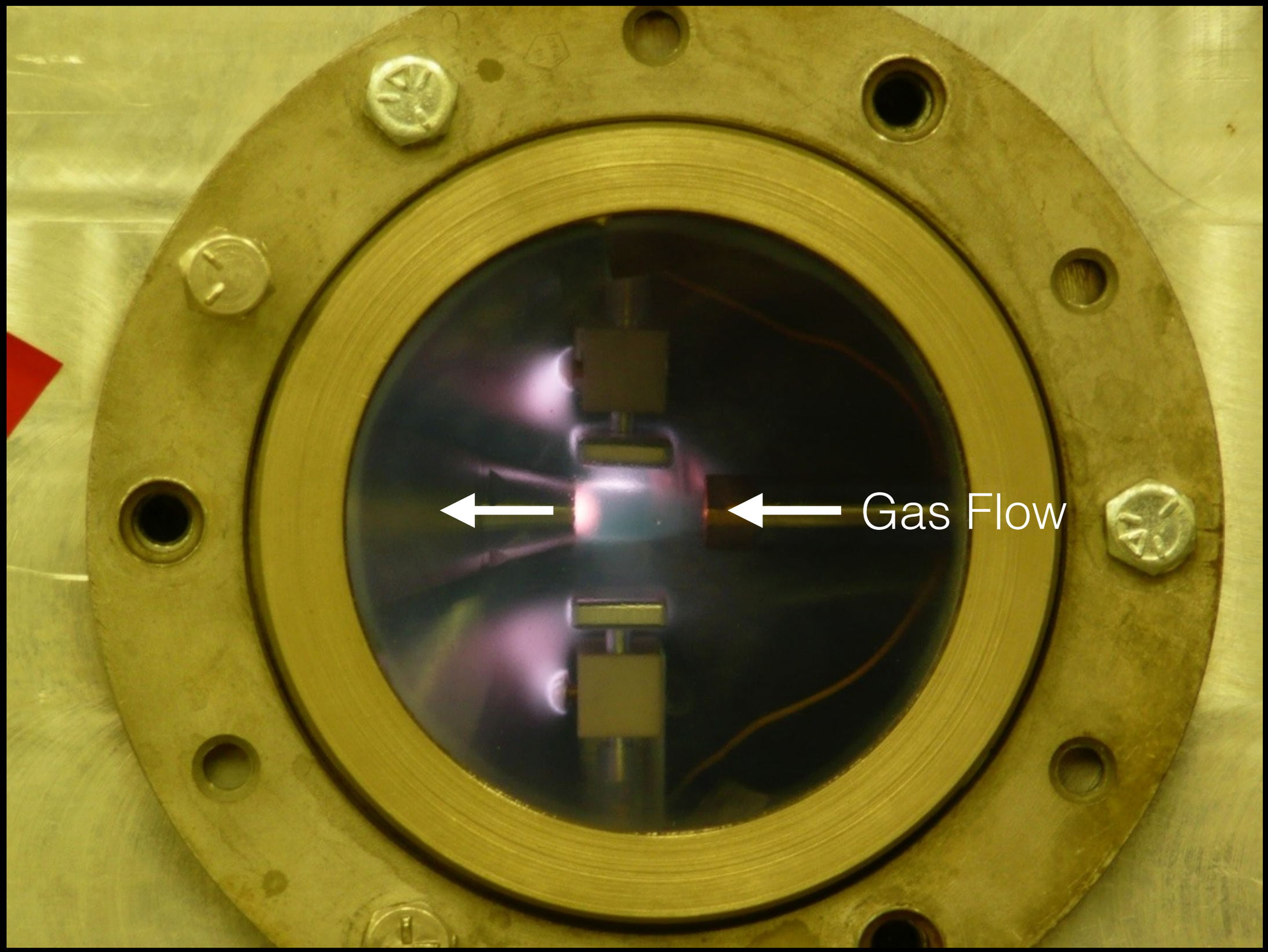
# Design Drivers for Scattered Light Baffles

