# CE/ET BEAMTUBE WORKSHOP III

Mechanical/Optical Design Options for Baffles

Marc **Andrés-Carcasona**, PhD
mandresc@mit.edu
Massachusetts Institute of Technology

24/08/2025

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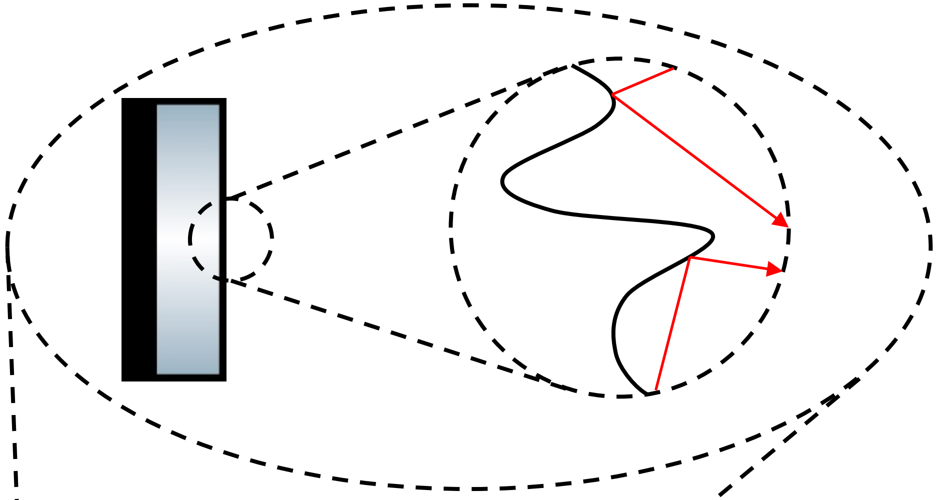
# INTRODUCTION

OVERVIEW OF THE TALK

# INTRODUCTION



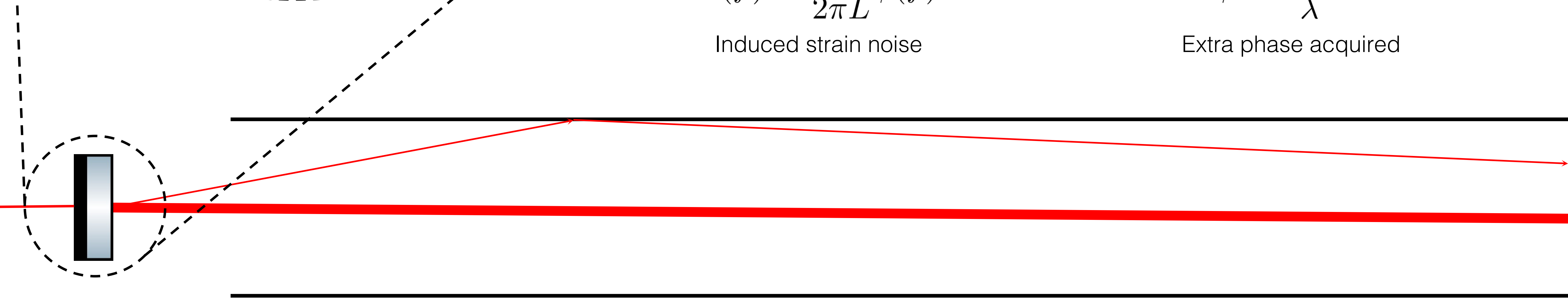
Scattered light is defined as all that light that instead of following the intended path, reaches some non-optical component, where it can interact and eventually recombine with the main beam. The strain noise generated by scattered photons is proportional to the spectrum of the extra phase acquired when following a different path than the one intended

