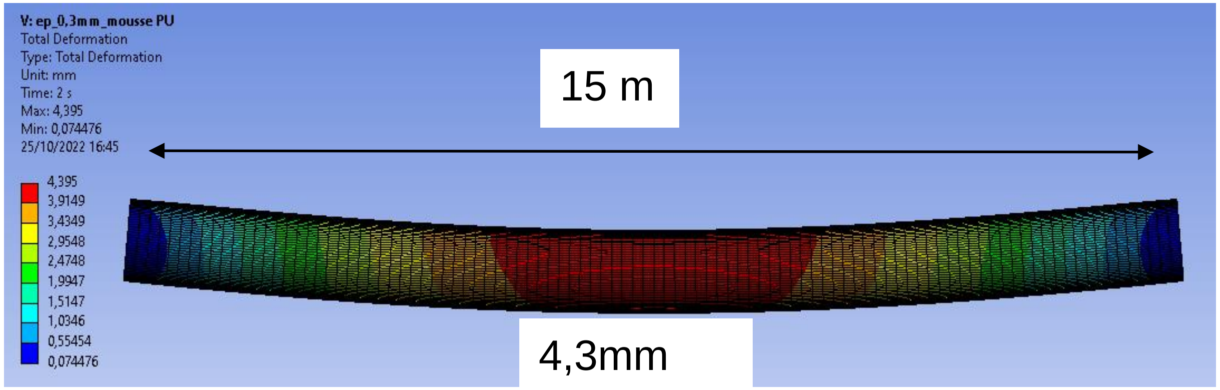
Suspended solution more sensitive to direct force excitation on tube

<u>Two concentric stiffened tubes :</u>

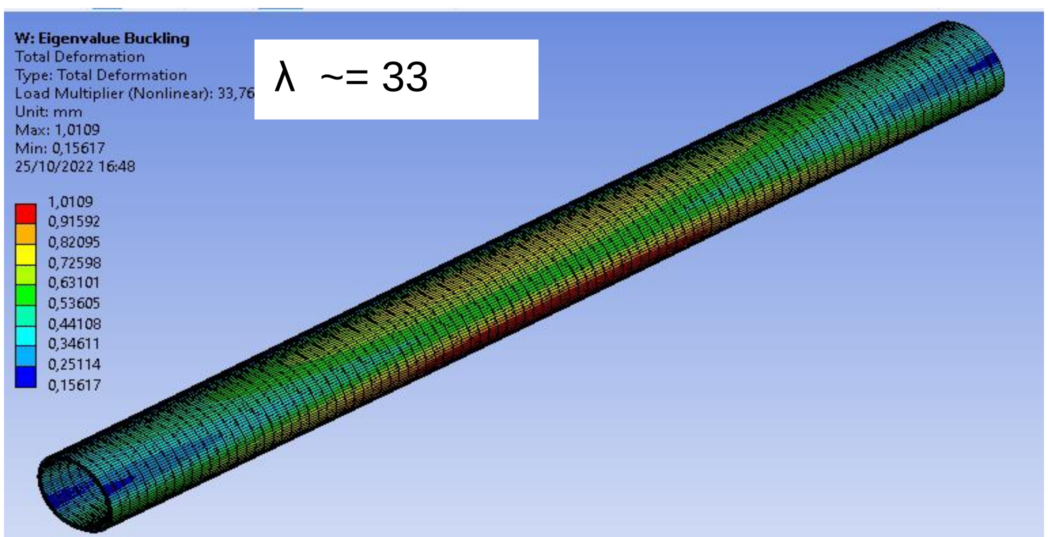
- thickness 0,5 to 0,3mm
- Coupled thanks to injected filler material (PU Foam, glass foam, …)







Simply supported at both end (remote displacement)