CE/ET Beamtube Workshop III, LHO
2025-10-01

Antonios Kontos, Bard College

# Gas target



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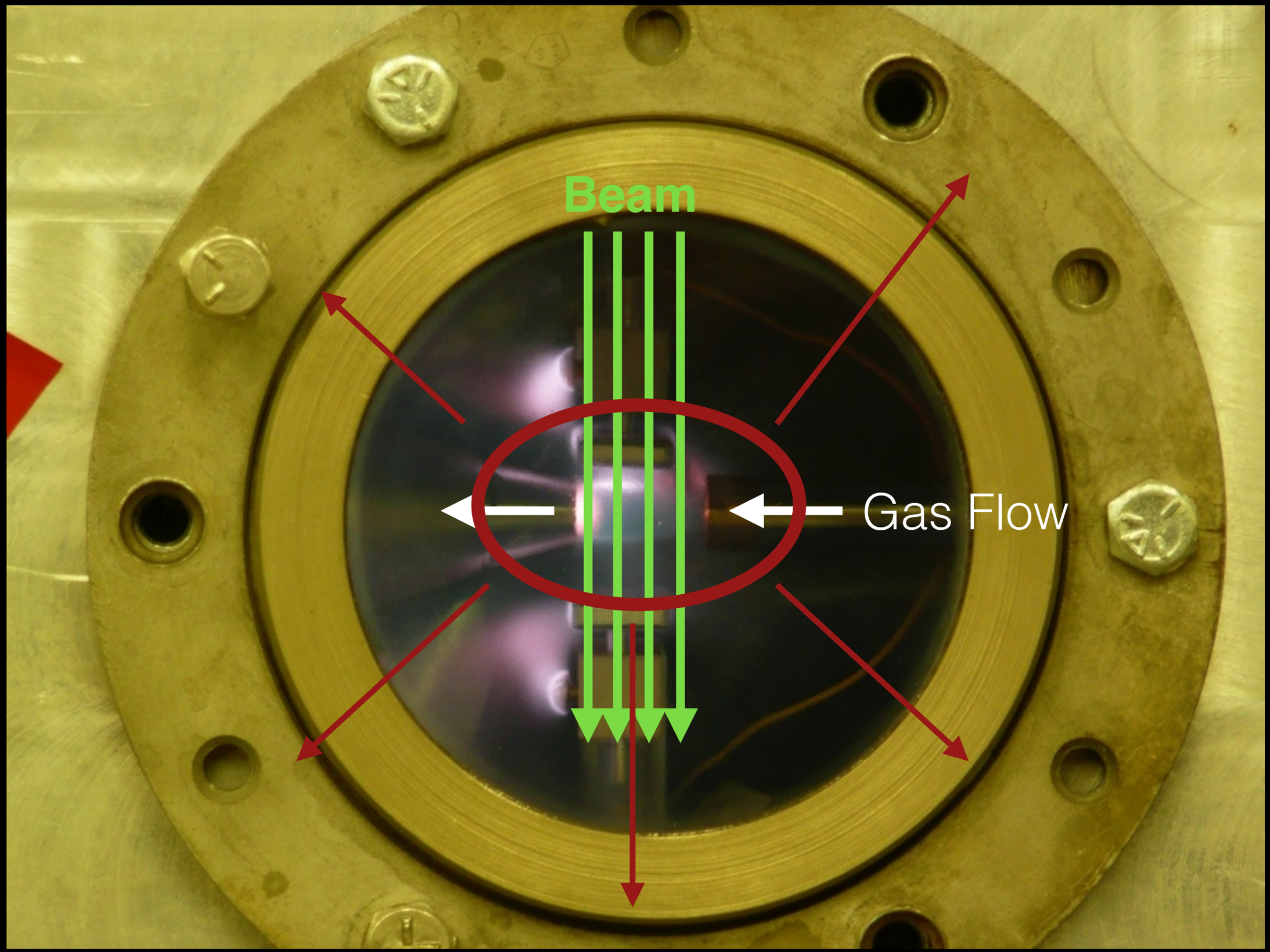
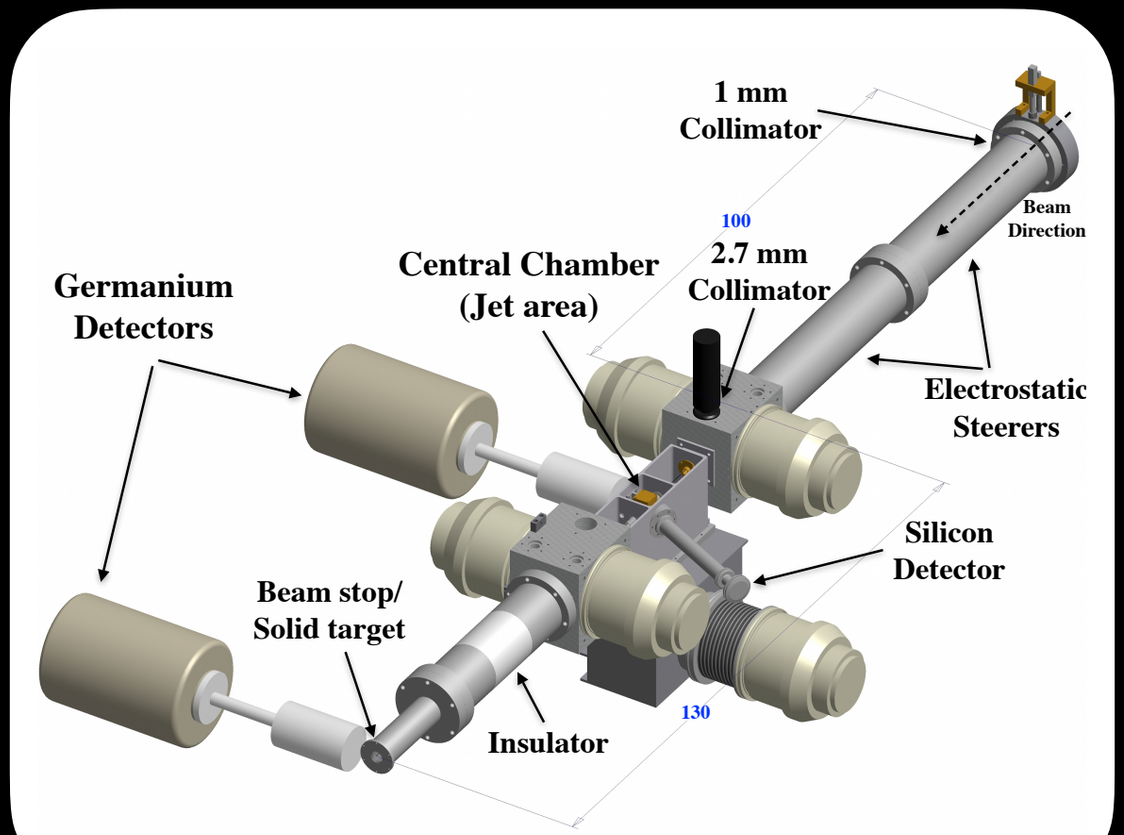
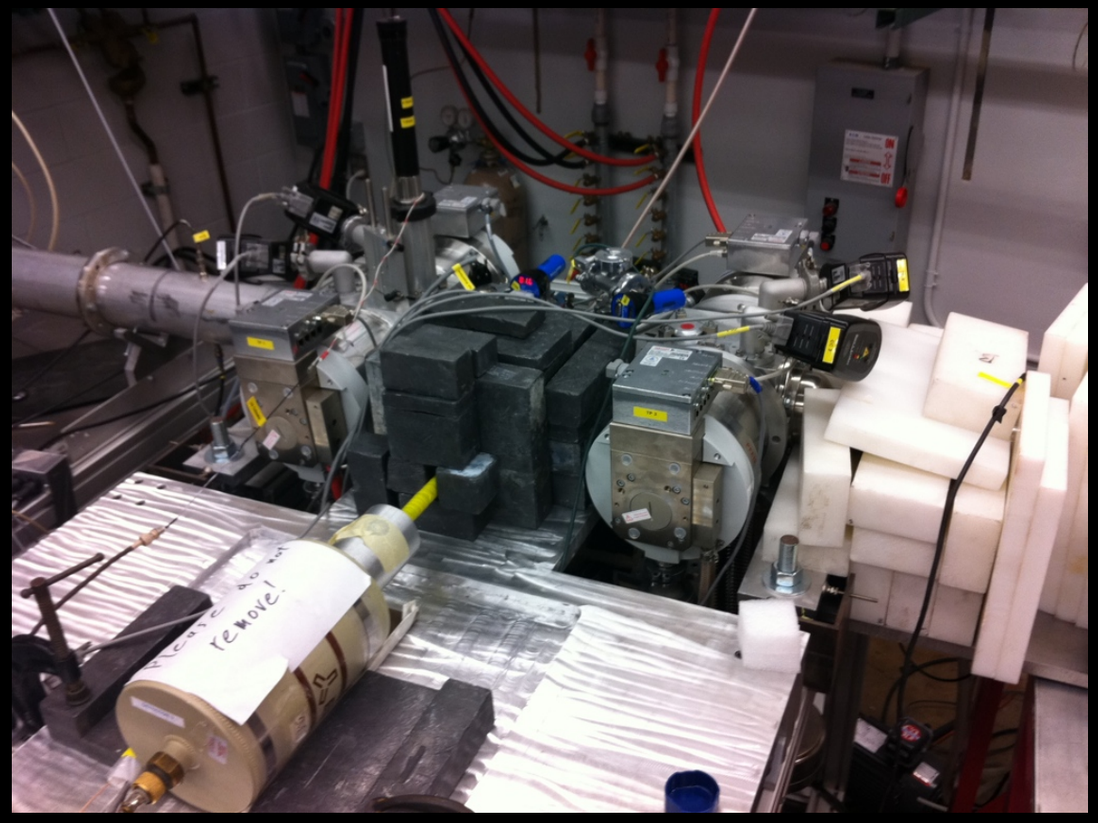
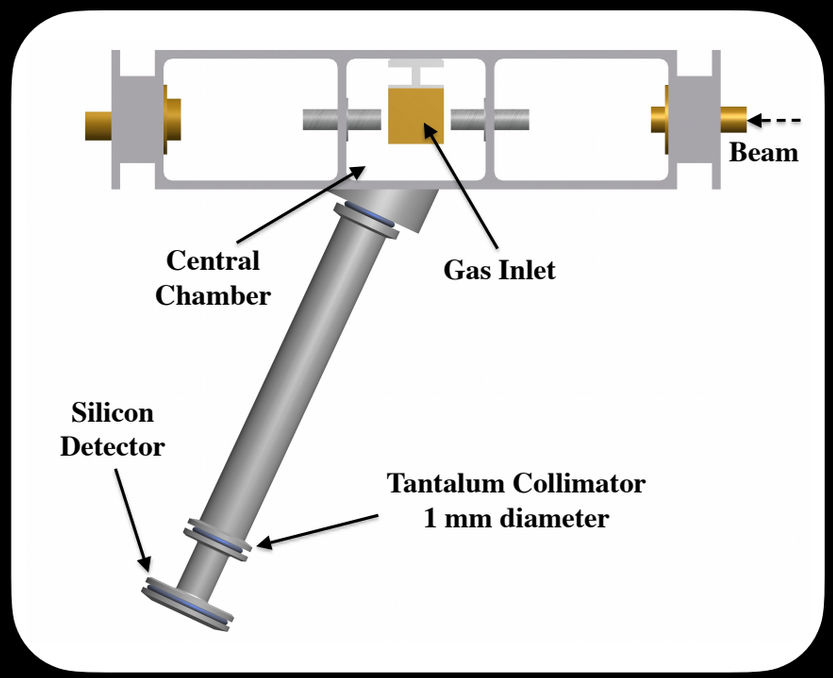


# How to measure the $^{3}He(\alpha,\gamma)^{7}Be$ cross section!
# HIPPO gas-jet target @ Notre Dame



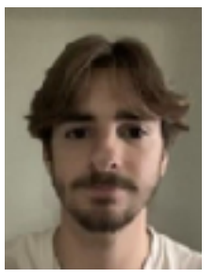



# Gas Targets

HIPPO, Notre Dame

JENSA, MSU

# CE Stray Light Group



Kincade Avery
Undergrad @Bard

Syed Ibtesham
Undergrad @Bard

Antonios Kontos
Professor @Bard

Alena Ananyeva
Engineer @Caltech

## Baffle Material Measurements

Alena Ananyeva
Engineer @Caltech

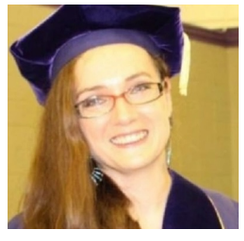
Antonios Kontos
Professor @Bard

Lee McCuller
Professor @Caltech

## Project Management

Marc Andres-Carcasona
Research Scientist @MIT

Adrian Helmling-Cornell
Postdoc @Bard
(Incoming)



Anamaria Effler
Scientist @LLO

Hiro Yamamoto
(Caltech-Retired)

## Stray Light Modeling

Antonios Kontos
Professor @Bard

Rodica Martin
Professor @Montclair

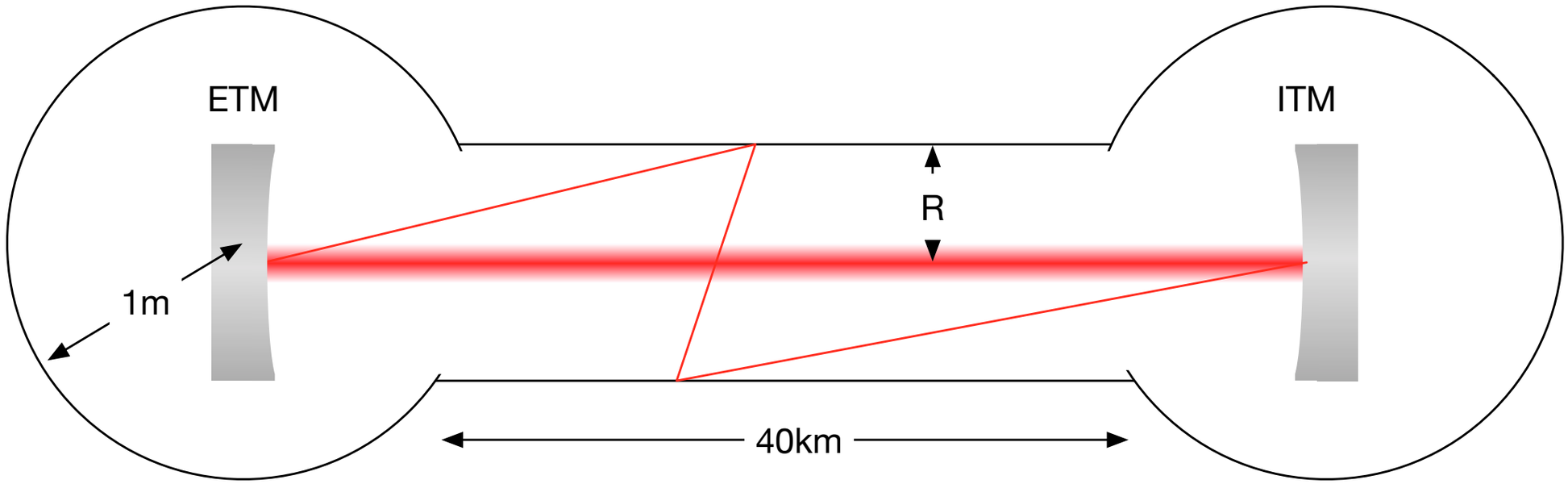
Alena Ananyeva
Engineer @Caltech

Antonios Kontos
Professor @Bard

## Non-beamtube Stray Light

# What are we focused on first?

- Beamtube Baffles to prevent scattered light from reaching the beamtube and then back to our optics



