Cosmic Explorer

Beamtube Experiment (CEBEX):

Design proposal of tube supports, end caps, and pump port spools for CEBEX/CE

Cosmic Explorer (CE)-Einstein Telescope (ET) Beam Tube Workshop III
LIGO-CERN

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LIGO-G2502110

LIGO Hanford Observatory, Richland, Washington, USA

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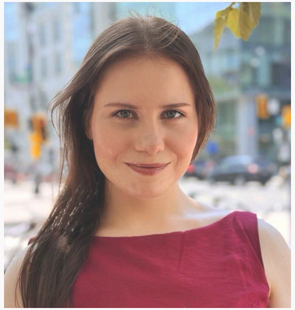
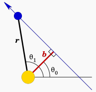
Introduction



Anna Iudintseva (AI)
Mechanical Engineer – CEBEX, Caltech

- LIGO Hanford, WA
- CEBEX engineering
- Space Systems engineering background (Russia and the US)
- Parametric design of supports, end caps, spool pieces for CEBEX



Today is 3 months since my 1st day at LIGO!

Summary

- Design requirements and decision points for CEBEX

- LIGO reference

- Update on the SolidWorks CAD models *parametric design*:

1. End Caps
2. Spool pieces for the pumping instrumentation
3. Supports for CEBEX

- Ongoing and future work

- Things to keep in mind and consider for CE

Credits and Acknowledgement

CEBEX technical team: Michael Zucker, Dennis Coyne, Janos Csizmazia, Alberto Franco-Ordovas, Jon Feicht, Jan-Carlo (JC) Sanchez, Albert Lazzarini – *design requirements, mentorship*

LIGO Hanford staff: vacuum team – *training me on the LIGO systems*, facilities team – *CEBEX building*, CE researchers – *discussions of the real-life integration and feasibility*, administrative team – *CE site discussions, navigating diplomacy, and supporting my outreach initiatives*

CEBEX design background

CEBEX: goals, design requirements, and considerations

The project goal: to mimic a subsection of the 80 km long Cosmic Explorer system by testing a 110 meter-long UHV beamtube w/ instrumentation & bakeout at LIGO Hanford as a proof-of-concept to reduce the cost of manufacturing.

Major milestones:

- Construct the beamtube at LIGO
- Test the technology
- Make the CE-scale decisions

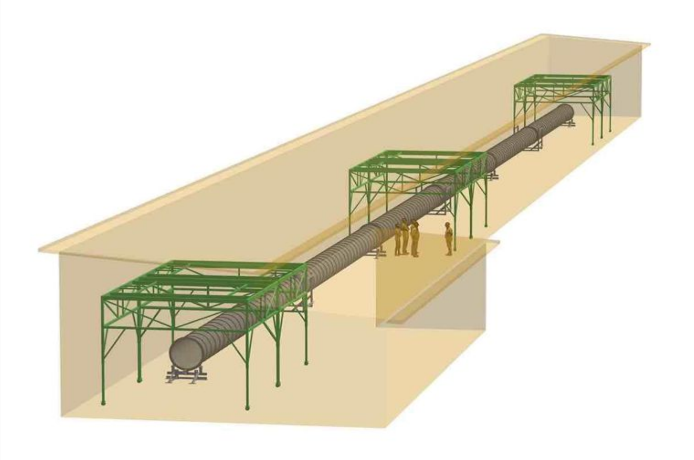
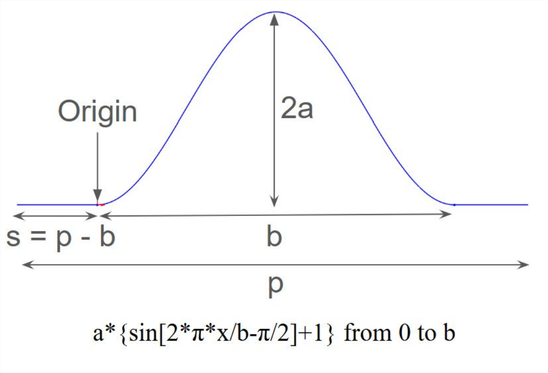


Figure 1. – CEBEX project concept [LIGO-G2402499]

Corrugated BT (base) idea

- **Sine Corrugations** are chosen to increase the moment of inertia of the tube, eliminating the need for ring stiffeners, and to account for the thermal expansion.