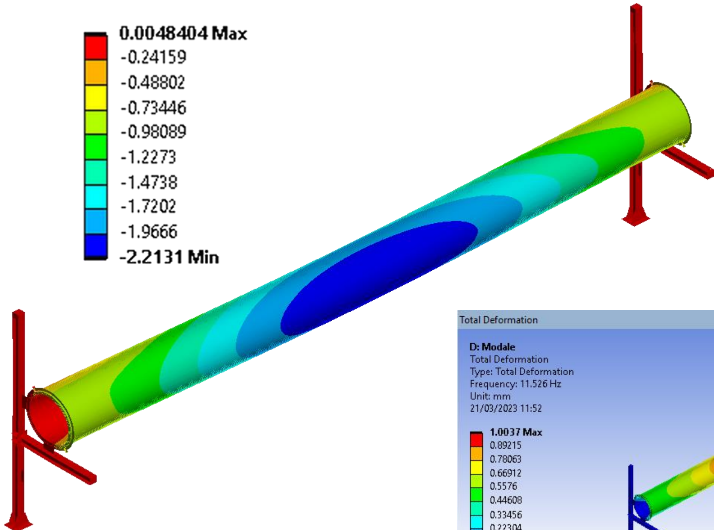
First buckling mode(without compression load & initial imperfection)

First Eigen frequencies

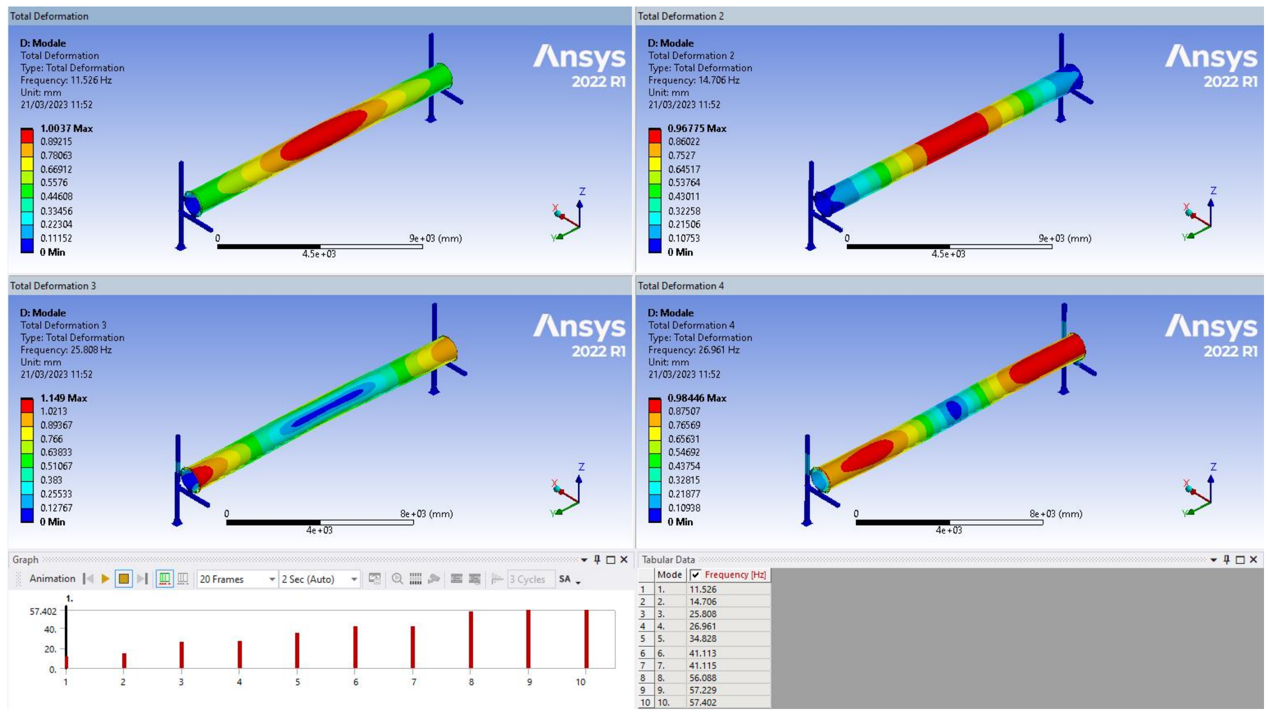
Tabular Data

	Mode	Frequency [Hz]
1	1.	7,5704
2	2.	8,6288
3	3.	24,325
4	4.	25,705
5	5.	48,491
6	6.	50,118