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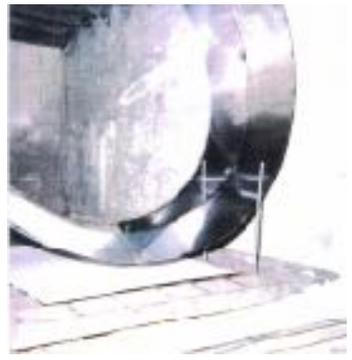

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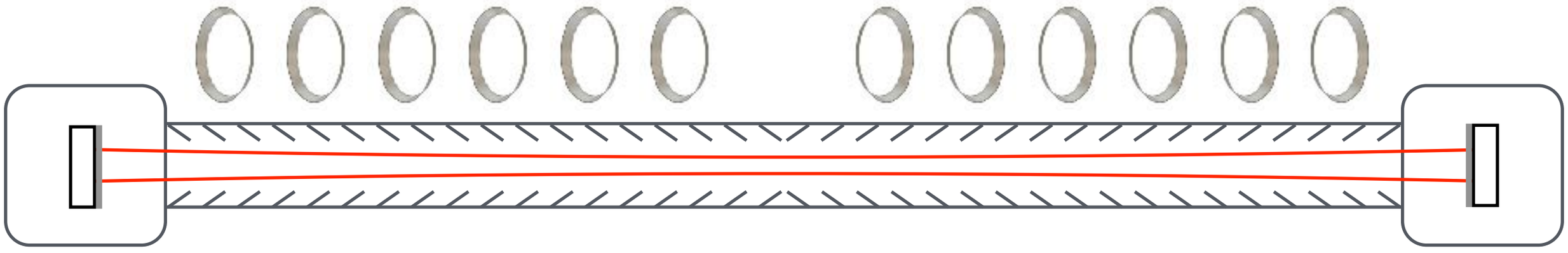
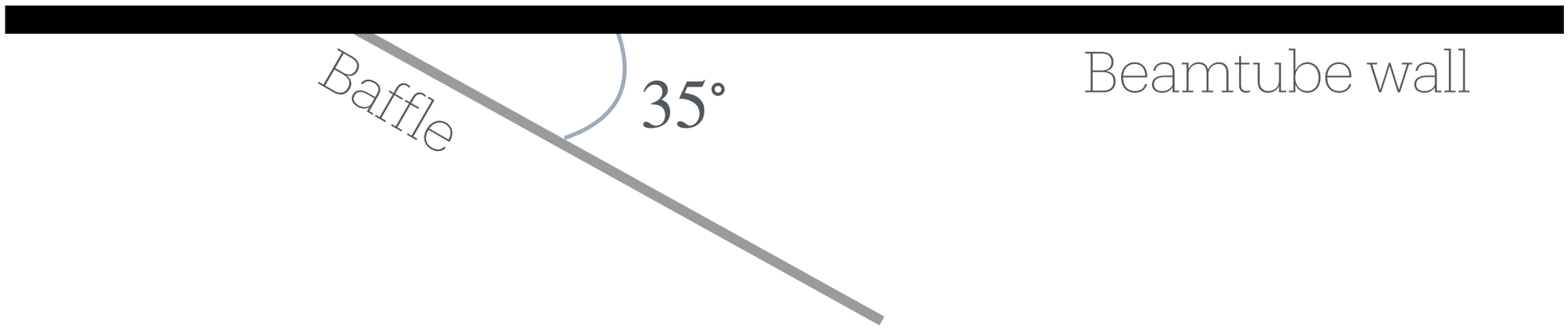
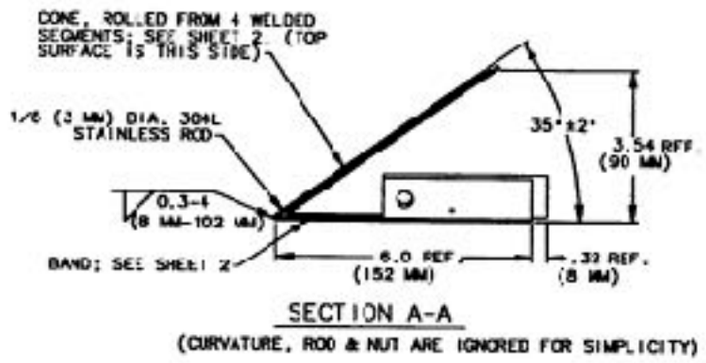





Near Side

Far Side



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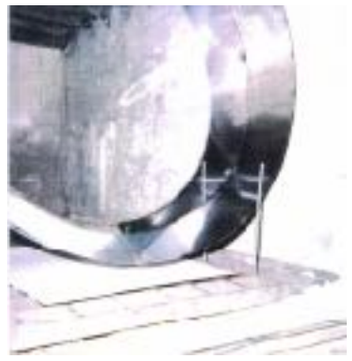

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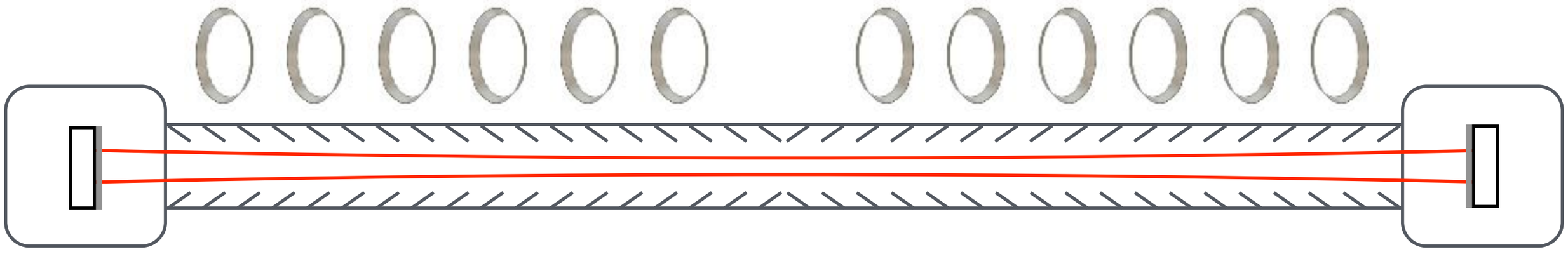

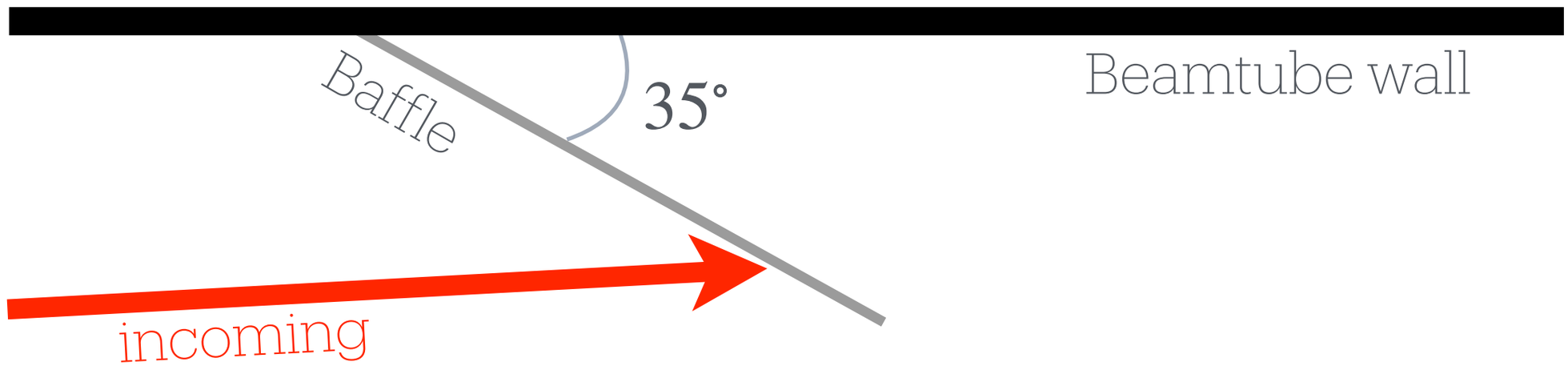


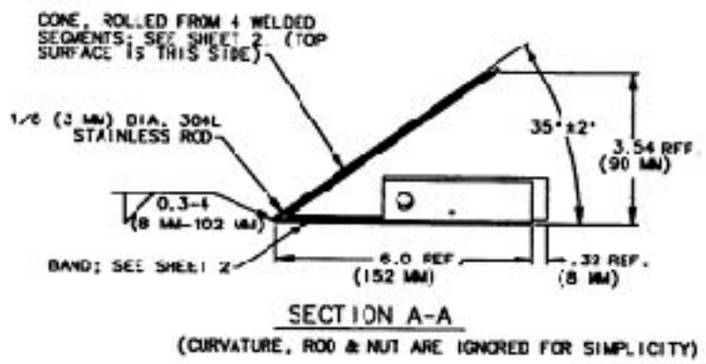

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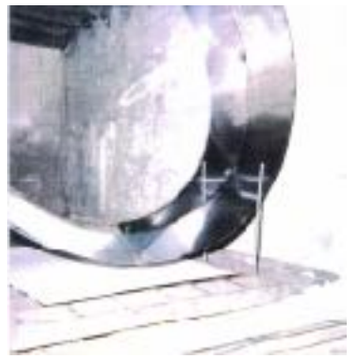