- **304/304L** is being used for modelling since it has the lowest yield stress, other materials can be analyzed later on.



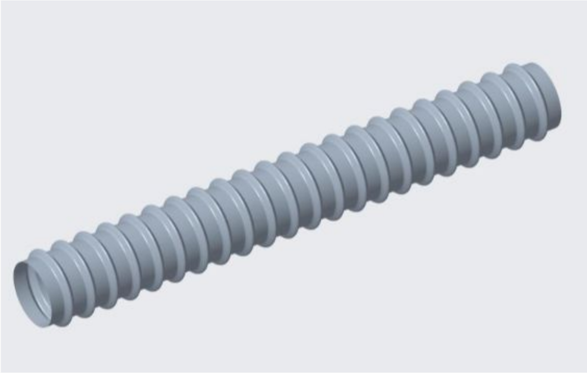


Figure 2. a - sine corrugation function, b - a 10 m tube section model [LIGO-G2500320]

Parametric Design Definition

The way of developing CAD models with an opportunity to change *any geometric parameter* without re-creating the model.

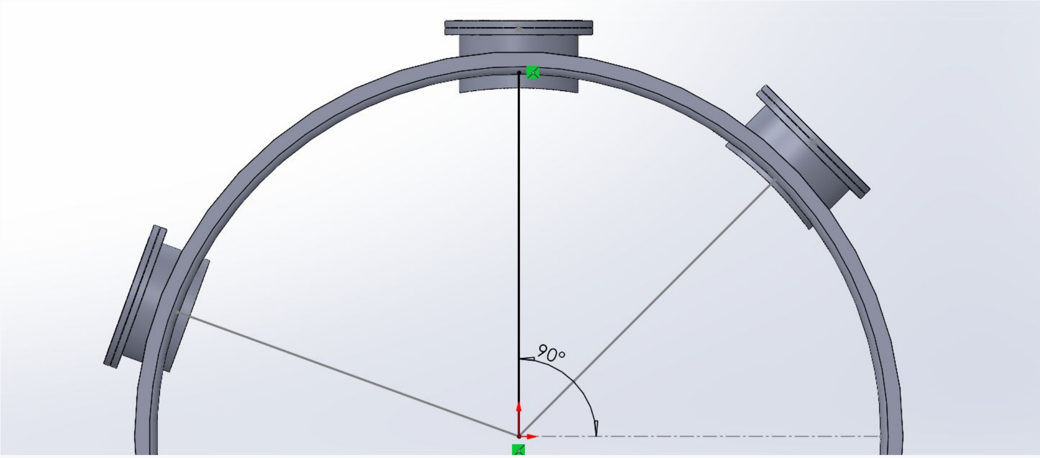


Figure 3. — Spool SolidWorks model with an adjustable ports positioning

1. End Caps

General decisions drivers and requirements

1. **Geometry and thickness:**

- **Thinner** the material = easier to bake it out
- **Simple enough shape for manufacturing**

2. **Material:** 3 options and 1 question: do we care about H_2?

3. **Parametric design:** geometry, orientation

4. **Ports positioning:** in alignment with the instrumentation requirements

1. Shape

Torispherical End Cap (model) vs Septum Plate (LIGO)