$$\tilde{h}(f) = \frac{\lambda}{2\pi L}\tilde{\phi}(f)$$

Induced strain noise

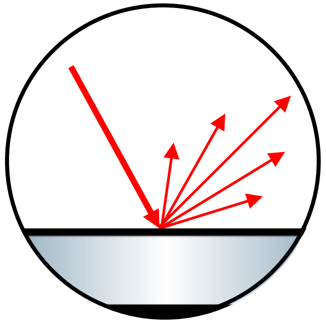
$$\phi = \frac{2\pi d}{\lambda}$$

Extra phase acquired

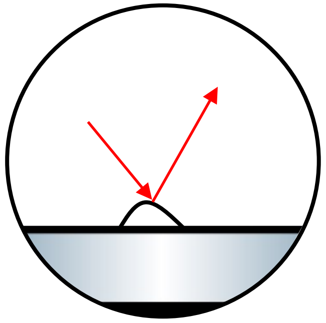


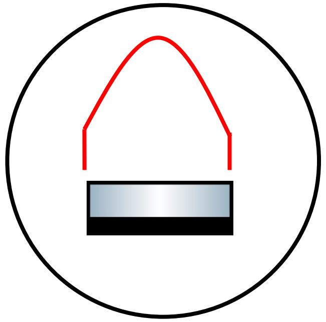
# INTRODUCTION

Surface imperfections

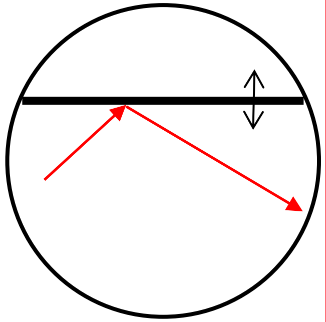


Thermal deformations

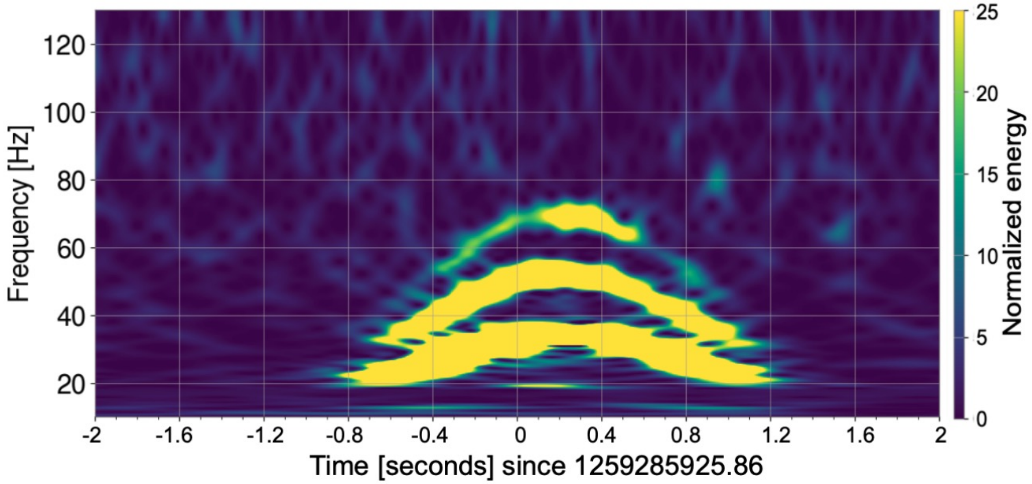


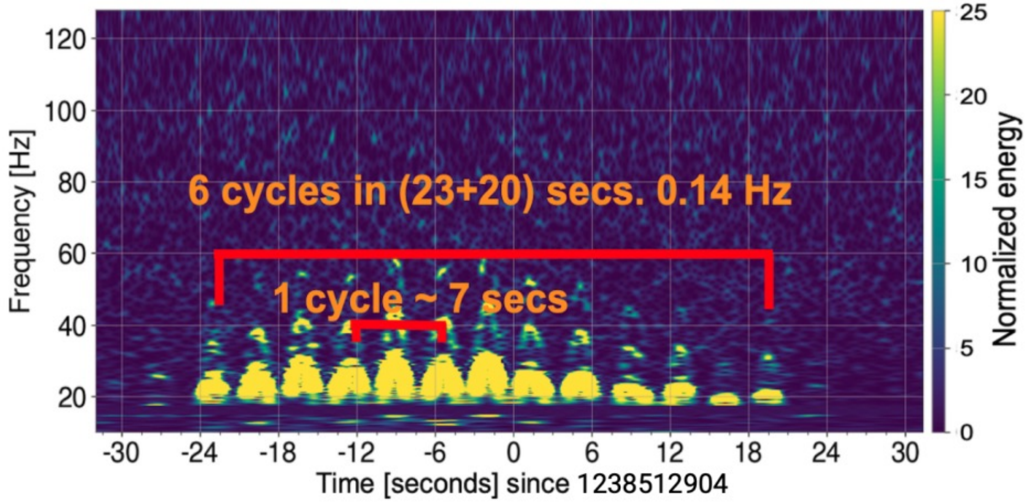


Finite mirror size



Vibrations of surfaces



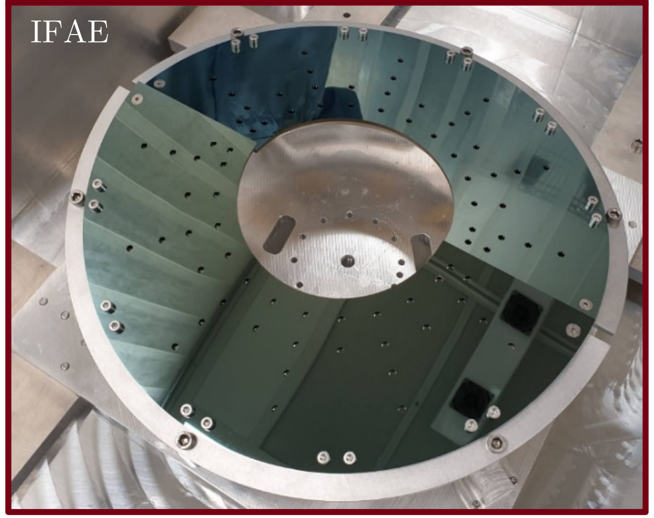



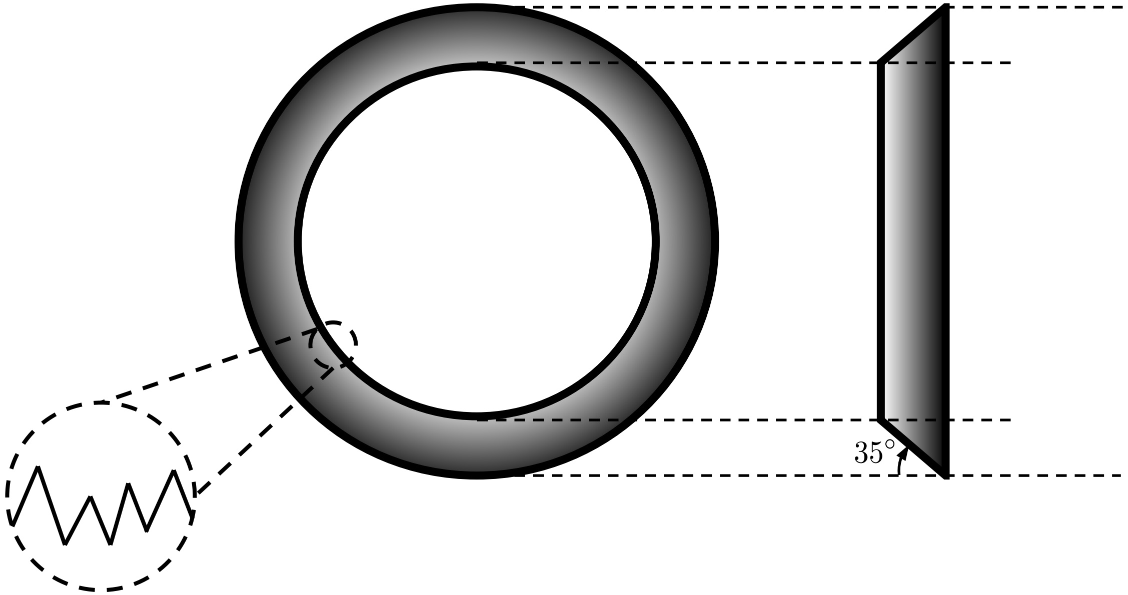

S. Soni, et al., CQG 38 025016

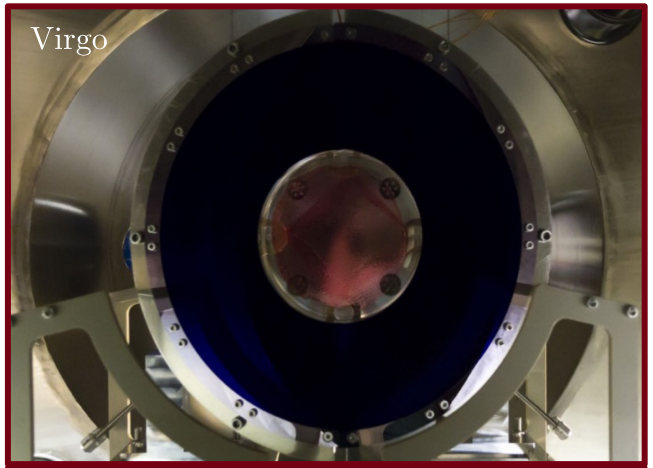
Some effective solutions include:

- ✦ Add baffles to absorb or redirect stray light.
- ✦ Improve the mirror coating and baffle/beampipe surface.

# INTRODUCTION


# SCATTERED LIGHT

SOME MORE DETAILS

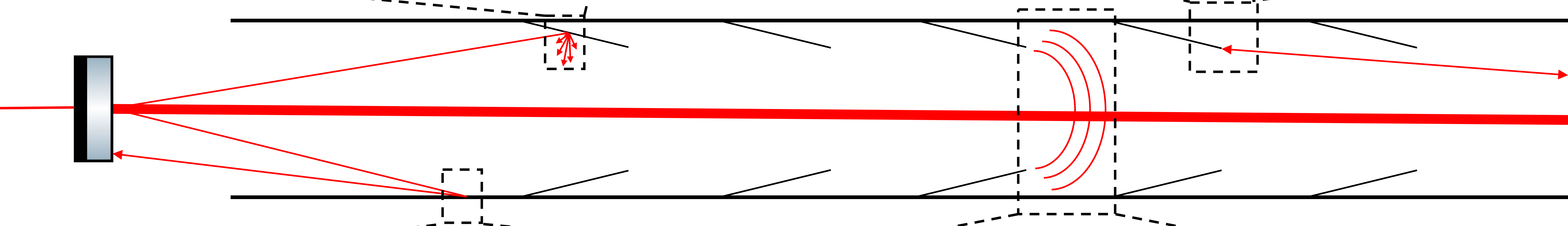
# SCATTERED LIGHT

### BACKSCATTERING

Light that upon reaching the baffle is scattered again reaching any of the mirrors

### BAFFLE EDGE BACKREFLECTION

The edges of the baffle can reflect the light back to the emitting mirror



### SHINING FACET

Any piece of highly-reflecting material

### DIFFRACTION

The finite aperture of the baffles will generate a diffraction pattern capable of affecting the sensitivity

# SCATTERED LIGHT

## BAFFLE BACKSCATTERING

This noise is mainly a function of:

- Amount of light that reaches the baffle:
  - Geometry/design
  - Mirror quality
  - Cavity conditions
- Baffle material
- **Baffle displacement/vibration**

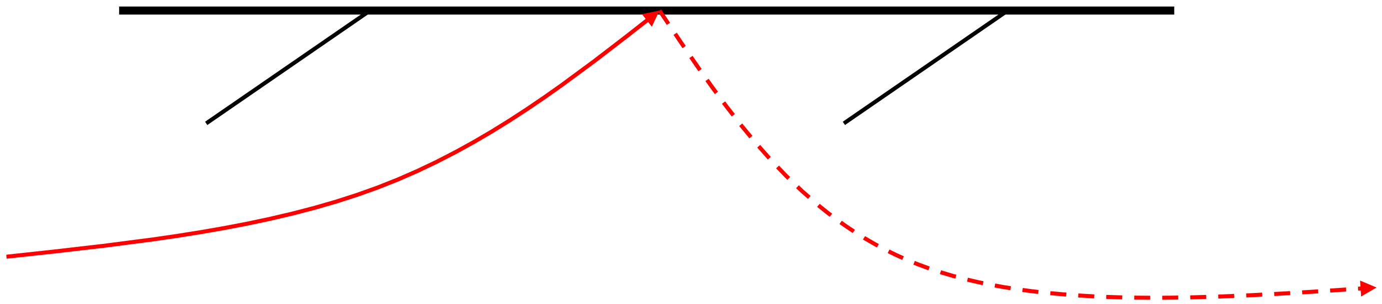
## BAFFLE DIFFRACTION

This noise is mainly a function of:

- Overlap of the diffracted field with the resonating one:
  - Geometry/design
  - Mirror quality
  - Cavity conditions
- Baffle serration
- **Baffle displacement/vibration**

For the details, there is a dedicated talk about the methods in the parallel session of scattered light

# SCATTERED LIGHT

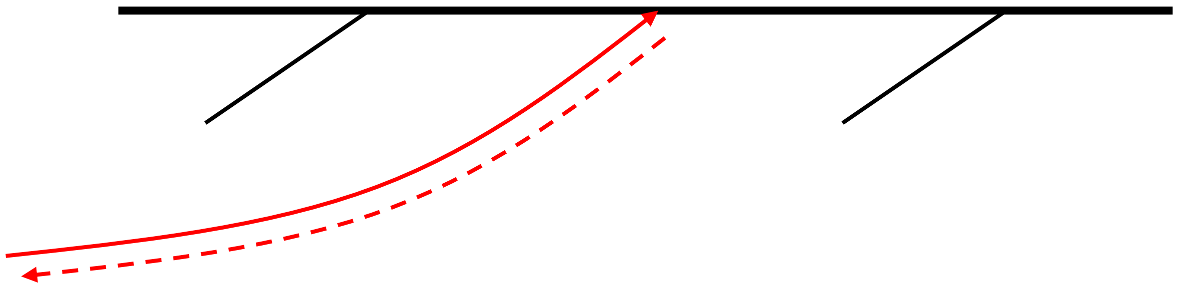


**FORWARD TUBE SCATTERING**

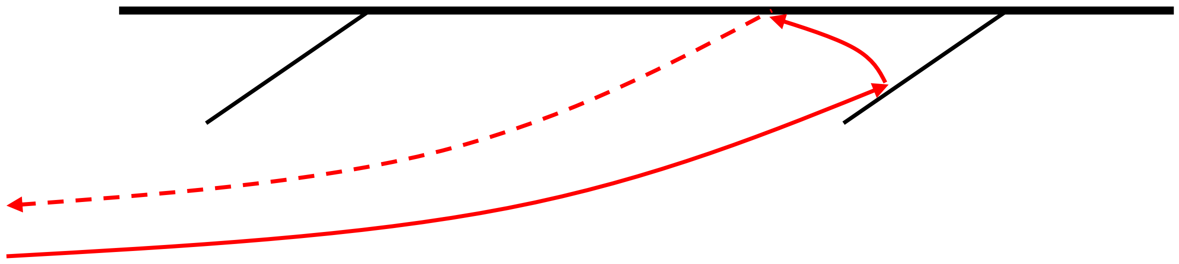
This represents the noise generated by light that hits the tube and reflects (scatters) and reaches the non-emitting mirror

**BACKWARD TUBE SCATTERING**
**(TUBE BACKSCATTERING)**

This represents the noise generated by light that hits the tube and scatters back to the emitting mirror



# SCATTERED LIGHT

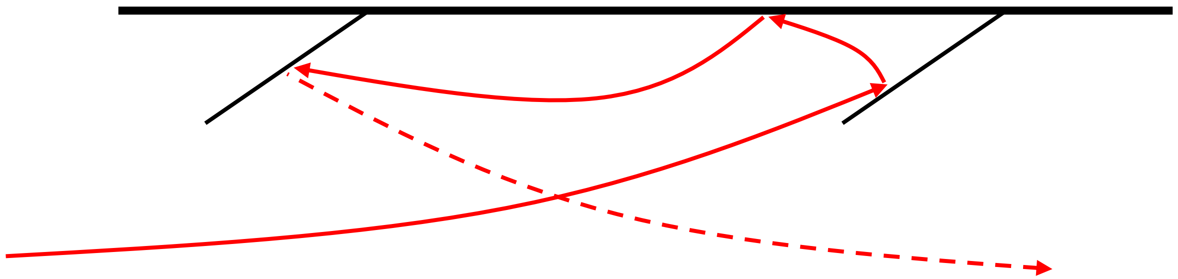


## DOUBLE BOUNCE TUBE SCATTERING

This represents the noise generated by light that hits the tube, then the baffle (or first the baffle and then the tube) and then reaches the emitting mirror

## TRIPLE BOUNCE TUBE SCATTERING

This represents the noise generated by light that hits a baffle, then the tube, then the other baffle and scatters back to the emitting mirror