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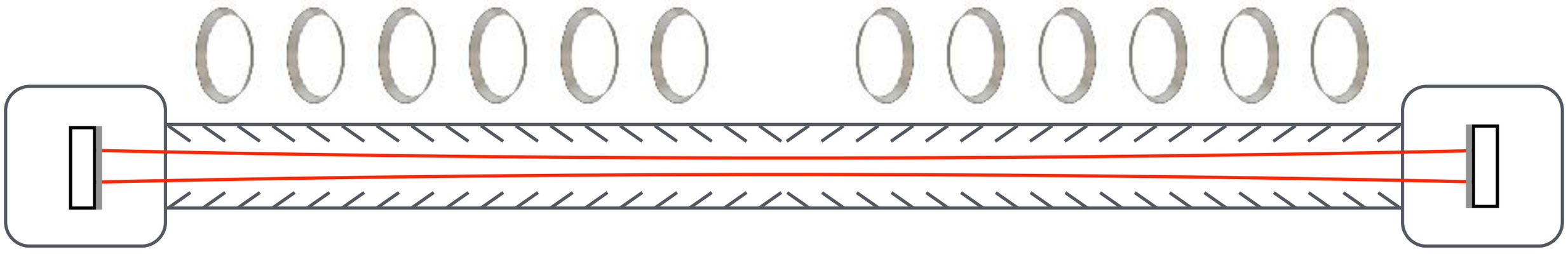

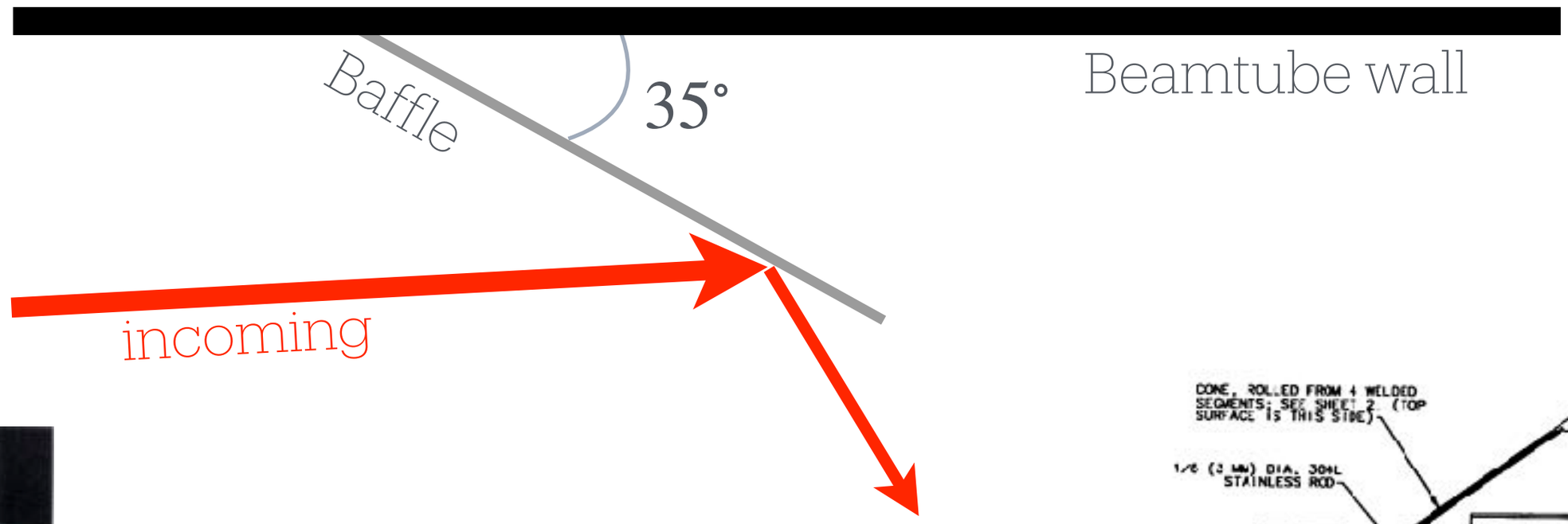


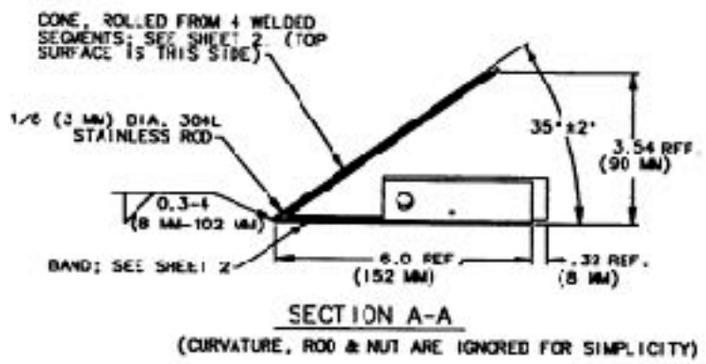

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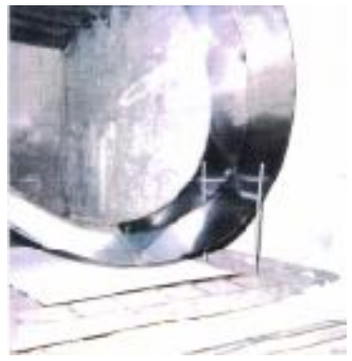

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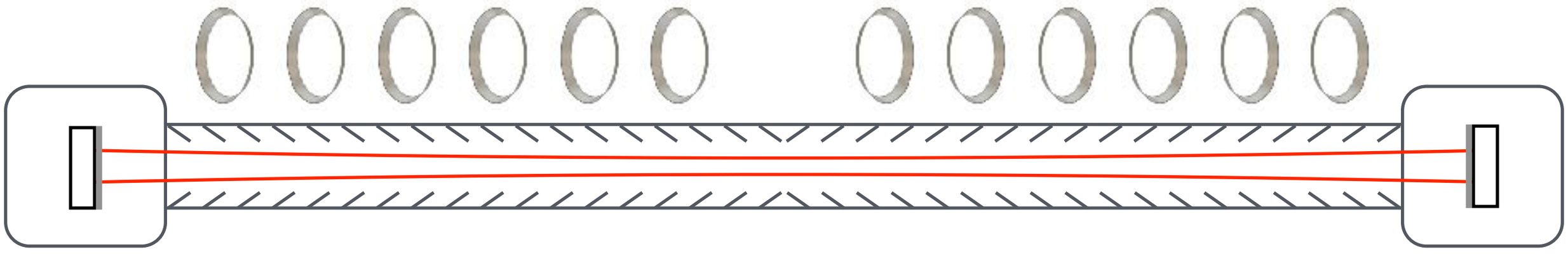