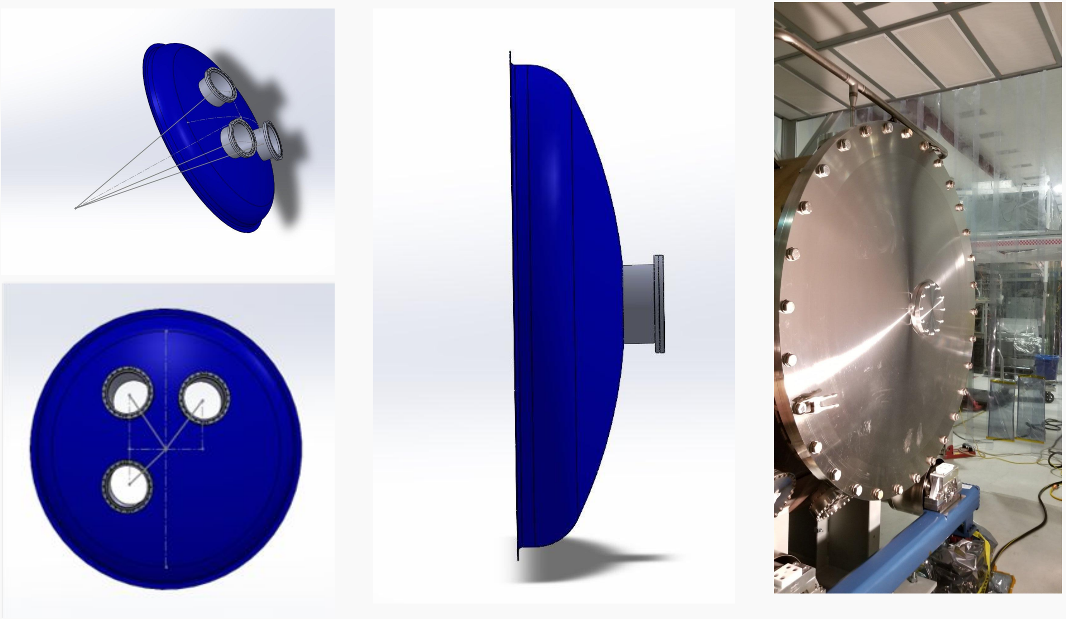


Figure 4 a,b,c – toripsherical SolidWorks model;

d – a photograph of the LIGO septum plate

Shape: The torispherical geometry [Figure 4- a,b,c] minimizes membrane stresses, enabling ***reduced wall thickness*** compared to a flat septum plate as shown on the Figure 4 - d.

This lowers thermal mass and diffusion path length, ***improving hydrogen degassing*** *efficiency* during bakeout.

> *If low residual H_2 content is critical*, the torispherical end cap can be depleted prior the welding.

2. Material

Table 1 – Material comparison for the end caps

Material	Thickness	H_2 contamination	Structural Additions
304 L Stainless Steel (same as BT)	low (~3 mm)	low H_2	strengthening ribs required
304 L Stainless Steel (same as BT)	thick (10+ mm)	high H_2	no ribs
A36 Carbon Steel	thick (10+ mm)	low H_2	no ribs

An open question: do we care about H_2 contamination?

3. Parametric Design

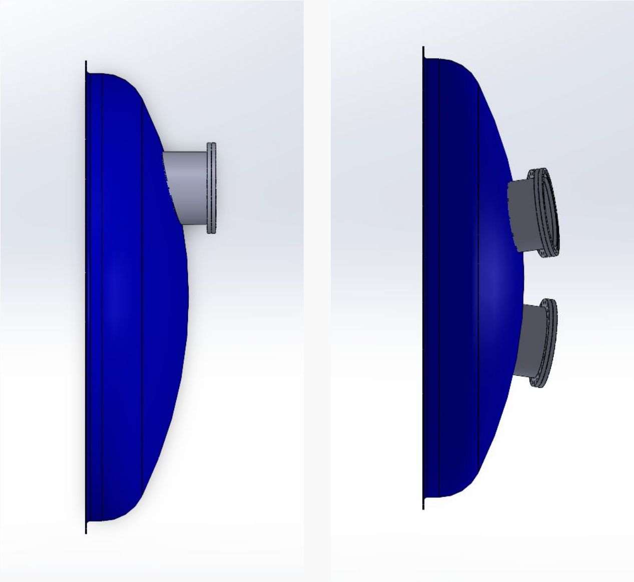


Figure 5 – 2 options of the ports positioning in a parametric model of the end cap
a) 90 deg (fixed) to the main plain
b) adjustable radial positioning

Variables/adjustable parameters:

- Positioning of the ports
- D of the ports
- Thickness of the walls
- Weld geometry

Ports positioning: radially aligned [Figure 5 – a] or parallel to the main plane [Figure 5 – b]

The final design depends on the **cost of manufacturing** and practicality.

4. Ports Positioning

Per vacuum instrumentation requirements:

- Top 12” CF flange for Turbo pump
- Side 10” CF for roughing + spare
- Side 13 ¼” CF for gauge + RGA equipment

[See Janos Csizmazia’s report on the instrumentation]