# SCATTERED LIGHT

## BAFFLING STRATEGIES

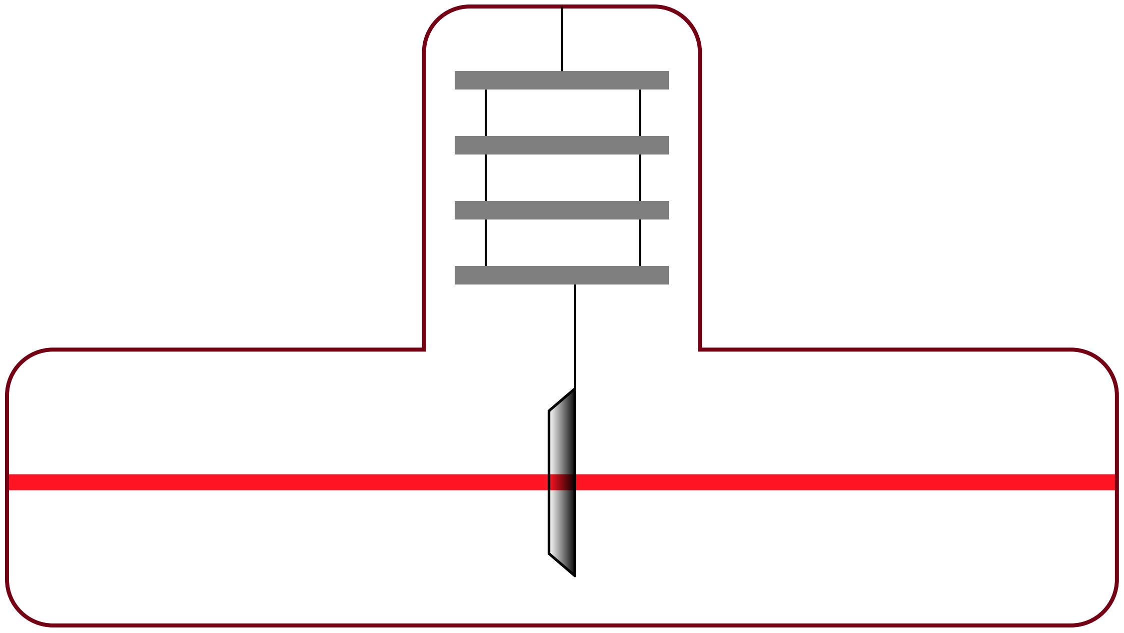
## RAY OPTICS

## WAVE OPTICS

Regular baffle design but different strategies to decide its placement

## SUSPENDED BAFFLES

New concept to minimize the number of baffles

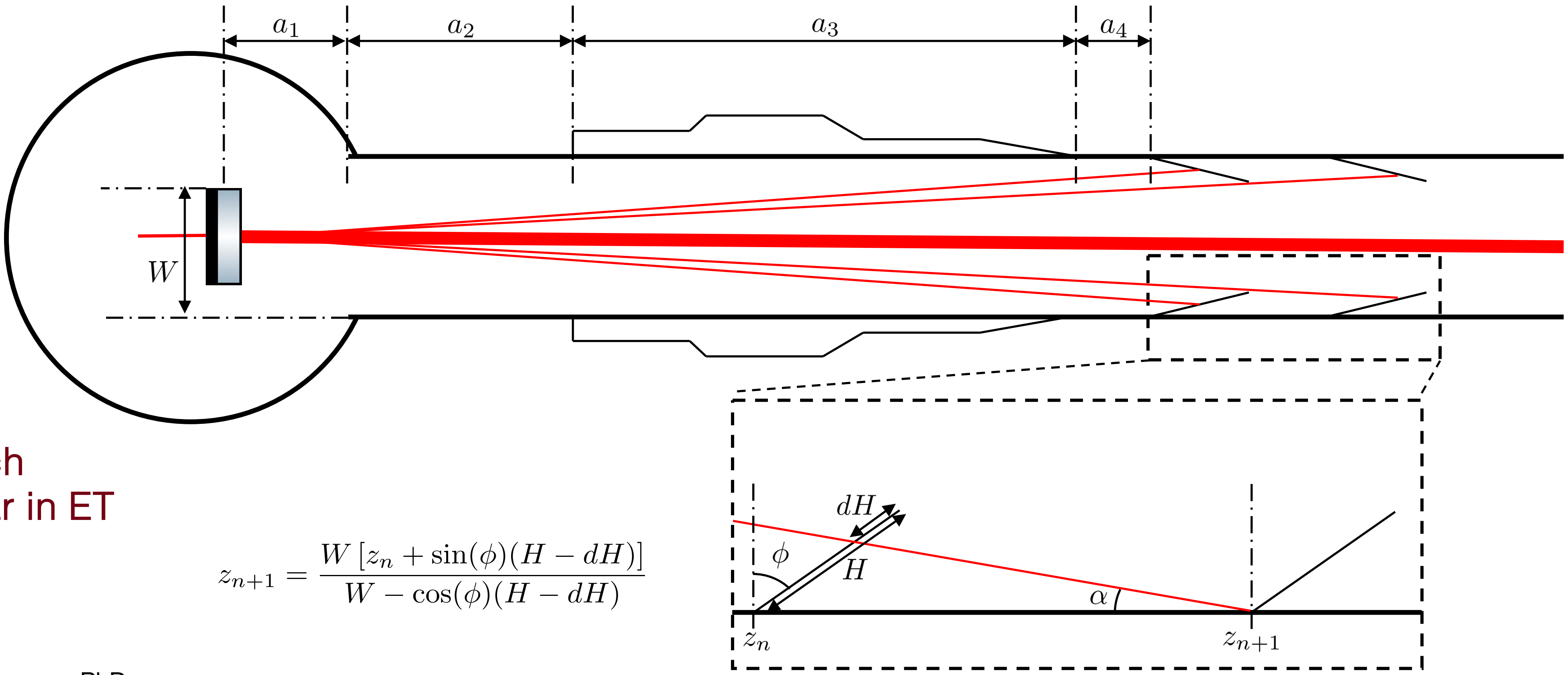


# SCATTERED LIGHT

## BAFFLING STRATEGIES

### RAY OPTICS

Placing baffles shielding the tube according the direct line of sight from the emitting mirrors.




Main approach followed so far in ET

$$z_{n+1} = \frac{W\left[z_n + \sin(\phi)(H - dH)\right]}{W - \cos(\phi)(H - dH)}$$



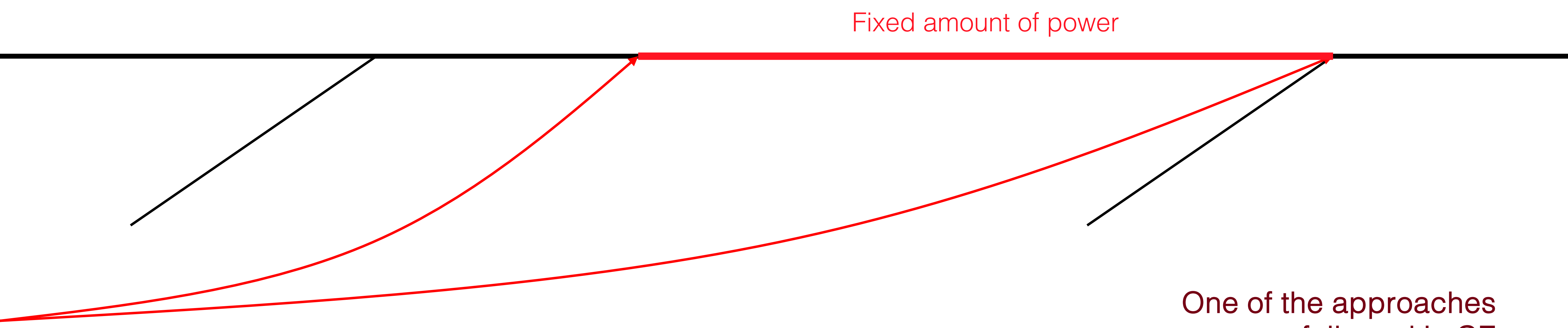
M. Andrés-Carcasona, et al., Phys. Rev. D 108, 102001

# SCATTERED LIGHT

## BAFFLING STRATEGIES

### WAVE OPTICS

Placing baffles such that a fixed and controlled amount of light reaches the tube



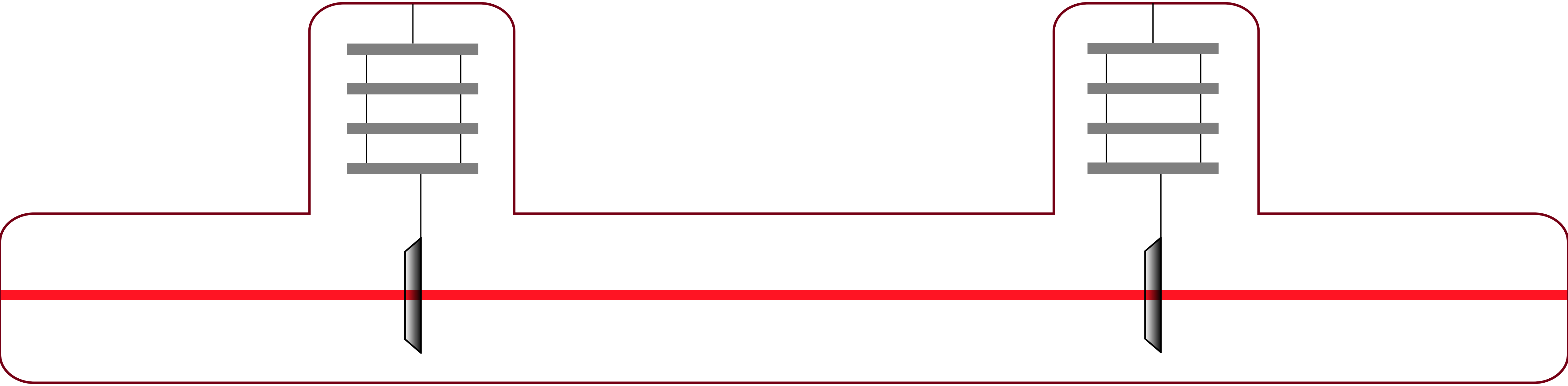

One of the approaches followed in CE

# SCATTERED LIGHT

## BAFFLING STRATEGIES

### SUSPENDED BAFFLES

Placing way less baffles (~6), but suspended to avoid the vibration and with a much tighter aperture