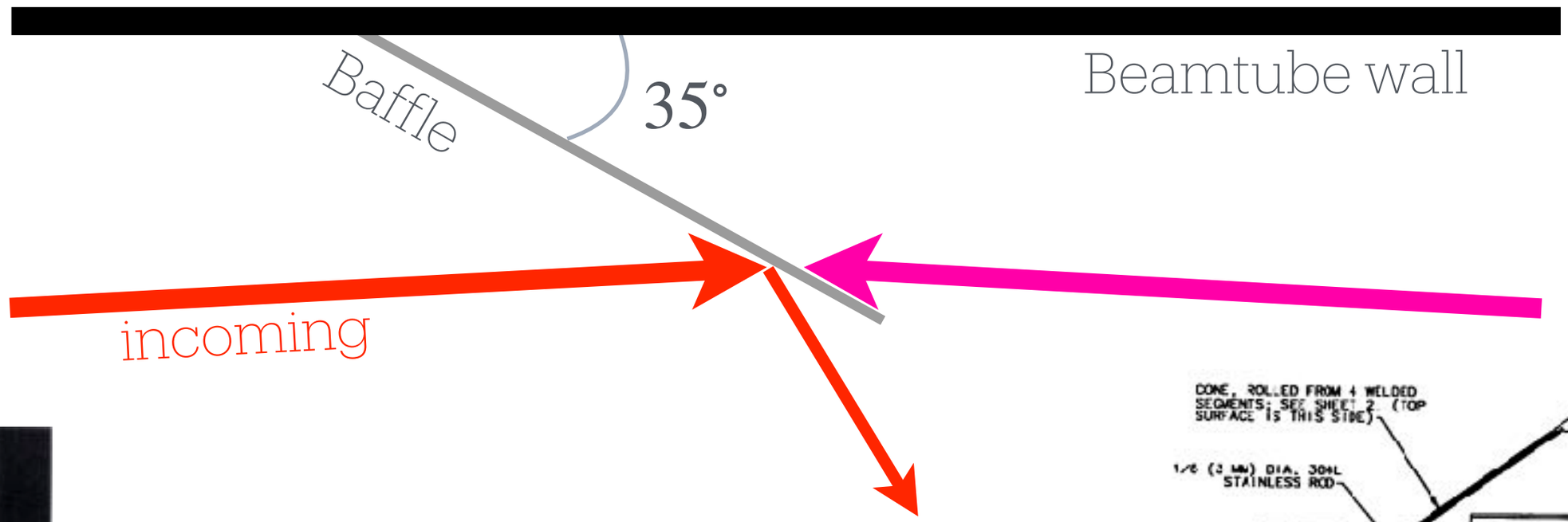


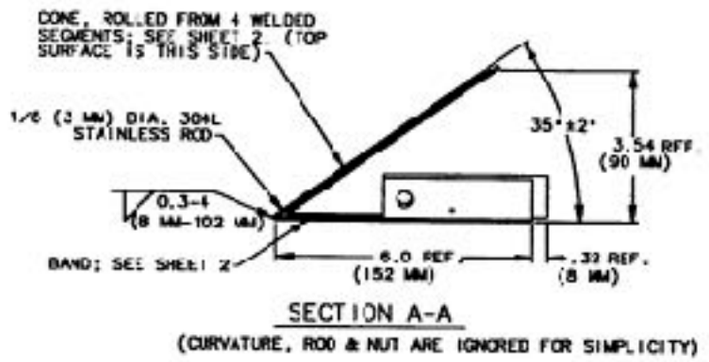

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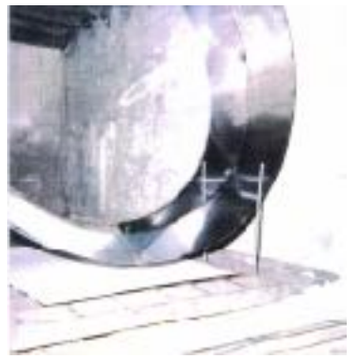

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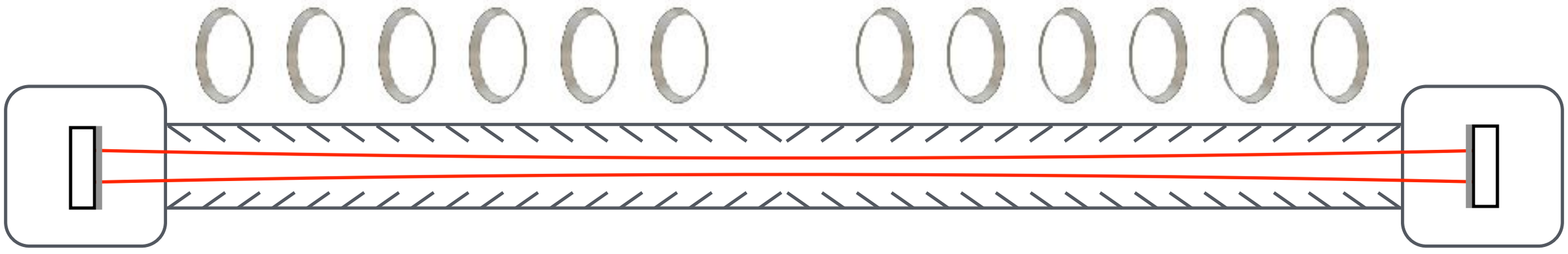

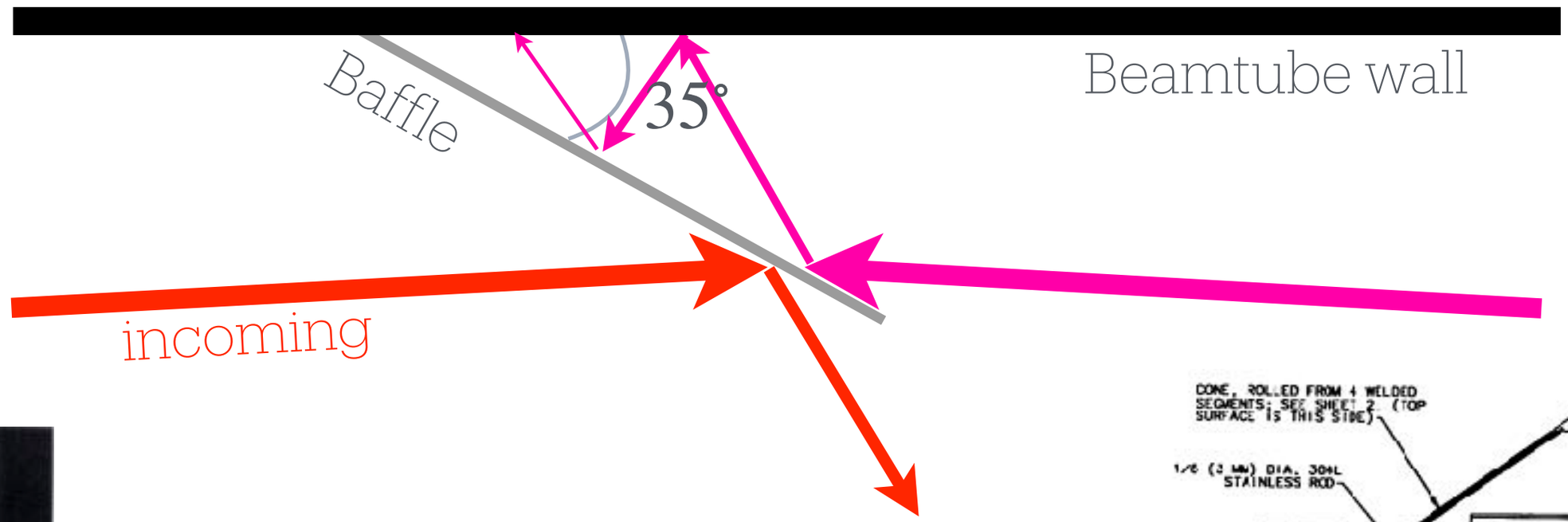


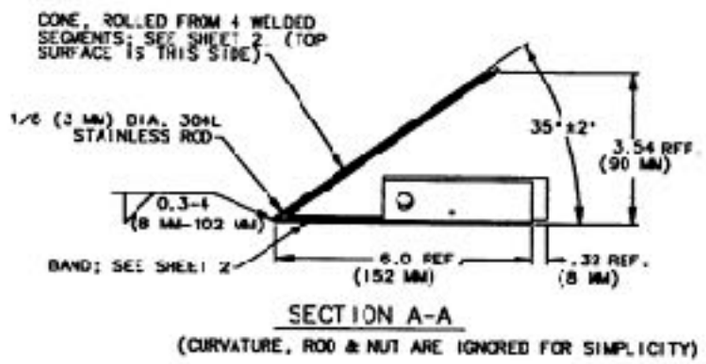

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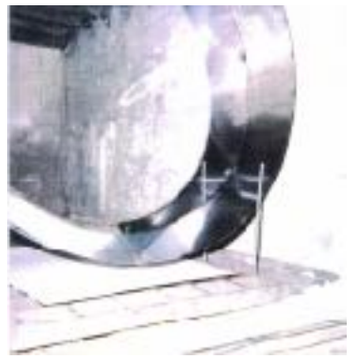

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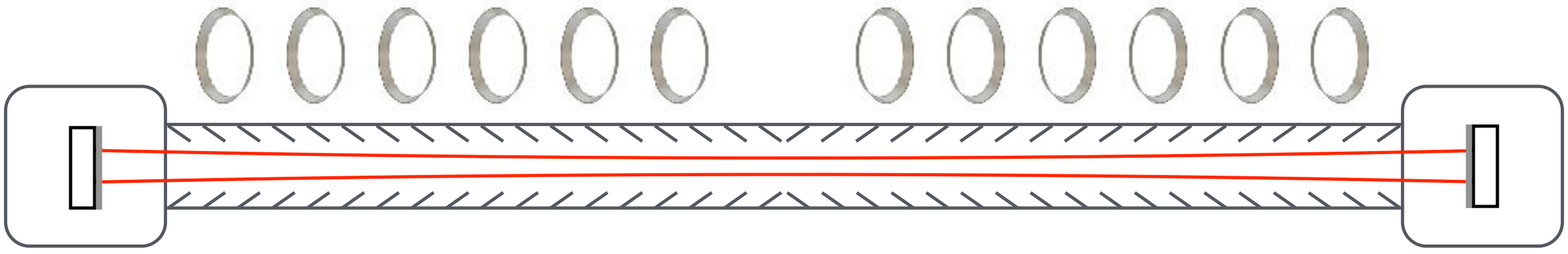