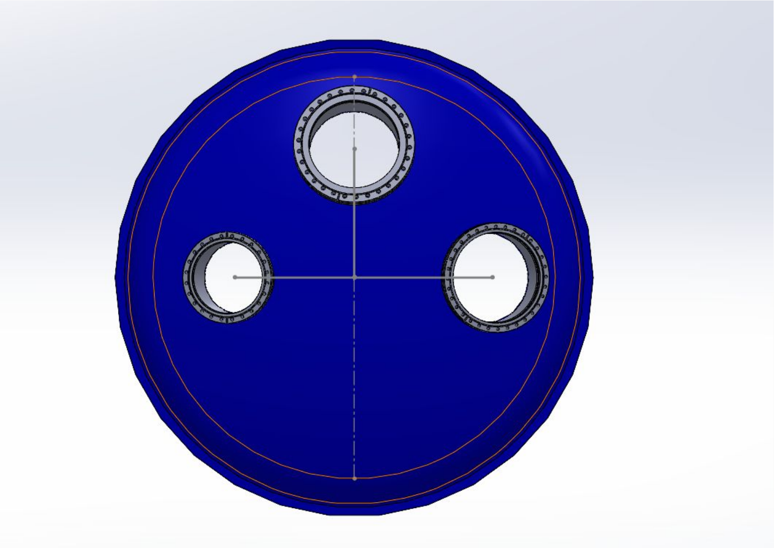


Figure 6 – toripsherical SolidWorks end cap model with 3 vacuum ports

2. Pump port spools

General decisions drivers and requirements

1. **Geometry:** same D as tubes
2. **Material:** same options apply as for the end cap
3. **Parametric design:** geometry, port orientation
4. **Ports positioning:** in alignment with the instrumentation requirements

3. Parametric design

Variables/adjustable parameters:

- Radial positioning of the ports
- D of the ports
- Thickness of the walls
- D of the tube
- Linear positioning of the ports (right/left along the tube)

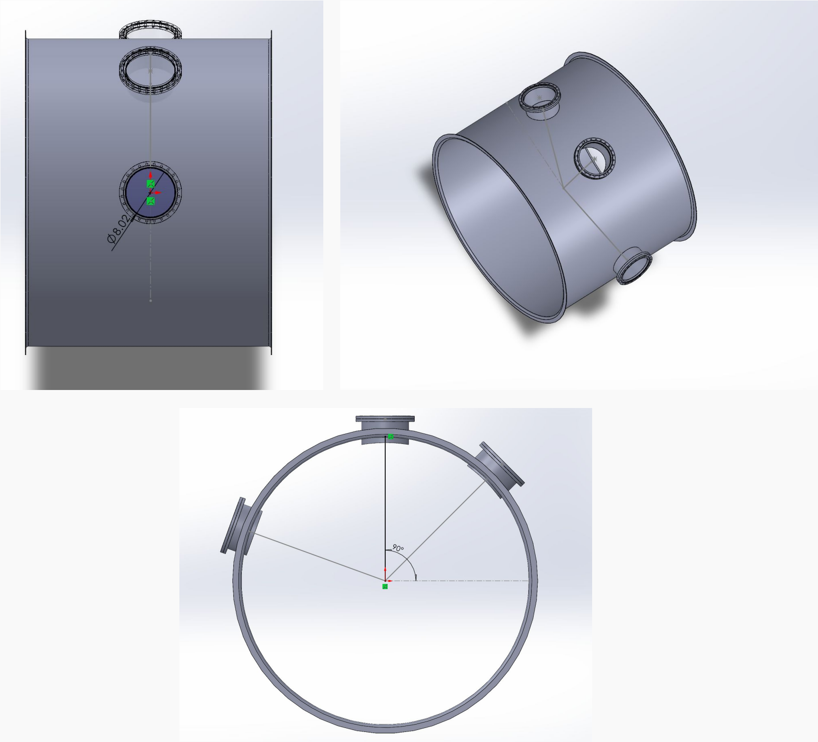


Figure 7 a,b,c – parametric SolidWorks model of the spool piece

4. Specific Ports positioning

Per vacuum instrumentation requirements:

- 10″ CF nipple on the top
- 13 ¼″ CF nipple on the left
- 12″ CF nipple on the right

[See Janos Csizmazia's report on the instrumentation]