One of the approaches considered for CE

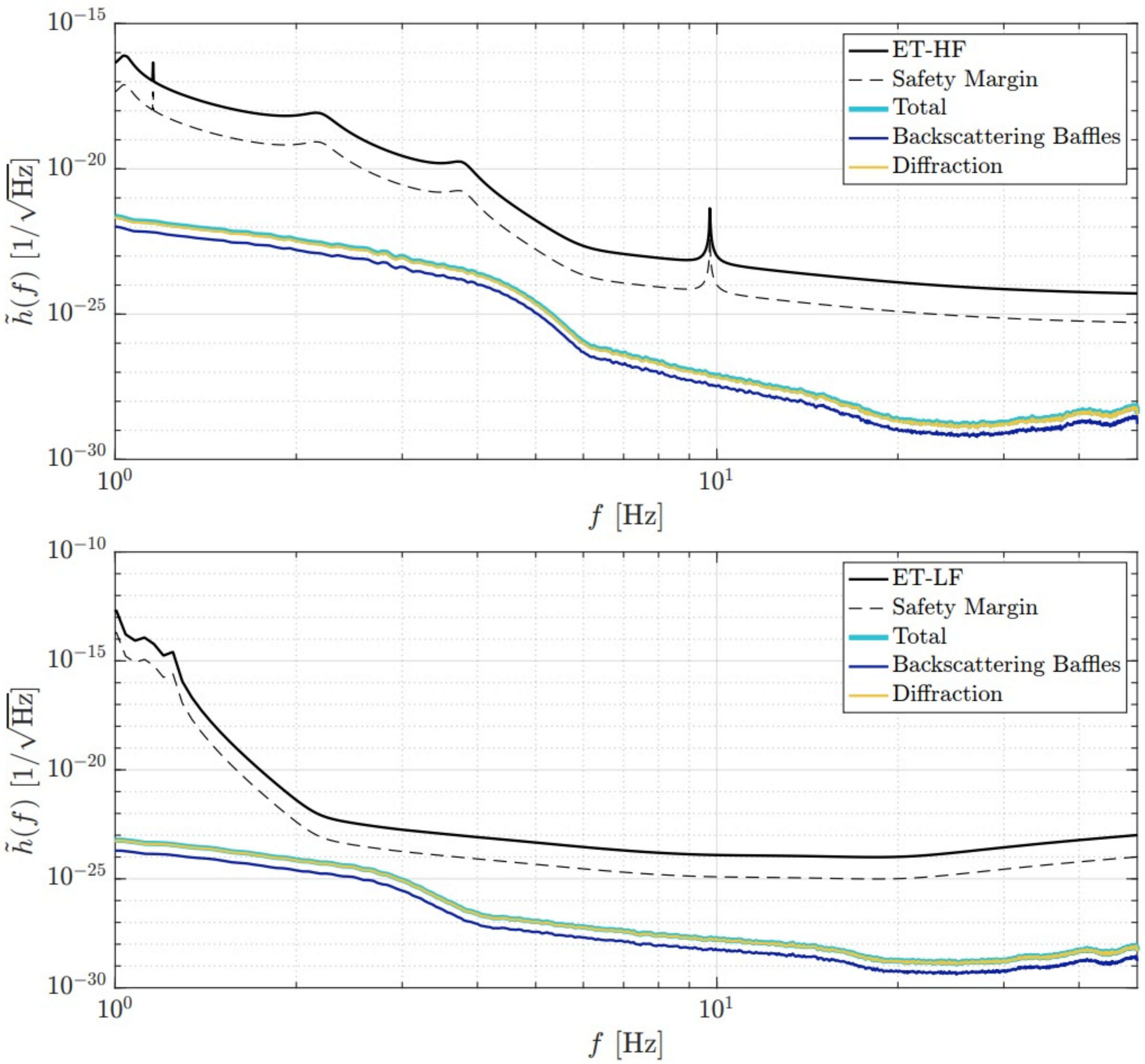
# SCATTERED LIGHT

## EXAMPLE NOISE ESTIMATION FOR ET

### RAY OPTICS BAFFLING

Example calculation for the **baffle backscattering** noise and **diffraction** noises for the ET detector. These calculations ignore the noise from the beampipe as the baffle placing and design should cover it completely.

We observe how the **diffraction noise dominates over the backscattering**, implying that the number of baffles is big enough so as to pile up enough noise over them. This result calls for a baffle optimization.

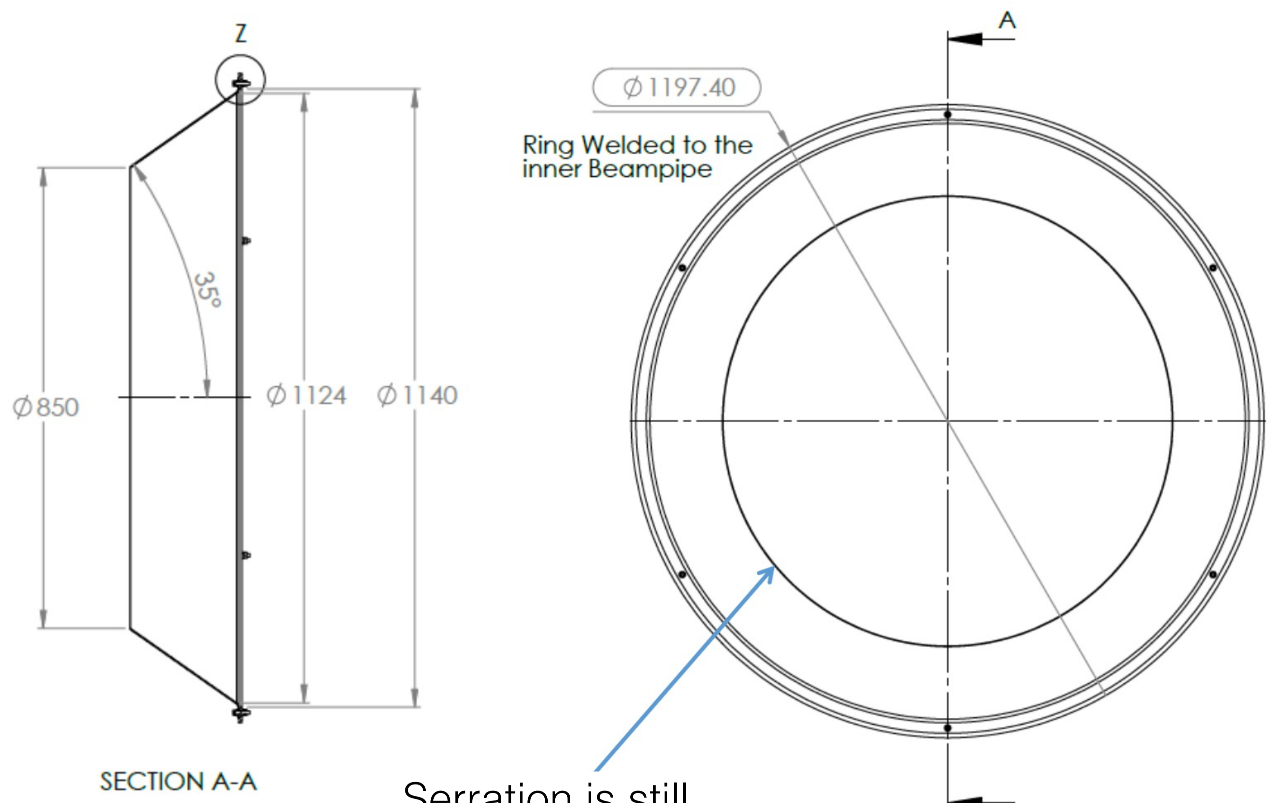


# MECHANICAL DESIGN

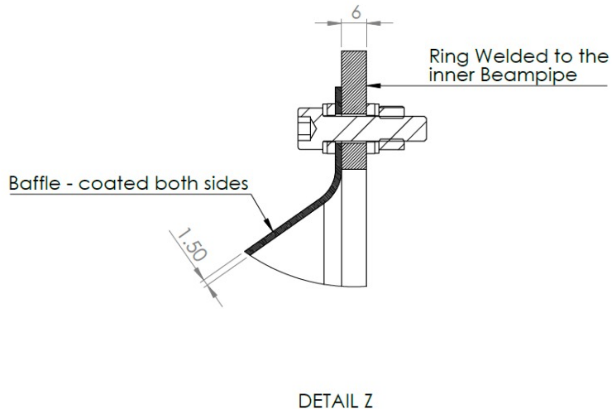
WHAT DOES THIS IMPLY FOR THE MECHANICS?

# MECHANICAL DESIGN

Example of the mechanical design considered for ET's beampipe baffles




Serration is still not included




| ITEM NO. | PART NUMBER | QTY. |
|---|---|---|
| 1 | ET-Beampipe-Baffle | 1 |
| 2 | ET-Beampipe-Baffle fixation ring | 1 |
| 3 | ET-Beampipe-DIN 7349 M6 customized | 12 |
| 4 | Hexagon Nut ISO 4034 - M6 - N | 6 |
| 5 | DIN 912 M6 x 25 --- 25N | 6 |



Credit to engineers J. Mundet (IFAE) and R. García (IFAE)

# MECHANICAL DESIGN

| Parameter | Value | Unit |
|---|---|---|
| Thickness | 1.5 | mm |
| Material | 304L SS | - |
| Flange outer ⌀ | 118 | cm |
| Inner ⌀ | 84 | cm |
| Cone angle | 35 | deg |
| Mass (incl. ring) | 10 | kg |

Credit of some values to engineers J. Mundet (IFAE) and R. García (IFAE)

This mechanical design under consideration of the baffle assume a **“Bolted To a Welded Ring” (BTWR)** attachment to the beampipe. This method can allow for some decoupling of the tube fabrication and the baffle installation, since if the ring is already in placed, the baffle only needs to be screwed.

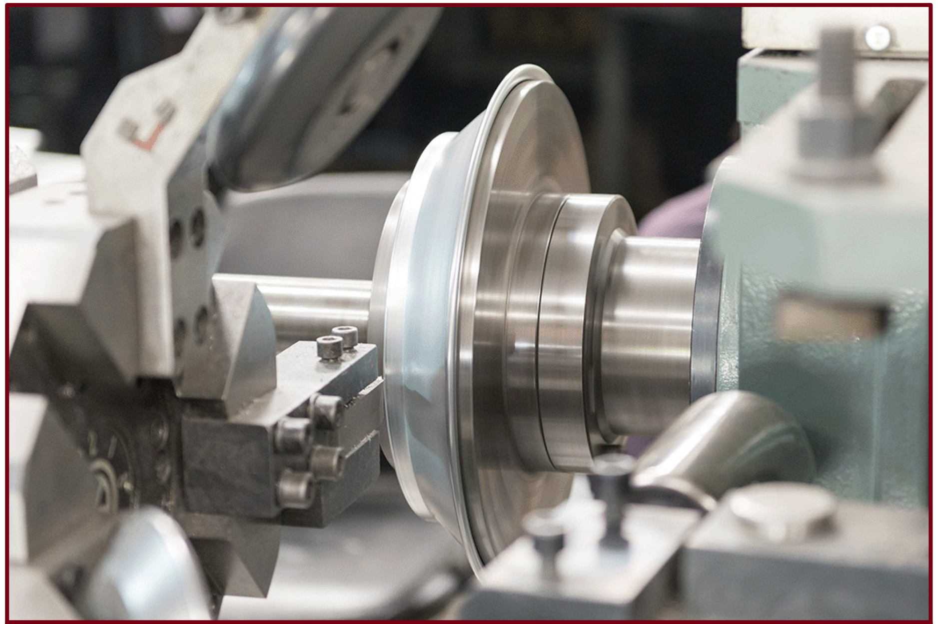
Ideally, the presence of the ring can allow a better alignment and placement of the baffle than directly welding it to the beampipe. Important if the tolerances/requirements are very strict.