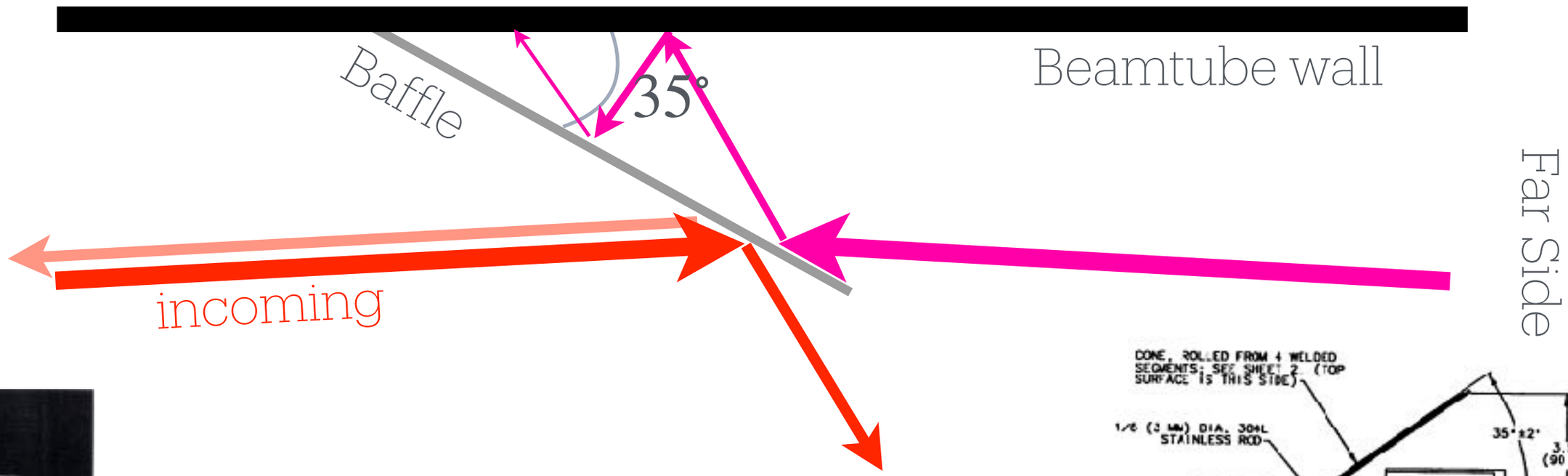


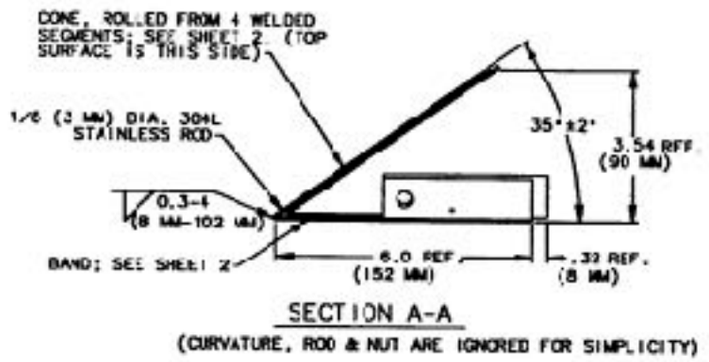

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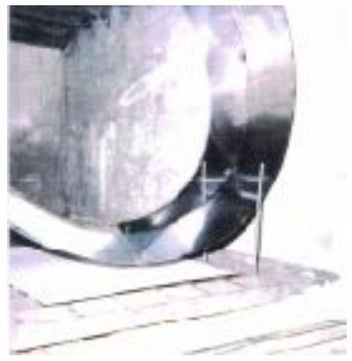

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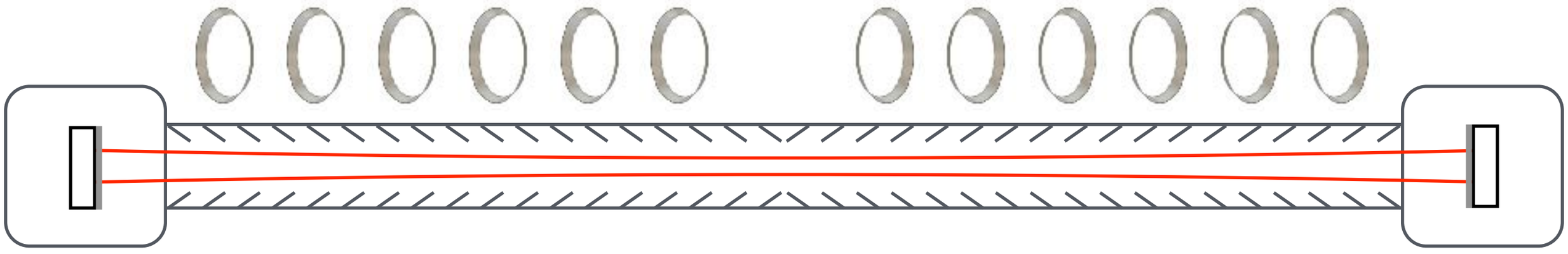

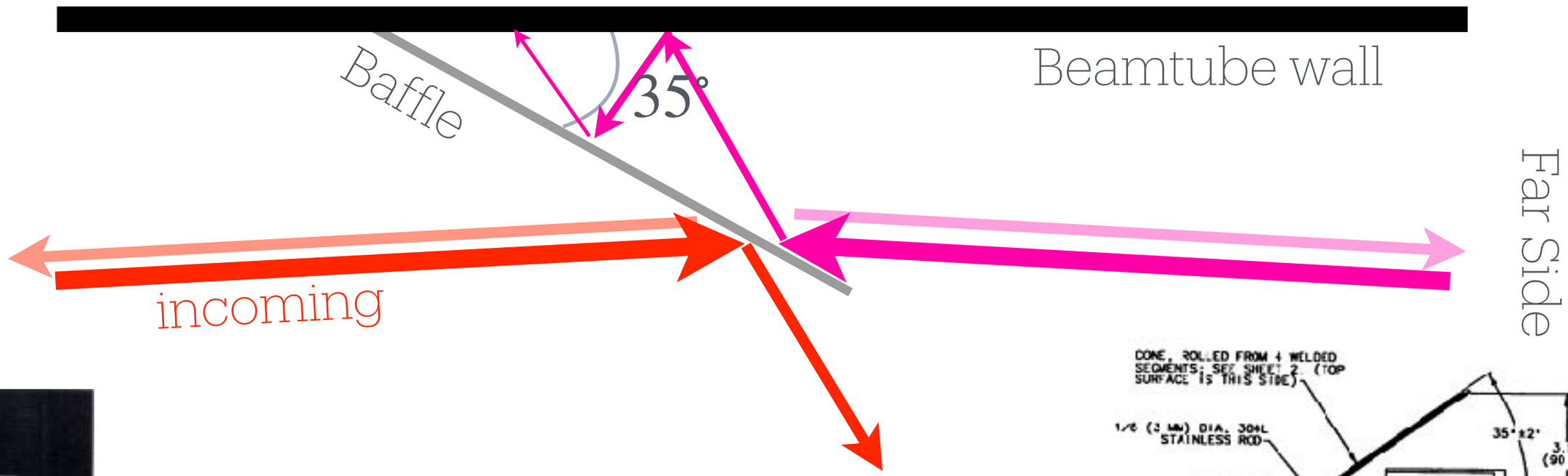


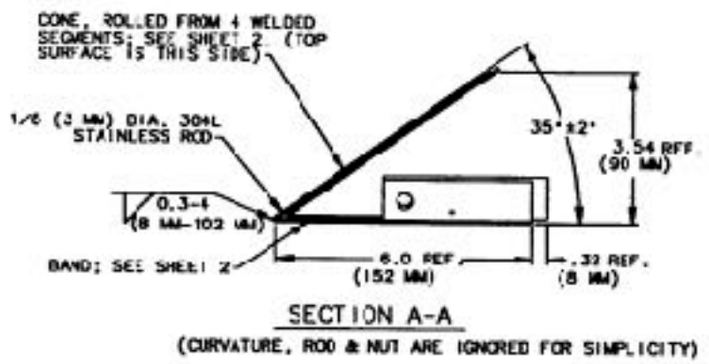

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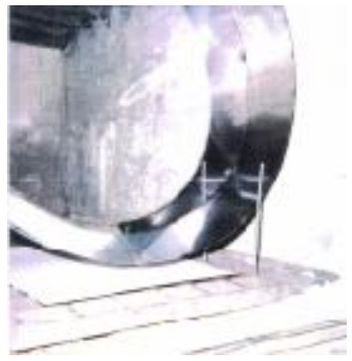