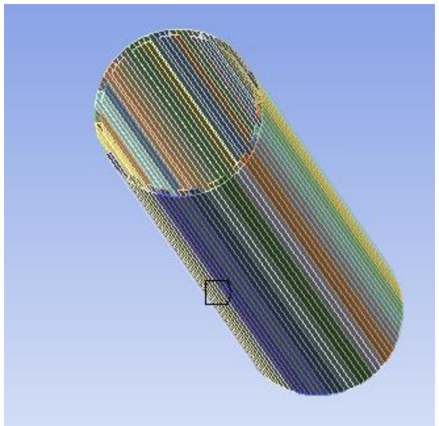
Work is ongoing to develop in further details this concept

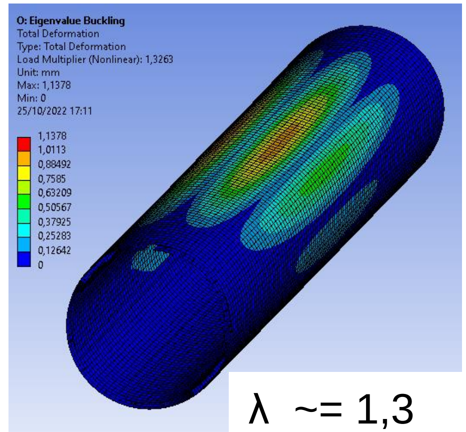


	Mode	Frequency [Hz]
1	1.	11.526
2	2.	14.706
3	3.	25.808
4	4.	26.961
5	5.	34.828
6	6.	41.113
7	7.	41.115
8	8.	56.088
9	9.	57.229
10	10.	57.402