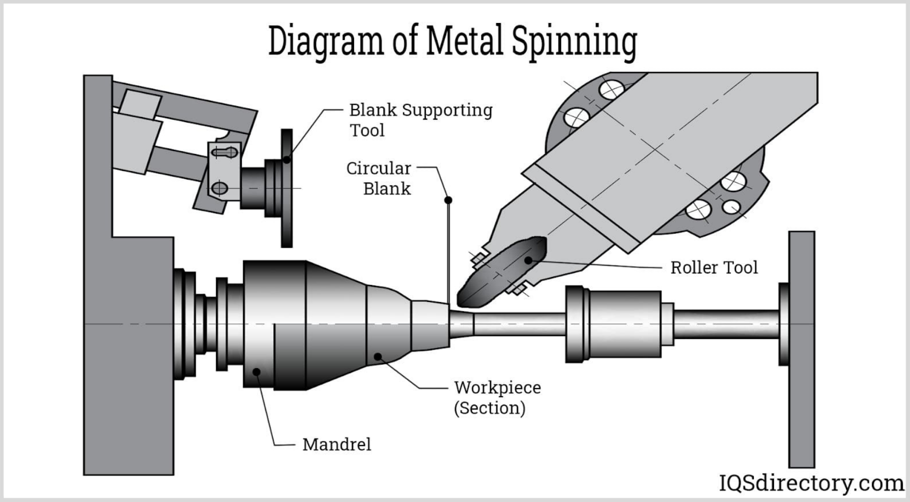
These parameters have interfaces with the beampipe: the mass, the size, the position and welding of the ring, ….

# MECHANICAL DESIGN

A manufacturing procedure that has been proposed by the IFAE engineers (although still preliminary) is the following:

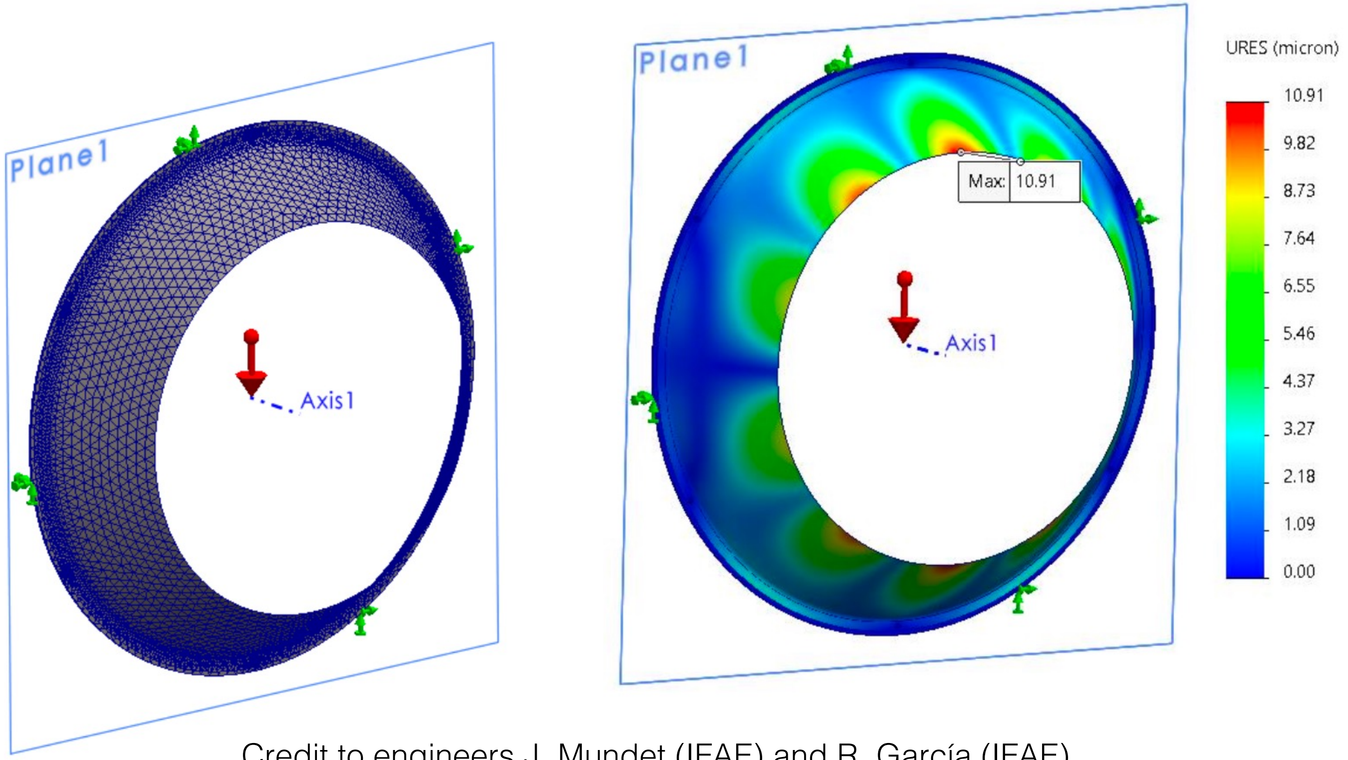
- ❑ New material: ASME specification SA-240, type 304L with mill finish (to be certified)
- ❑ Metal spinning forming (for the conical shape and the flange)
- ❑ Bead blasting with $AlO_2$
- ❑ Cleaning
- ❑ Laser cutting with 5 axis CNC for flange holes & serration
- ❑ Final cleaning
- ❑ Coating





# MECHANICAL DESIGN

A static baffle analysis shows that the maximum displacement under only its own weight is of the order of 10.91 $\mu$m. From the optics perspective, this should not be extremely problematic.

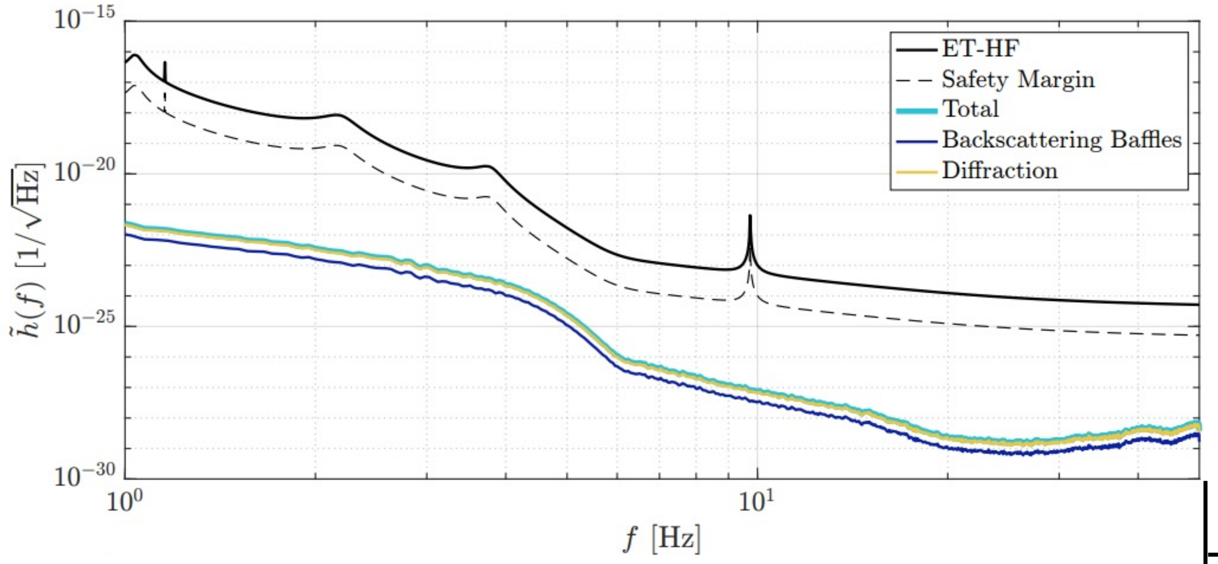



Credit to engineers J. Mundet (IFAE) and R. García (IFAE)

# MECHANICAL DESIGN

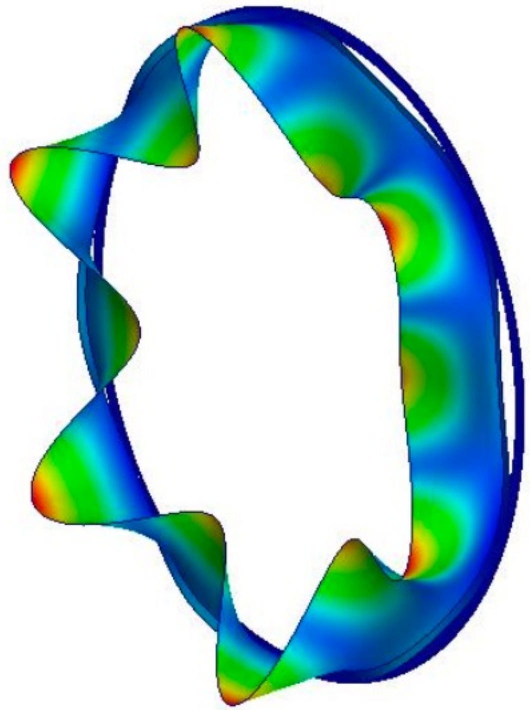
A dynamical analysis of the baffle and the ring can reveal the resonances of the system and the response to vibrations of the baffles.

In this case, the first resonant mode is observed to occur at 136.1 Hz with a mass participation in the z-direction of about an 8%.