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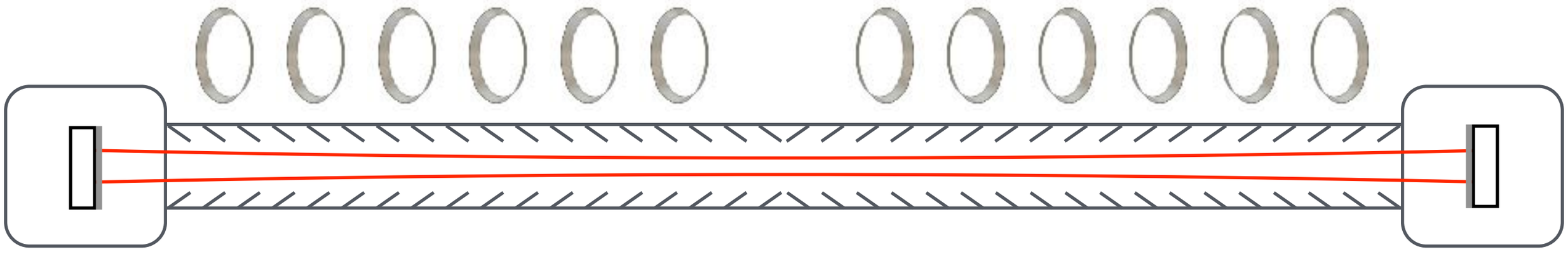
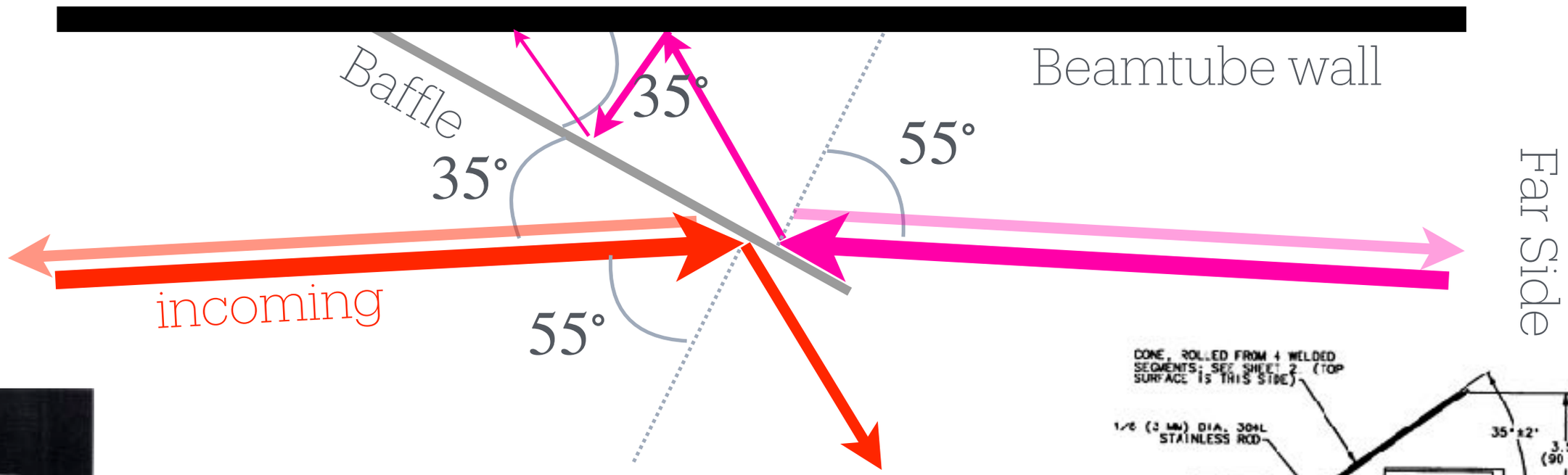
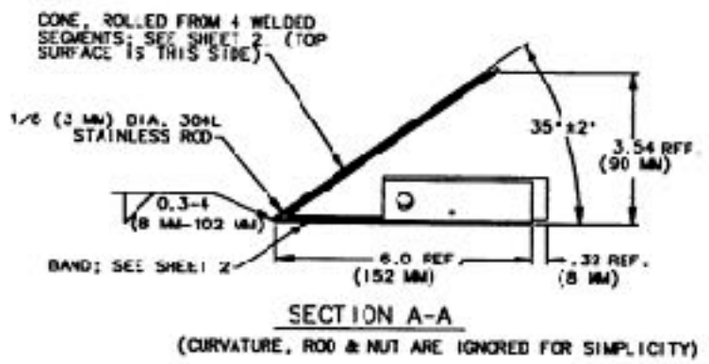


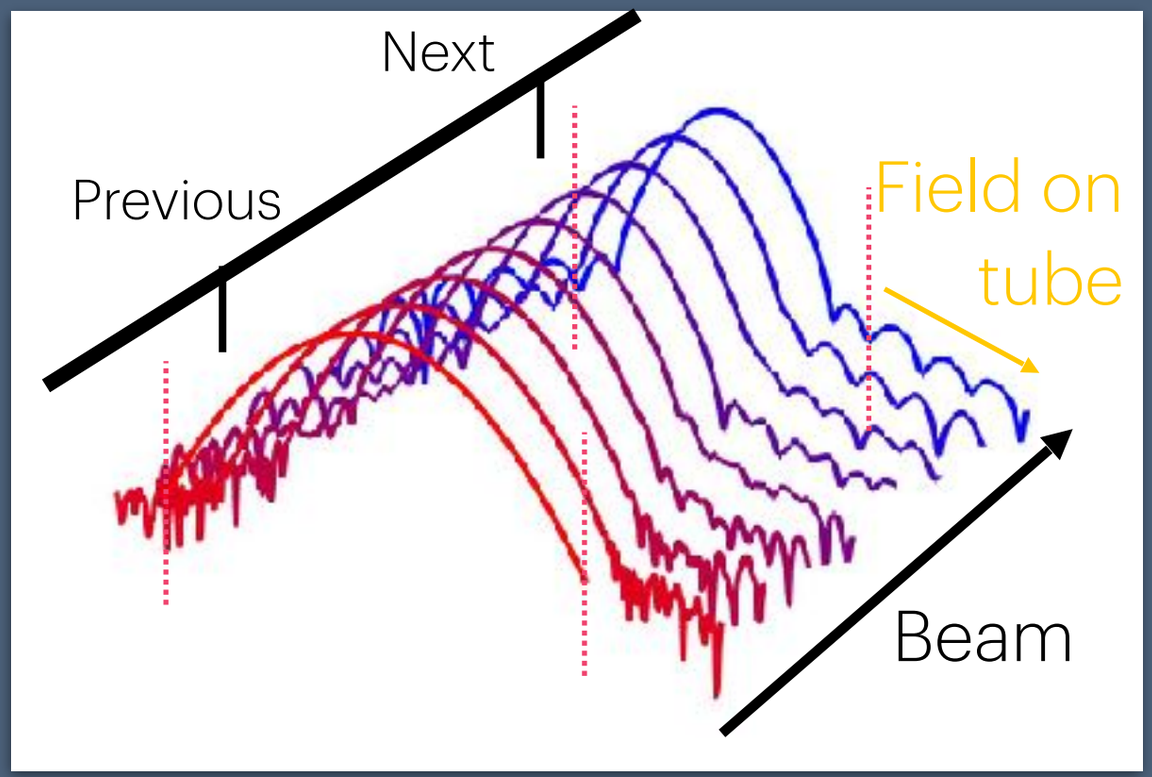


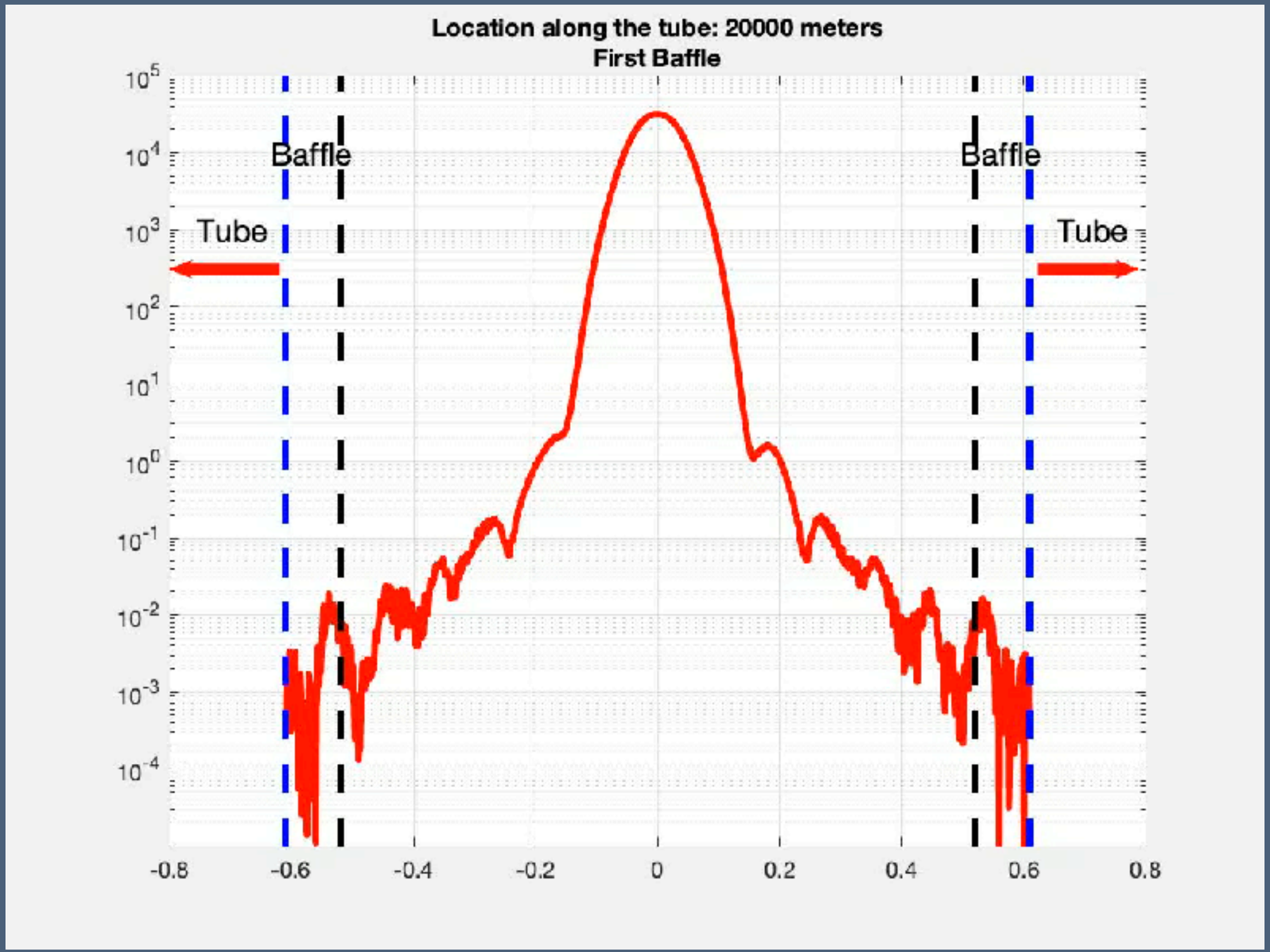
# A bit more “detail”