External tube supported underneath



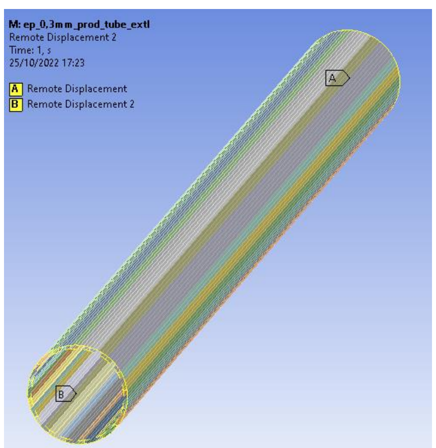


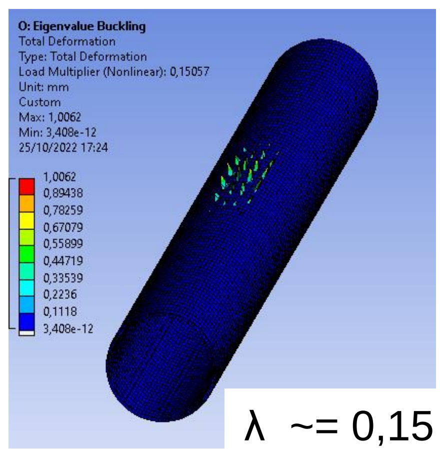
λ ~= 1,3

First buckling mode
under self weight

Comfortable safety margin

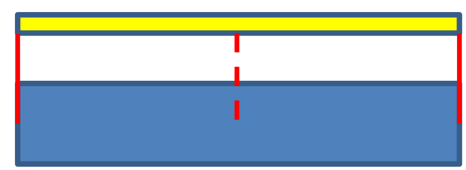
Tube supported at both ends





λ ~= 0,15

Low safety margin
Third central sling mandatory

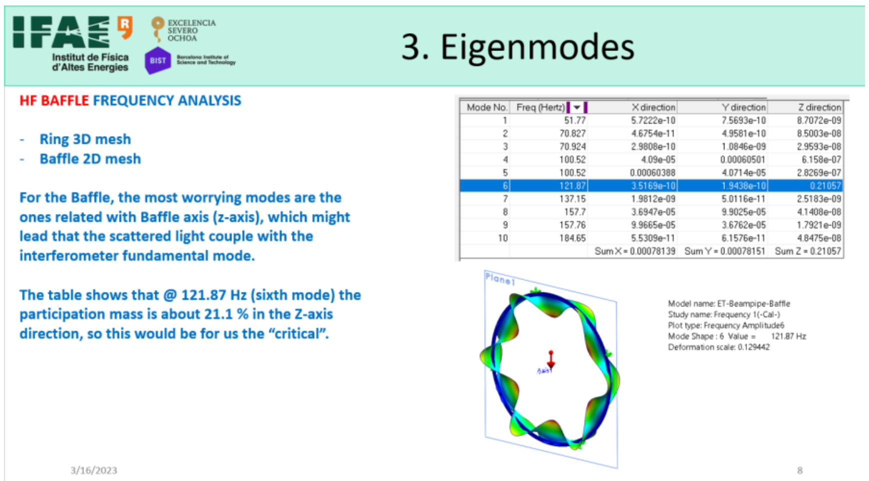


Producibility of such concept is probably be the critical point

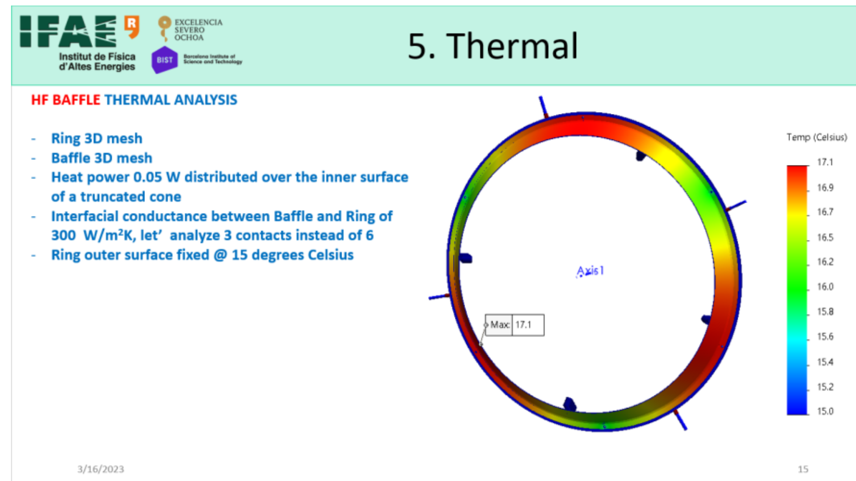
IFAE

IFAE activities for ET beampipe

IFAE is in charge of designing the ET beampipe baffles. Conducting modal and thermal analysis on the ET beampipe baffles to ensure optimal performance and prevent any potential disturbances in the instrument. By designing and analyzing the baffles, IFAE aims to verify that they meet the required specifications and operate seamlessly without impacting the overall functionality of the instrument



Mode No.	Freq (Hertz)	X direction	Y direction	Z direction
1	51.77	5.7222e-10	7.5693e-10	8.7072e-09
2	70.827	4.6754e-11	4.9581e-10	8.5003e-08
3	70.924	2.9808e-10	1.0846e-09	2.9593e-08
4	100.52	4.09e-05	0.00060501	6.158e-07
5	100.52	0.00060388	4.0714e-05	2.8269e-07
6	121.87	3.5169e-10	1.9438e-10	0.21057
7	137.15	1.9812e-09	5.0116e-11	2.5183e-09
8	157.7	3.6947e-05	9.9025e-05	4.1408e-08
9	157.76	9.9665e-05	3.6762e-05	1.7921e-09
10	184.65	5.5309e-11	6.1576e-11	4.8475e-08
		Sum X = 0.00078139	Sum Y = 0.00078151	Sum Z = 0.21057



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BIST Barcelona Institute of Science and Technology