Remember that the seismic motion scales as $1/f^2$

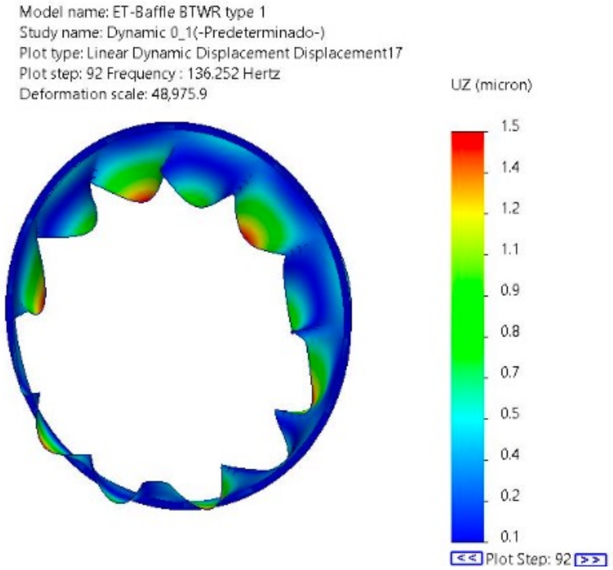
The first resonant frequency is **well above the relevant range of frequencies** that can pose a problem for scattered light

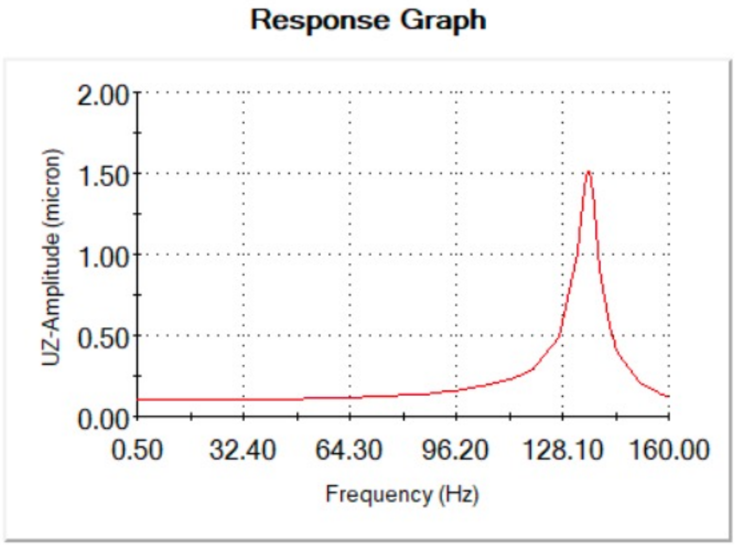


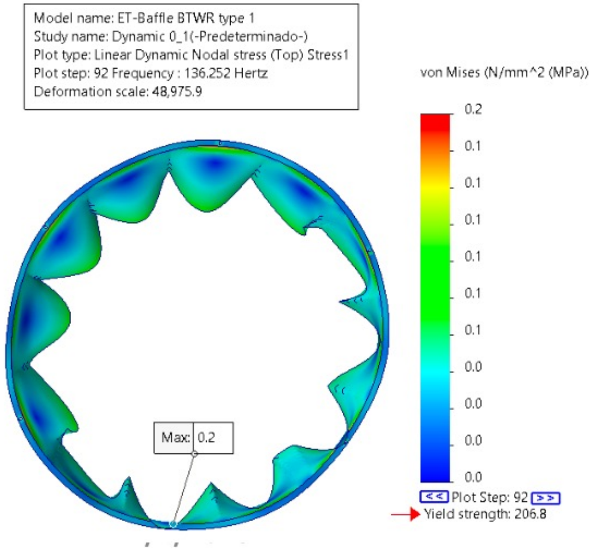
Credit to engineers J. Mundet (IFAE) and R. García (IFAE)

# MECHANICAL DESIGN

Similarly, we can study the frequency response of the baffle design by adding an excitation in the z-axis (horizontal direction) with a displacement of 0.1, 1, 10, & 100 μm of amplitude between a range of 0.5 and 100/200 Hz.




Max. yield below yield strength of SS

Credit to engineers J. Mundet (IFAE) and R. García (IFAE)

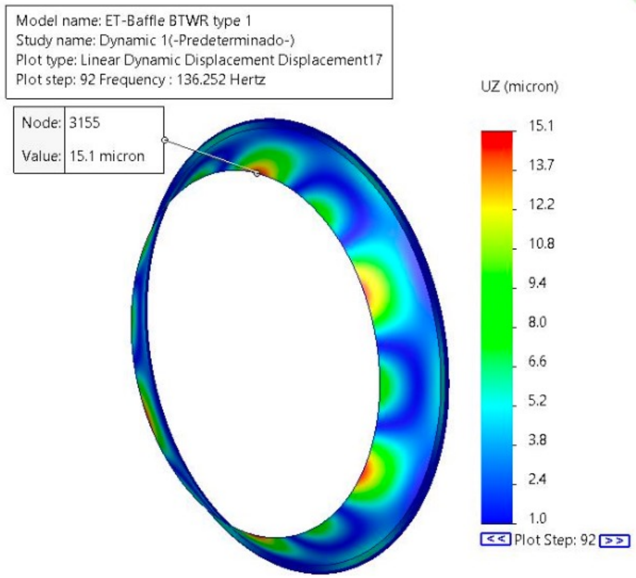
Amplification:

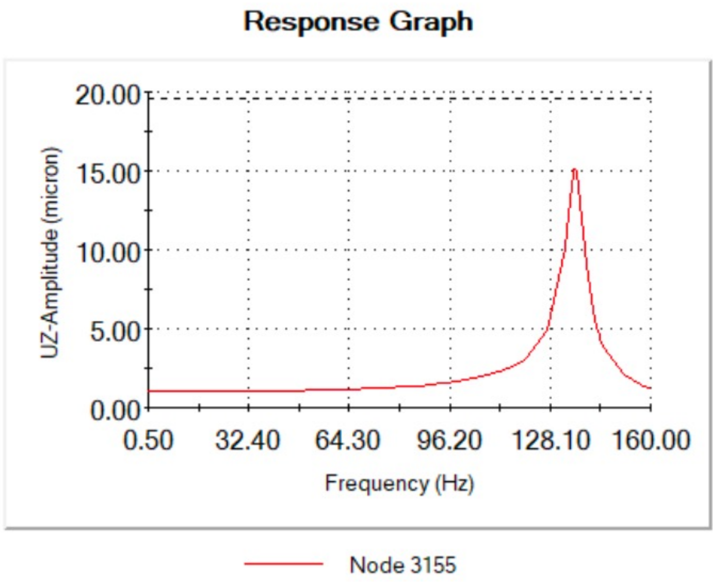
1.51 microns / 0.1 microns

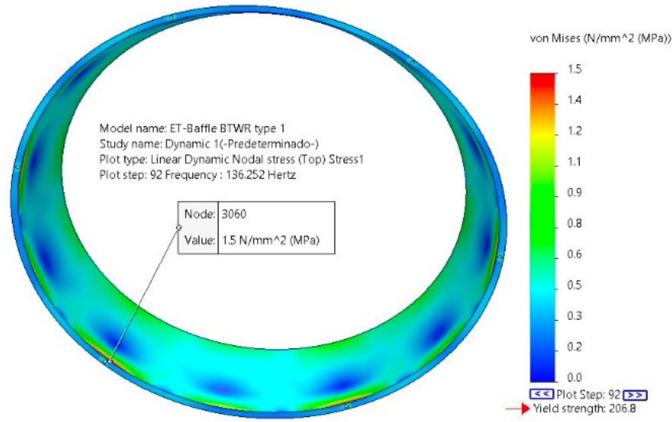
15.1

# MECHANICAL DESIGN

Similarly, we can study the frequency response of the baffle design by adding an excitation in the z-axis (horizontal direction) with a displacement of 0.1, 1, 10, & 100 μm of amplitude between a range of 0.5 and 100/200 Hz.




Max. yield below yield strength of SS

Credit to engineers J. Mundet (IFAE) and R. García (IFAE)

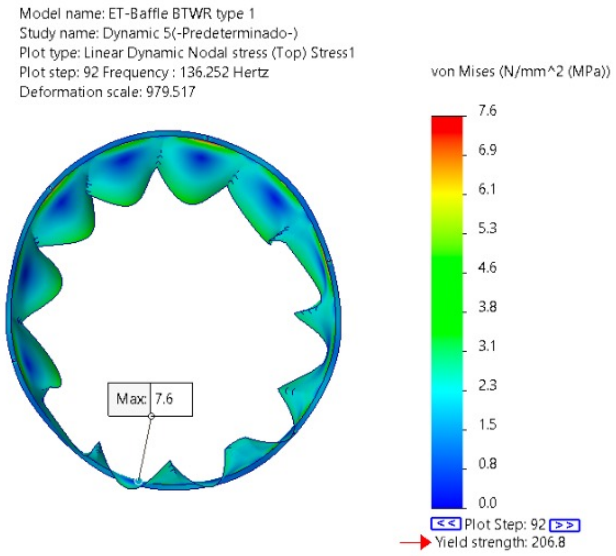
Amplification:

15.1 microns / 1 microns

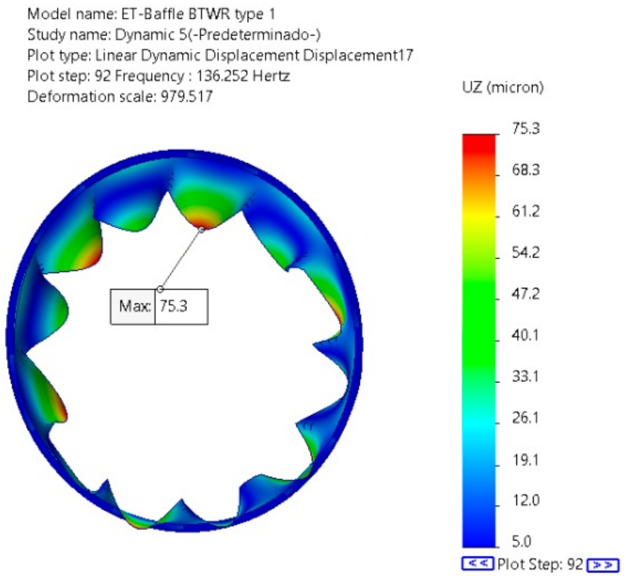
15.1

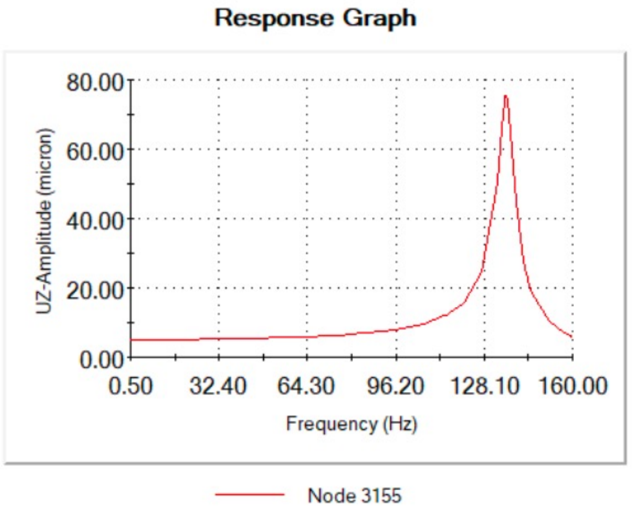
# MECHANICAL DESIGN

Similarly, we can study the frequency response of the baffle design by adding an excitation in the z-axis (horizontal direction) with a displacement of 0.1, 1, 5, & 100 µm of amplitude between a range of 0.5 and 100/200 Hz.