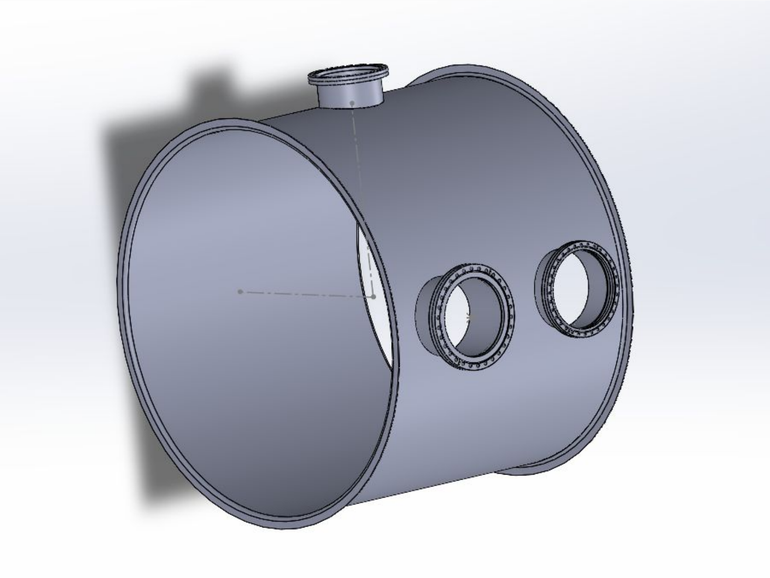


Figure 8 – SolidWorks model of the spool with 3 vacuum ports

3. Supports

LIGO beamtube supports

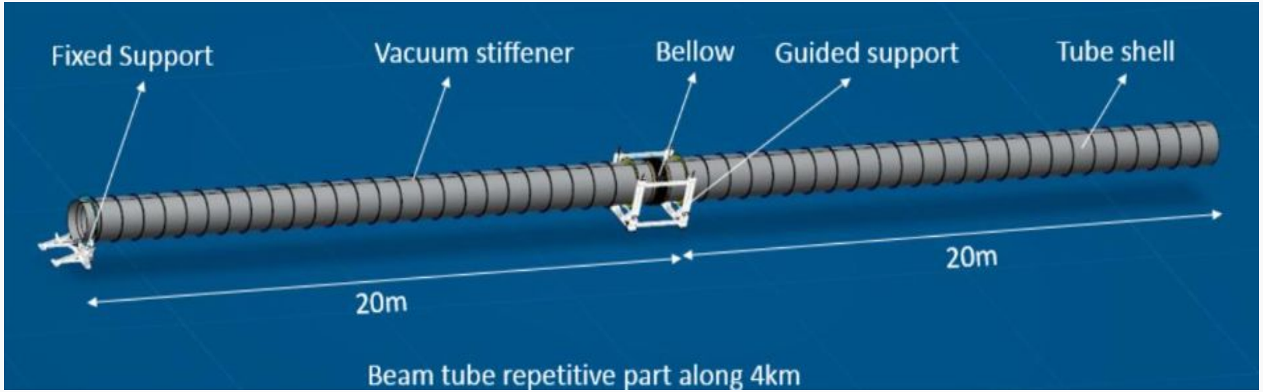


Figure 9 a – LIGO Livingston BT picture; b – 20+20 m LIGO BT section [LIGO- L2500049]

Each LIGO module (20+20m tube) contains:

- A bellow (not needed for CEBEX due to corrugated design on the slide #7)
- A **fixed support every 40 m**
- A **"guided" cable support every 20 m** [LIGO- L2500049]

General decisions drivers and requirements

1. **CEBEX assembly model:** spools+tubes+end caps

2. **Number of supports and spacing:** need for the Fixed and/or movable “guided” supports?

3. **Design priorities:** simplicity for manufacturing and degrees of freedom for the alignment

1. CEBEX assembly model

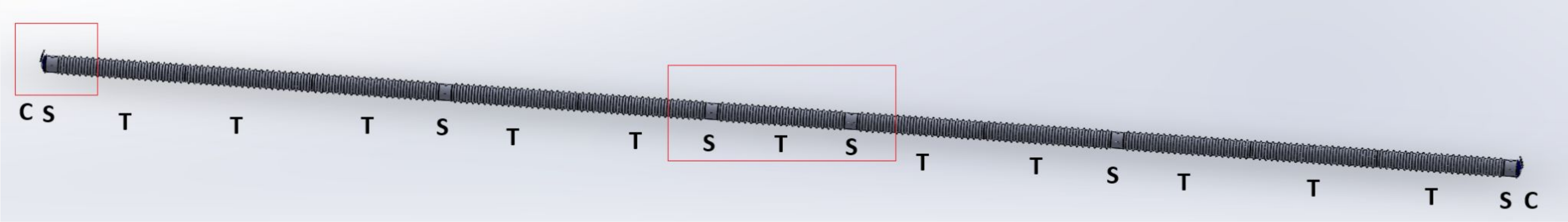


Figure 10 – CEBEX SolidWorks assembly model: spools+tubes+end caps [credits: Janos Csizmazia]