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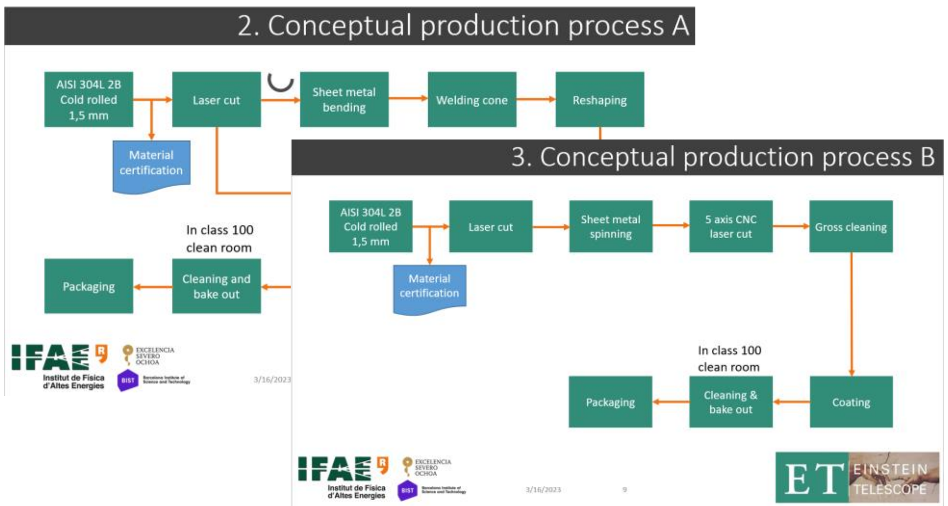
IFAE activities for ET beampipe

IFAE is also researching a mass production process for the ET beampipe baffles that satisfies the required technical specifications, cost-effectiveness, and ultrahigh vacuum (UHV) compatibility. This initiative aims to develop a feasible method for producing the baffles in large quantities while maintaining the necessary quality standards.



Welded + sheet metal bending

or

sheet metal spinning

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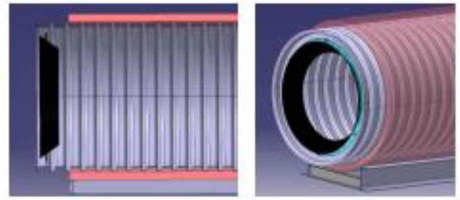
Some identified key points

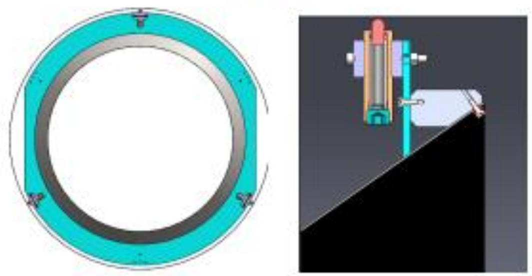
Baffle integration

- 2 options proposed by IFAE



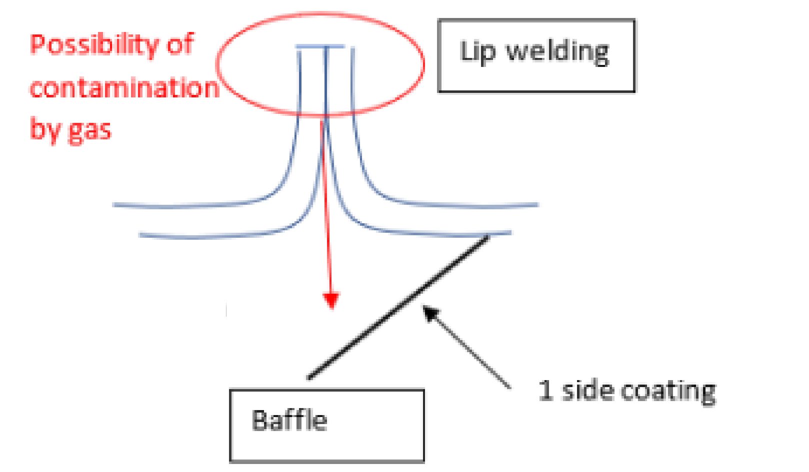
1. Fixed to beampipe inner ring (welding)