Max. yield below yield strength of SS




Credit to engineers J. Mundet (IFAE) and R. García (IFAE)

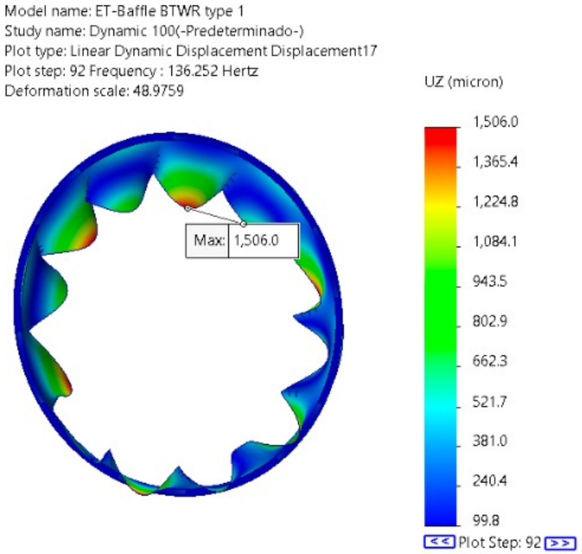
Amplification:

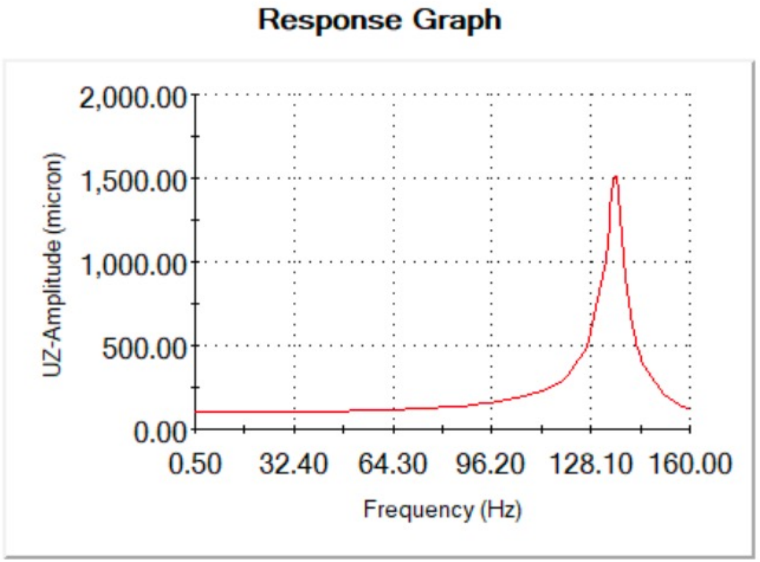
75.3 microns / 5 microns

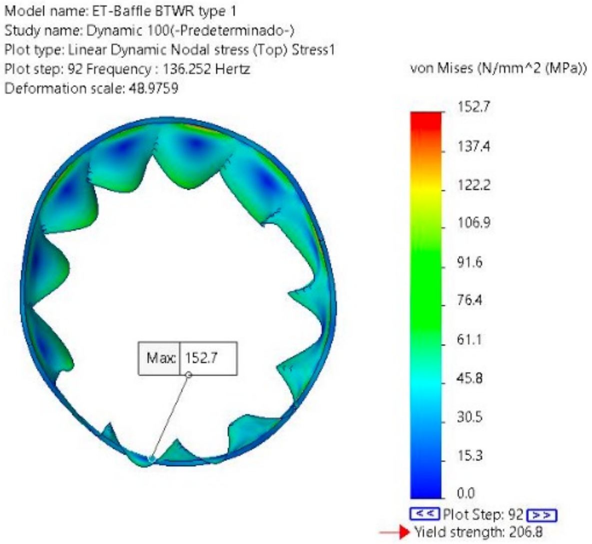
15.1

# MECHANICAL DESIGN

Similarly, we can study the frequency response of the baffle design by adding an excitation in the z-axis (horizontal direction) with a displacement of 0.1, 1, 5, & 100 μm of amplitude between a range of 0.5 and 100/200 Hz.




Max. yield below yield strength of SS

Credit to engineers J. Mundet (IFAE) and R. García (IFAE)

Amplification:
1506 microns / 100 microns
15.06

# MECHANICAL DESIGN

## CONCLUSIONS

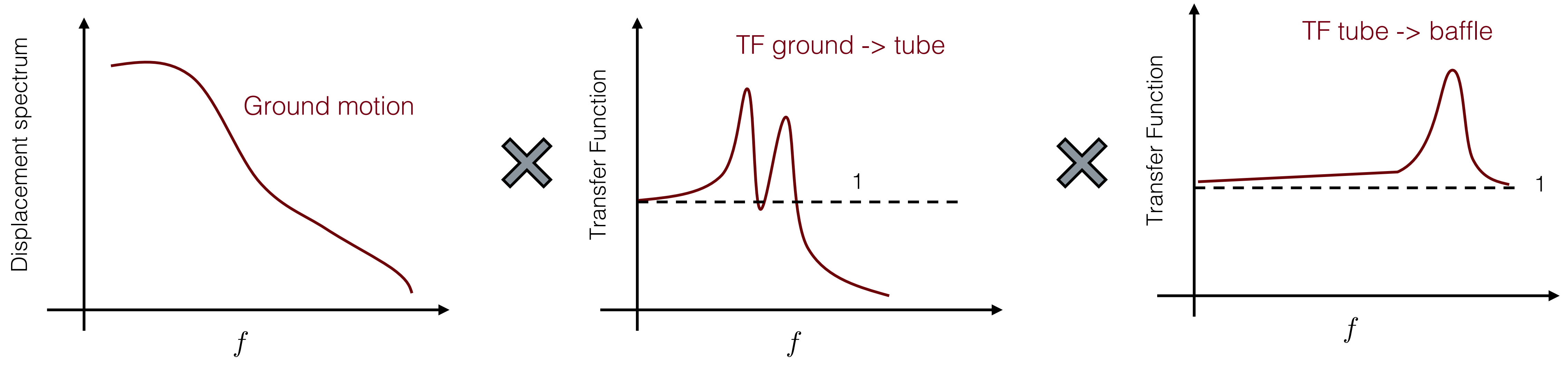
1. The first resonant frequency is well far from the range of frequencies where scattered light is relevant
2. The amplification at the resonance is of about an order of magnitude, which is also well within the margins
3. The material and attachment should easily withstand any reasonable seismic motion from the tube
4. Machining procedure is feasible with current technology and the technical requirements fulfilled

# TUBE VIBRATIONS

WHICH ARE THE LIMITS TO TUBE VIBRATIONS?

# VIBRATIONS

An important question to be addressed during the design of the vacuum beampipe is the maximum allowable level of vibrations, as an increase can pose a problem from the scattered light perspective.




The ground motion depends on the site, the transfer factor of the tube of its design and the one from the baffle due to its mechanical attachment.

We need a very good communication between teams to ensure that the product remains below acceptable levels

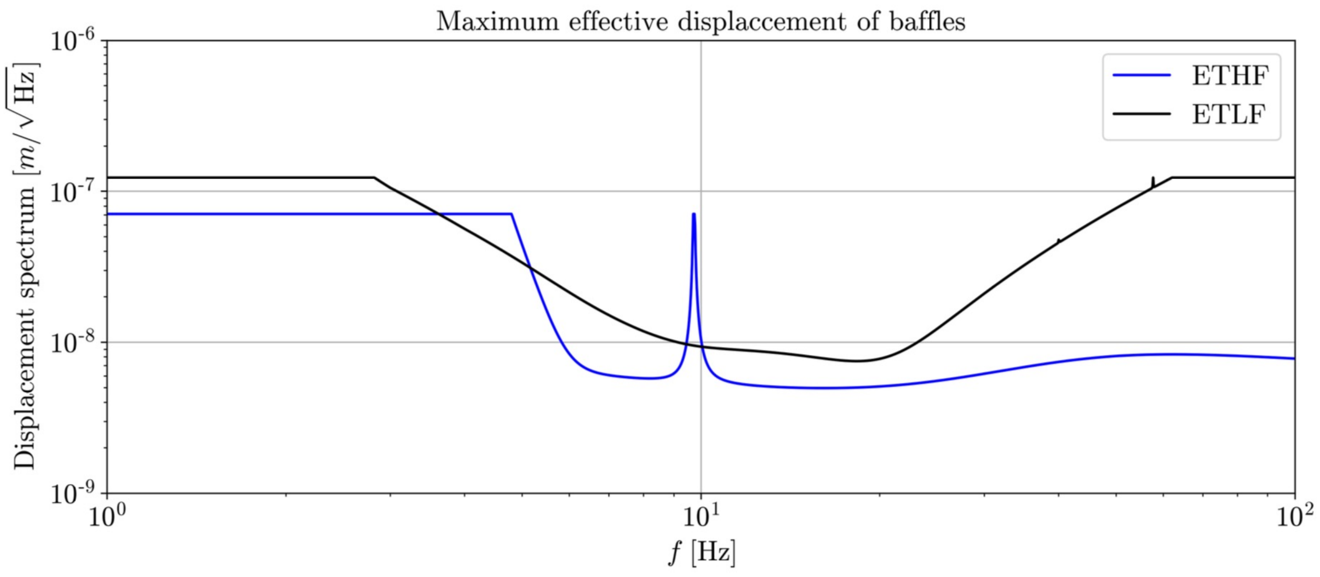
# VIBRATIONS

Procedure to compute if a design of the tube fulfills the vibration requirements:

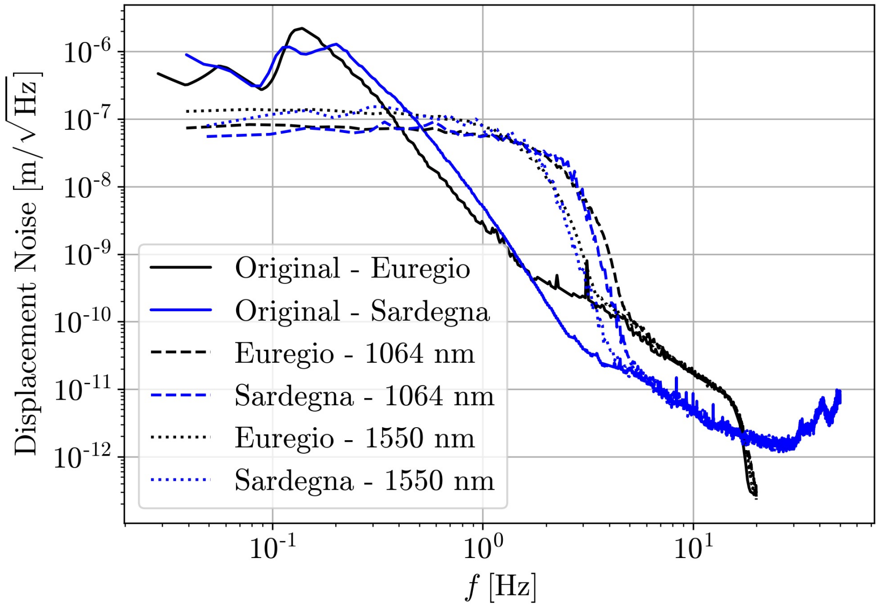
- Compute TF from the ground to the tube
- Compute the total baffle displacement (ground motion x TF tube x TF baffle)
- Upconvert the displacement
- Compare to the upper limit

The seismic noise must be upconverted or phase-wrapped to obtain the effective displacement. This can be done applying the following formula (LIGO-T1900854)

$$X(f) = \frac{\lambda_L}{4\pi}\sqrt{\mathrm{PSD}\left[\sin\left(\frac{4\pi}{\lambda_L}X(t)\right)\right] + \mathrm{PSD}\left[\cos\left(\frac{4\pi}{\lambda_L}X(t)\right)\right]}$$



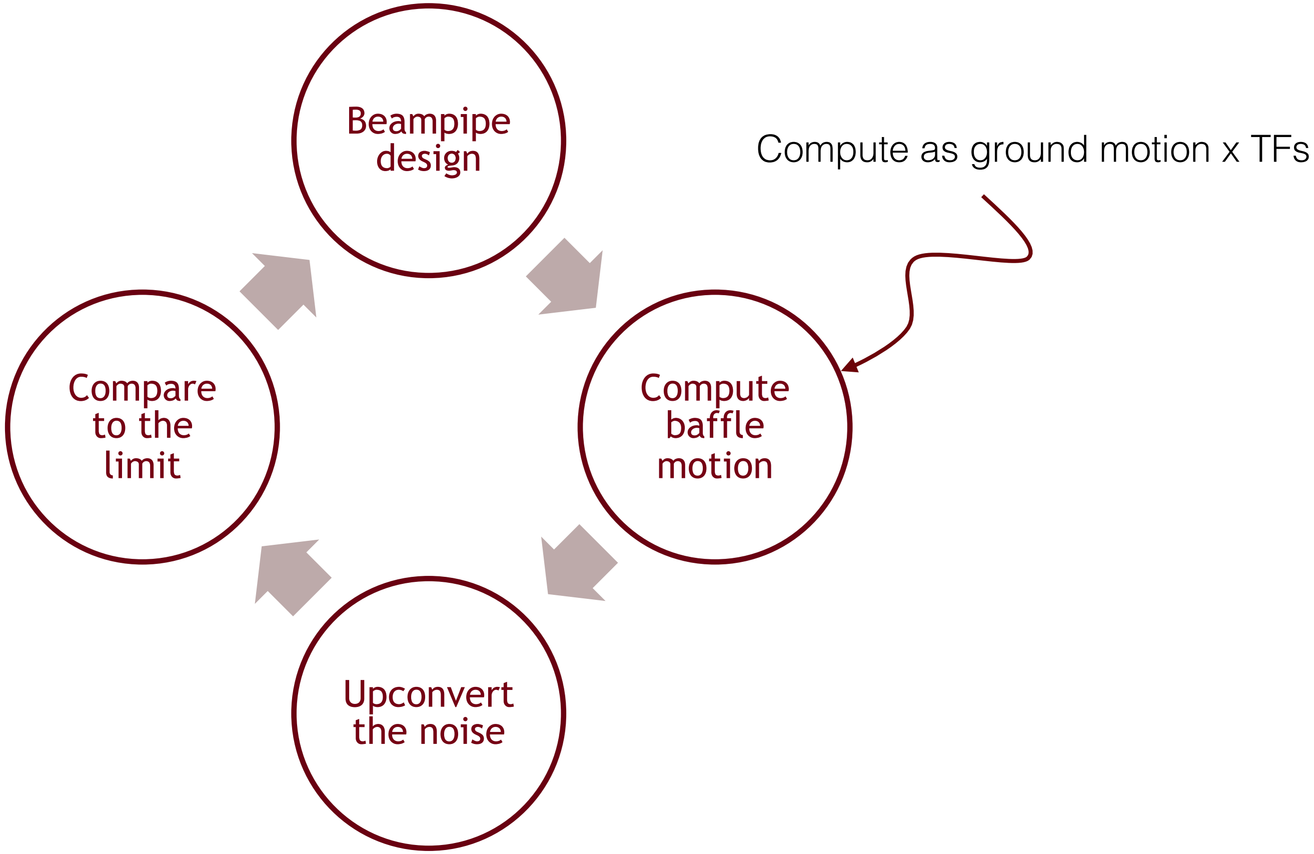

Example for ET from the Beampipe Requirements (ET-0385A-24)




M. Andrés-Carcasona, et al., Phys. Rev. D 108, 102001

# VIBRATIONS

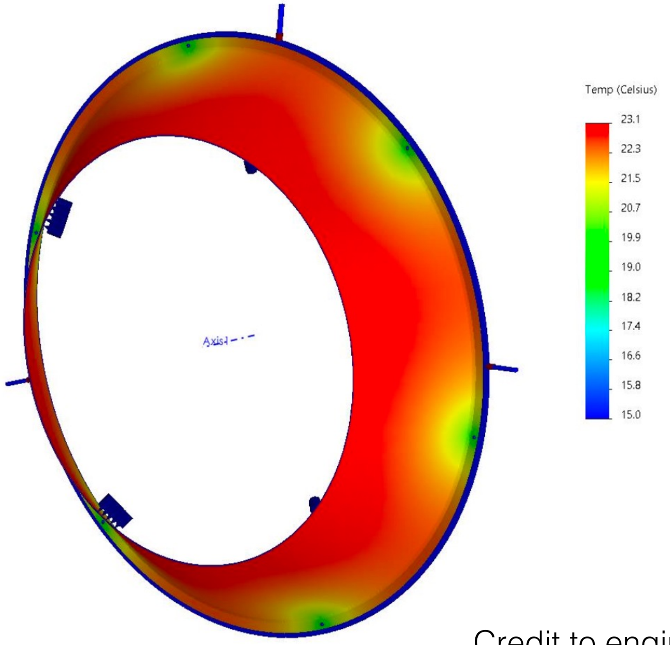
To properly aid the beampipe mechanical design we (the people from scattered light) can provide you with: upconversion code and the maximum tolerable displacement. The workflow can be



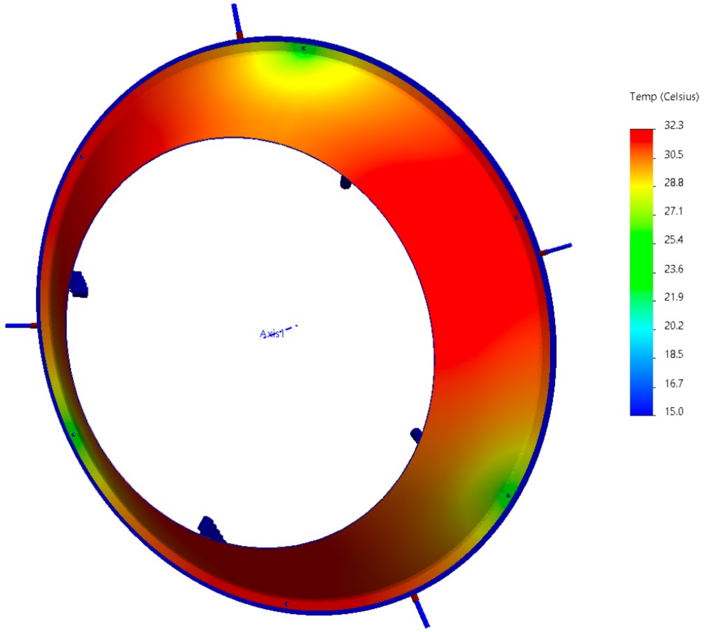
# THERMAL

We also need to study the thermal effects of a baffle being hit by a continuous amount of light, as thermal expansion can become a problem for the material. Not only that, but the material can emit thermal radiation that can affect the rest of the components of the interferometer. Of special importance can this be for the cryogenic areas.

6 points of contact




3 points of contact




Credit to engineers J. Mundet (IFAE) and R. García (IFAE)

If the baffle receives 0.5 W of power (input from a simulation) and that the initial baffle temperature of the baffle is 15ºC, the thermal simulation indicates a temperature of the baffle of:

- Assuming an interfacial conductance between baffle and ring of 300 $W/m^2K$:
  - 3 points: **32.2ºC** (dT = 17.3ºC)
  - 6 points: **23.1ºC** (dT = 8.1ºC)
- Assuming an interfacial conductance between baffle and ring of 3700 $W/m^2K$:
  - 3 points: **25.4ºC** (dT = 10.4ºC)
  - 6 points: **19.7ºC** (dT = 4.7ºC)

# CONCLUSIONS

# CONCLUSIONS

## 01.

The baffle and tube designs are highly tied and requires a lot of interaction

## 02.

We are considering two baffle designs with different impacts in the vacuum system

## 03.

Our current loop of the design seems to be feasible both from the scientific point of view and fabrication

## 04.

If the suspended baffle approach not only the optics are affected: vacuum, suspensions, thermal,…

# CE/ET BEAMTUBE WORKSHOP III

Mechanical/Optical Design Options for Baffles

Marc **Andrés-Carcasona**, PhD
mandresc@mit.edu

24/08/2025