Sequence:

- CSTTTSTTSTSTTSTTTSC
  - C: torispherical end cap - 1 at each end
  - S: spool piece - 6 pcs. symmetrical
  - T: tube section, 10 m - 11 pcs. symmetrical

2. Number of supports and spacing

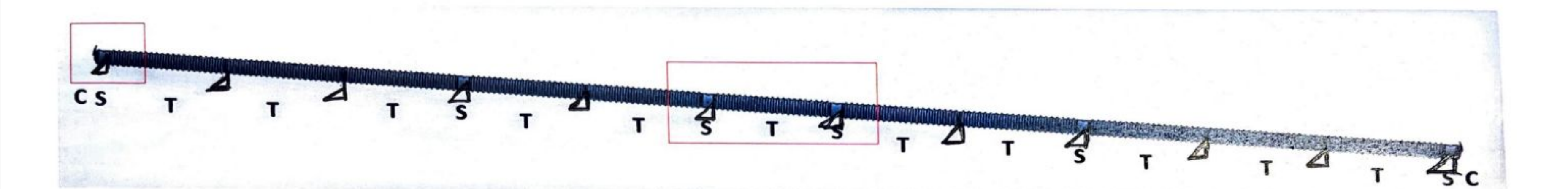


Figure 11 – CEBEX supports placement schematic

- Fixed supports **every 10 m** per Dennis Coyne's and Alberto Franco-Ordovas's axial forces and buckling analysis

- **No guided supports** [Figure 12] because the corrugations account for the thermal expansion

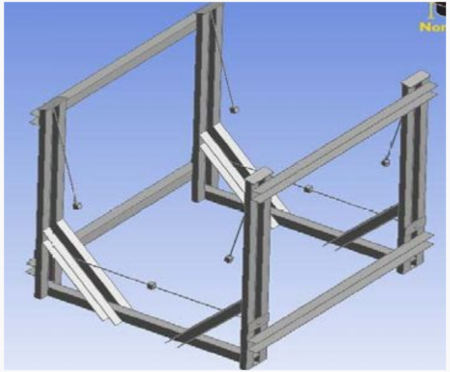
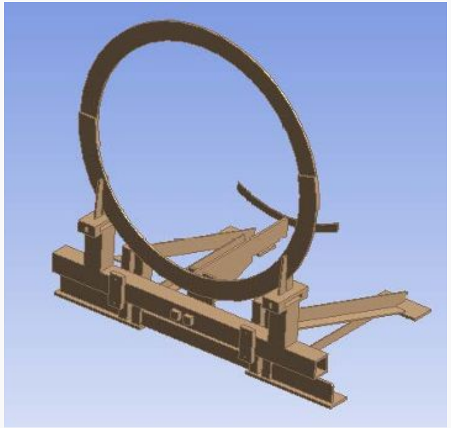


Figure 12 – LIGO Guided support model [LIGO-T1400698]

Parametric Design in progress



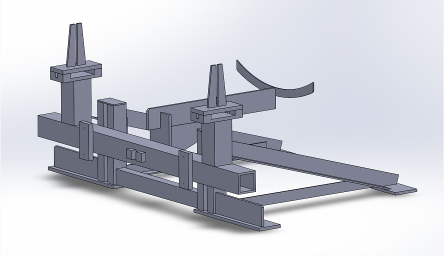


Figure 13 a,b – LIGO fixed support model [LIGO-T1400698]

- Referencing the LIGO fixed supports, the goal is to simplify the structure on Figure 13 to have less separate pieces while preserving the degrees of freedom for the tube alignment.
- Attached to the support ring at the center line (helps with the seismic and reaction forces)
- Prevents the potential “fisting” force at the support-ring joints
- Dimensions are adjustable