2. Fixed to beampipe inner wall (spring)



Baffle weight is ~12 Kg

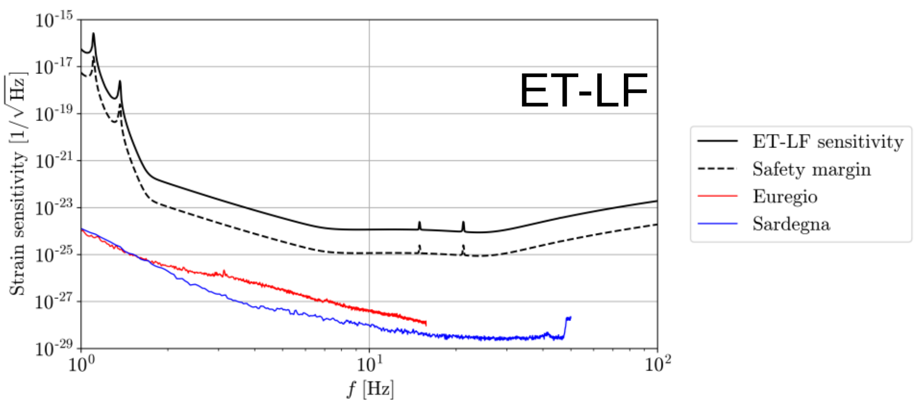
- Critical frequency: 1-100Hz.
- Lateral vibrations more critical than vertical ones.
- Possible contamination of baffles during welding to be assessed.
- Waiting for the vibration transfer function requirement (ground to baffle), to decide in which direction to go for the supporting system.

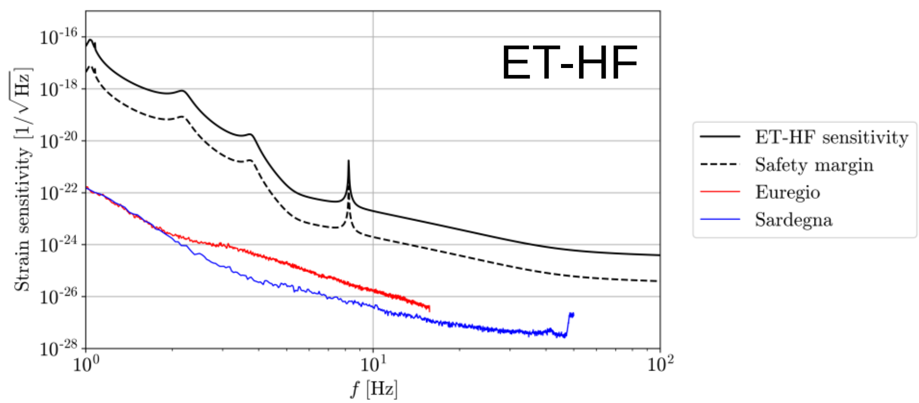


IFAE activities for ET beampipe

IFAE used analytic calculations and SIS simulations to evaluate important aspects of ET-HF & ET-LF

- Determine layout of baffle positions along the main arms
- Determine the induced stray light noise in main arms as a function of parameters
  - Seismic noise levels, baffle optical characteristics, mirror maps, wavelengths, apertures, transfer functions
  - For the moment considering beam pipe diameters of 1.0 m and 1.2 m for ET-LF and ET-HF, respectively





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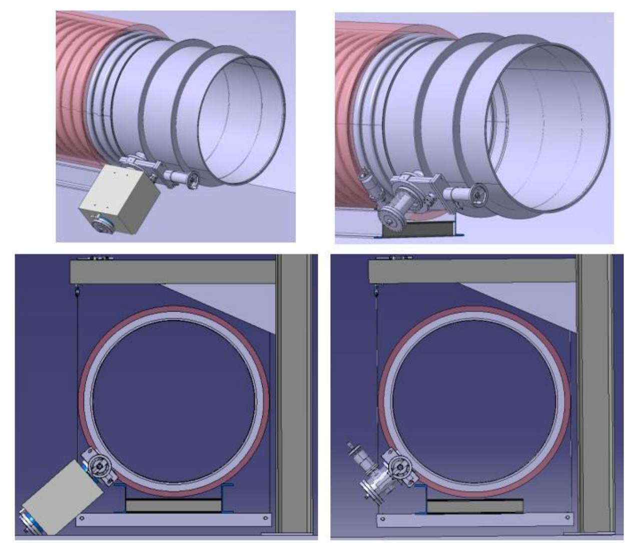
CONCLUSION

Conclusion 1/5

- Tubes boundary conditions :
  - Suspended solution :
    - Low pass filter for lateral basement excitation
    - Depending on wire stiffness Low pass filter for vertical basement excitation possible too
    - More sensitive to direct excitation (pumps, air flow , …)
  - Rigid connection through Supporting beams :
    - To minimize baffle vibrations it worth to put supports close to tube extremities
    - Less sensitive to direct excitation

Strong implications on :

- *pumping modules (mounting / decoupling)*
- *sector valves*
- *…*



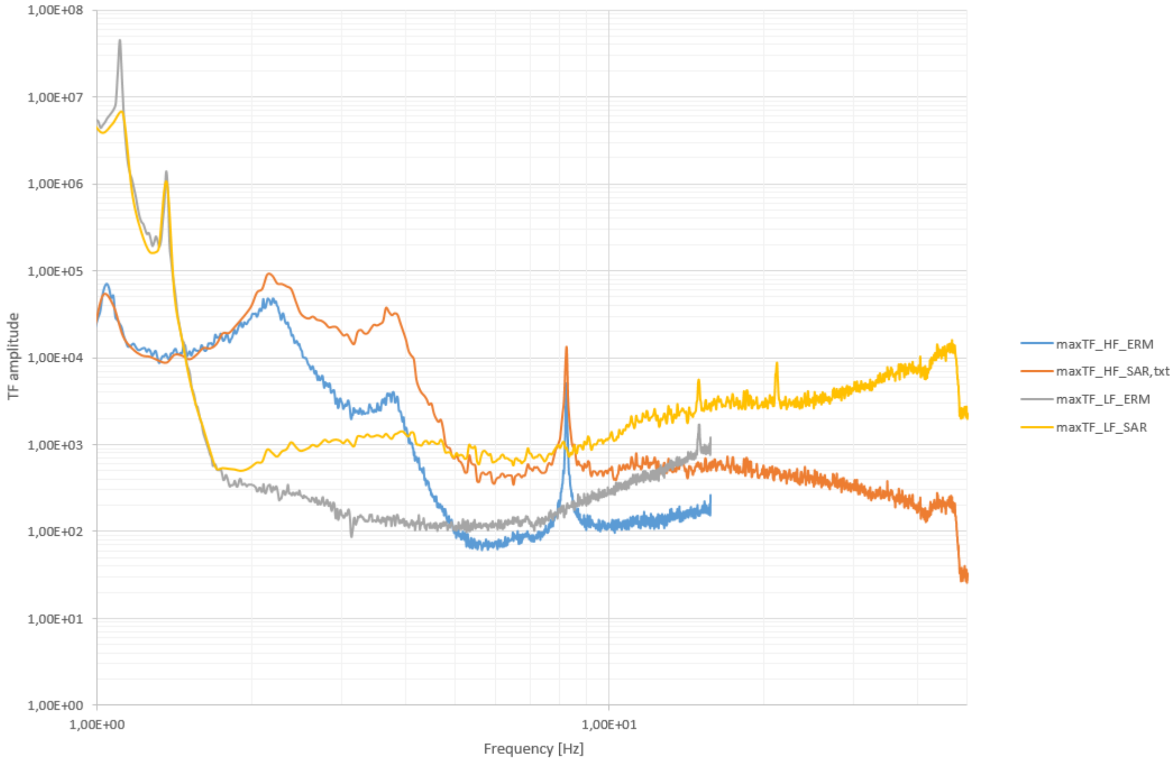
Tube concept comparison :

- Virgo ‘s tube scaling
  - Well known solution
  - Large quantity of stainless steel
- Corrugated solution :
  - Study is well advanced, prototyping on going
  - Minimization of stainless steel necessary
  - Relatively soft tube, no need of below
  - Necessity to invest more in supporting
- Double tube sandwich :
  - Concept seems to be interesting in terms of performance
  - Stiffer tube / corrugated :
    - Less support structure needed
    - Axial deformation compensation parts to be integrated
  - Fabrication is not straight forward : to be investigated in details

Stainless steel mass comparison	
solution	mass [Kg/m]
Virgo scaling	137
Corrugated	49
double tube	49 / 29

Pipe itself, no supports, …

- Thanks to collaboration & visit to IFAE :
  - Better knowledge/ understanding of baffle & their integration :
  - We now have maximal admissible ground to baffle transfer functions
- baffle vibrations = only dynamic criterion for ET tubes ?