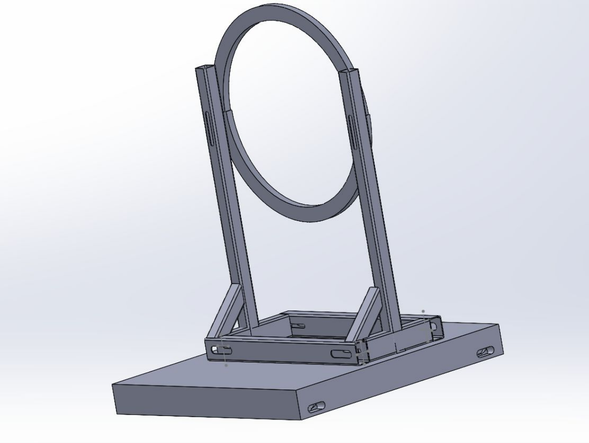


Figure 14 - conceptual CEBEX fixed support design in progress

Ongoing and Future Work

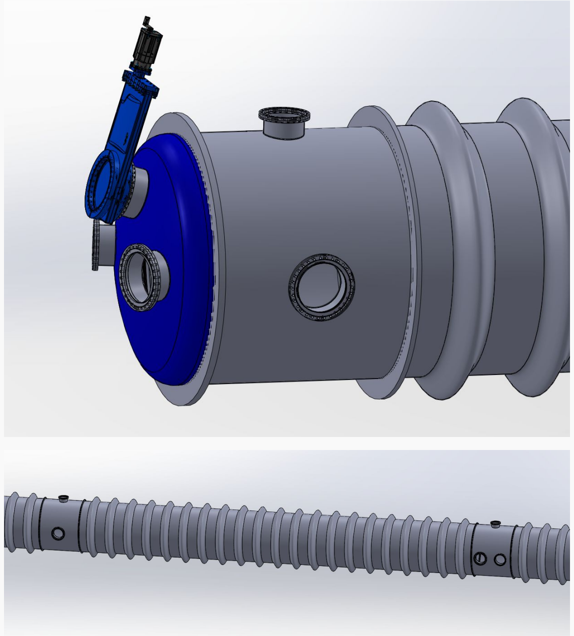


Figure 15 – SolidWorks assembly of the end cap + spool + instrumentation + the tube [credits: Janos Csizmazia]

- **End Caps:**

  1) H_2 requirement open question
  2) Stiffening features (ribs)

- **Spools:** material selection, similar to the End caps

- **Supports:**

1) Adding ports for DC Power Cables for the bakeout
2) Electric insulation pieces
3) Different steel profile assembly (L shape) to make it even lighter
4) Testing the mechanical integrity in ANSYS

Things to keep in mind for CE

Fun: Supports for the CE BT ends considering the Newtonian Noise

CE scientists' concern:

Newtonian noise – local gravity fluctuations/gravity gradient, do not affect the optics on the LIGO scale but are concerning at the CE scale.

"Small changes in the mass distribution of the environment surrounding the test masses — caused mainly by ambient seismic and atmospheric waves — accelerate the test masses and add noise to Cosmic Explorer's gravitational-wave readout"

Leading solution discussed: "**Soil excavation** is therefore suggested primarily for its ability to suppress gravity gradients sourced by Rayleigh waves"*.

= Digging a 10-meter hole under the ends of BT.

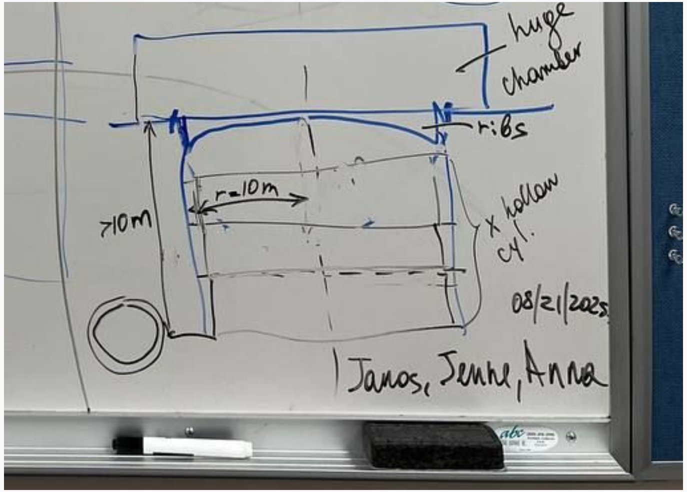


Figure 16 - Corridor white board doodle in collaboration with Jenne Driggers (CE, LHO) and Janos Csizmazia (CEBEX)

*CE–T2300010–v3

Contact Information

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