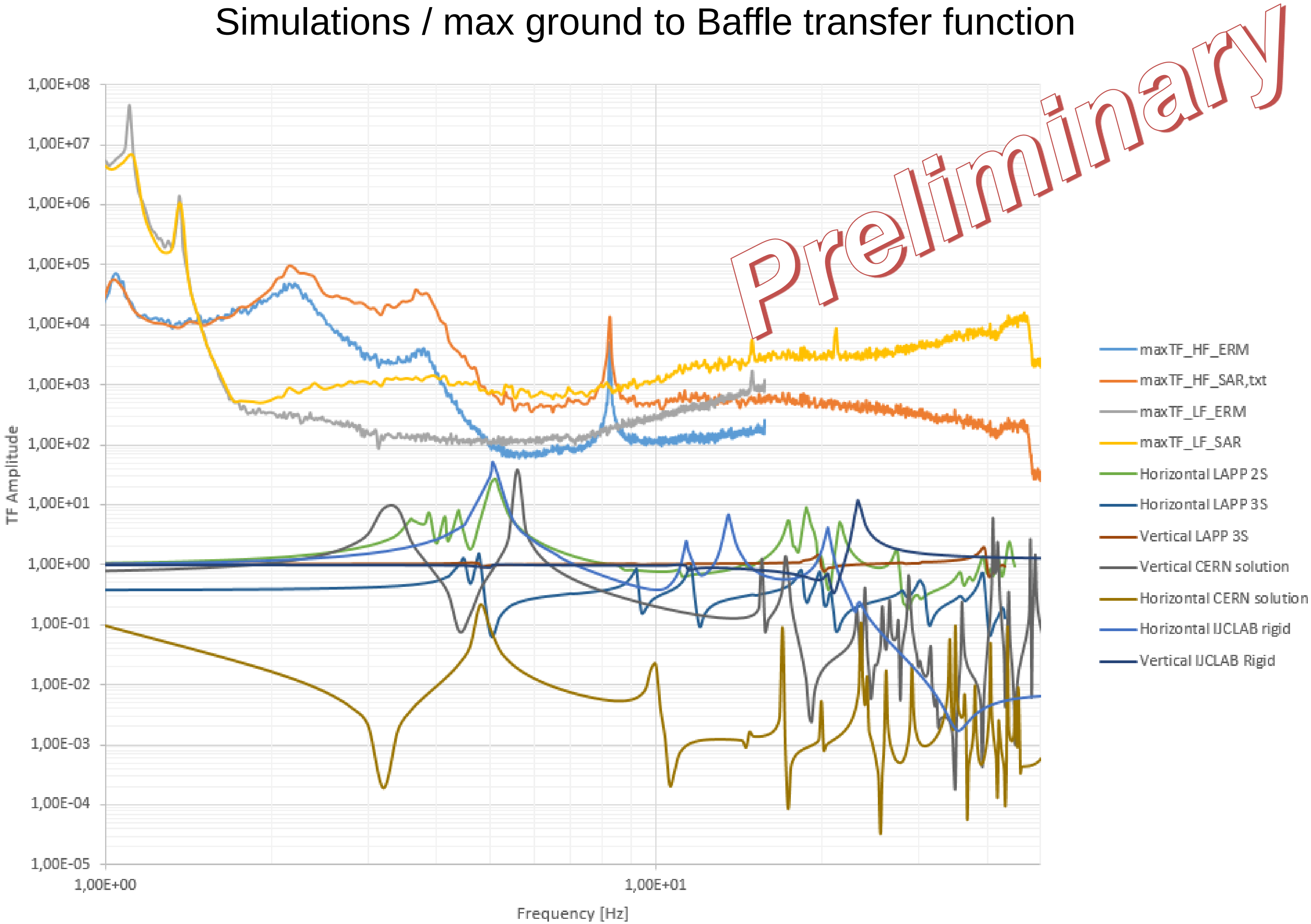


To be considered :

- for vertical ?
- for horizontal ?

In any case we have to address direct forces effects too

Simulations / max ground to Baffle transfer function



Conclusion 5/5

Others talks & Topical discussion foreseen during this meeting :

- Try to fix / confirm inputs for those study
- One 3 arms site / 2 x 2 arms sites
- Tubes diameter
- Possibility to install HF arm at first step and to complete with LF arm afterward
- Better knowledge of tunnel and integration constrains
- …

We should take advantage of those days to learn from each other & draw guidelines for furthers studies

THANKS