- There is really no way to shield the beamtube fully
- Some field always makes it to the tube due to diffraction

**Wave Optics** →



# Light Propagation through the tube



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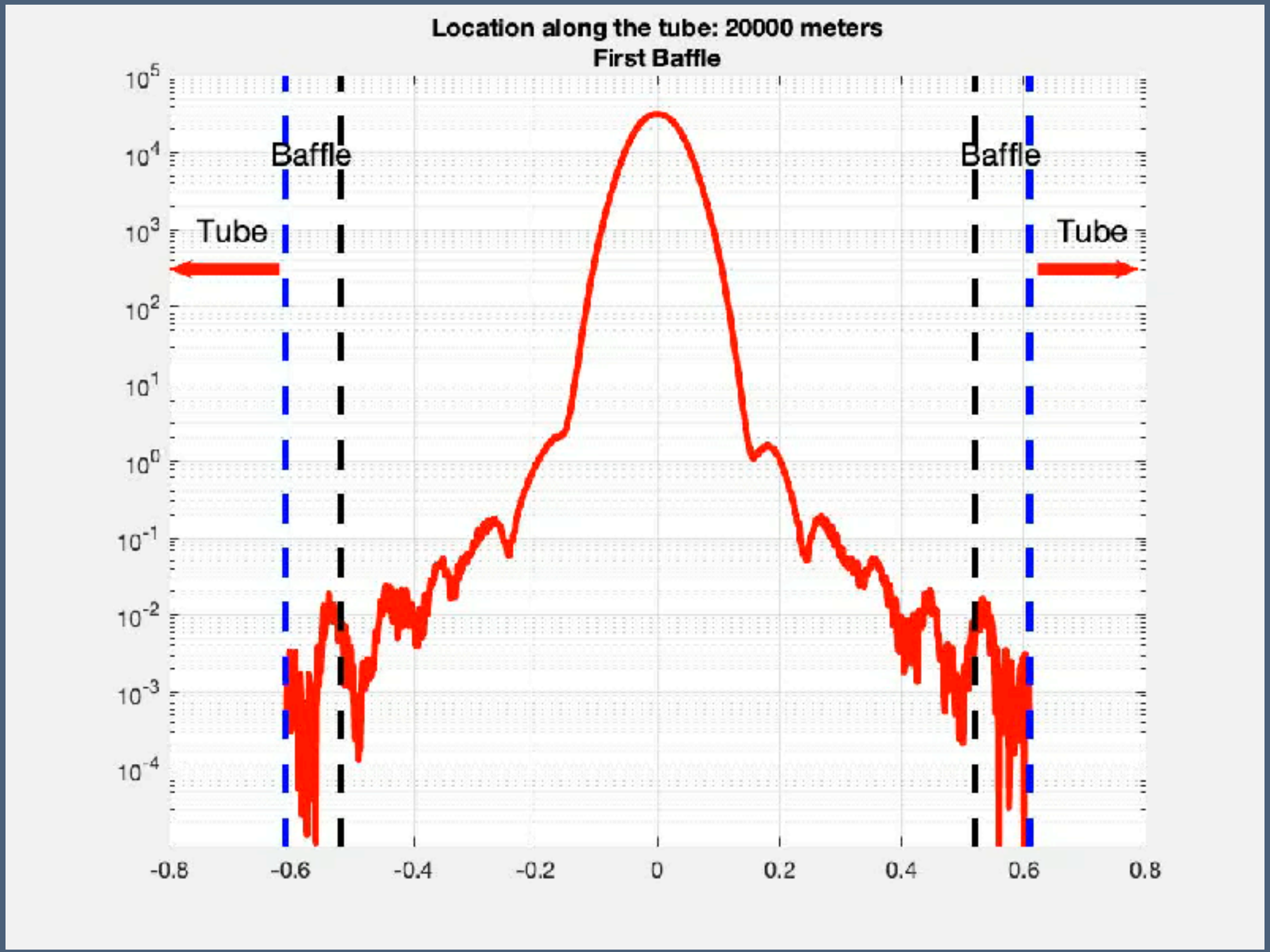
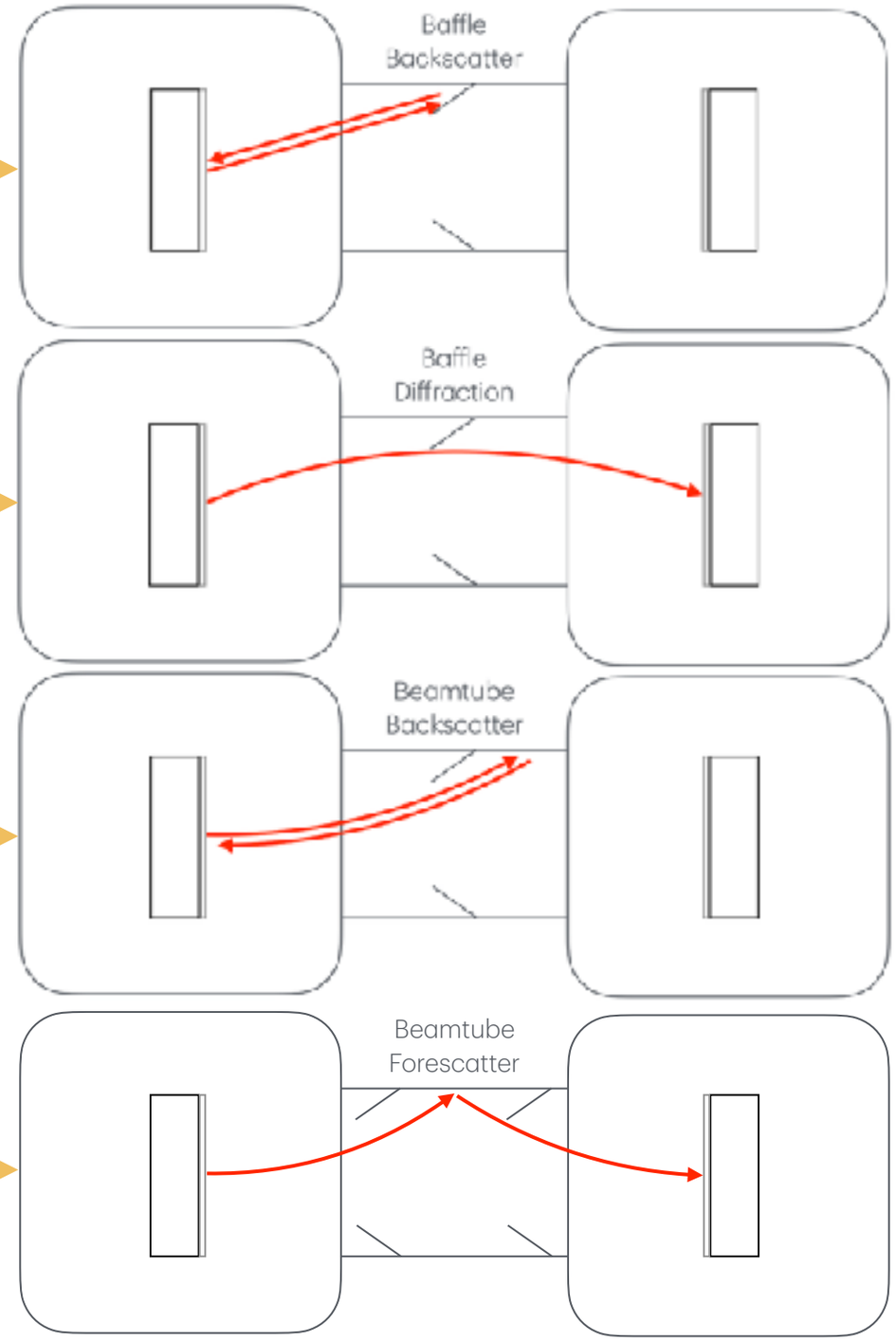


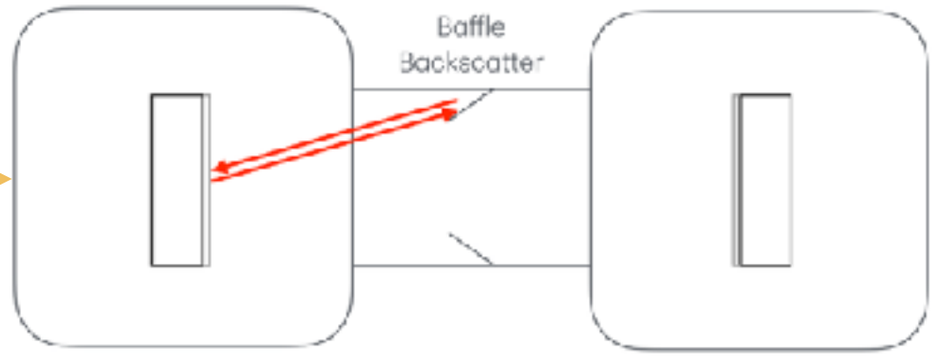
# What are we focused on first?

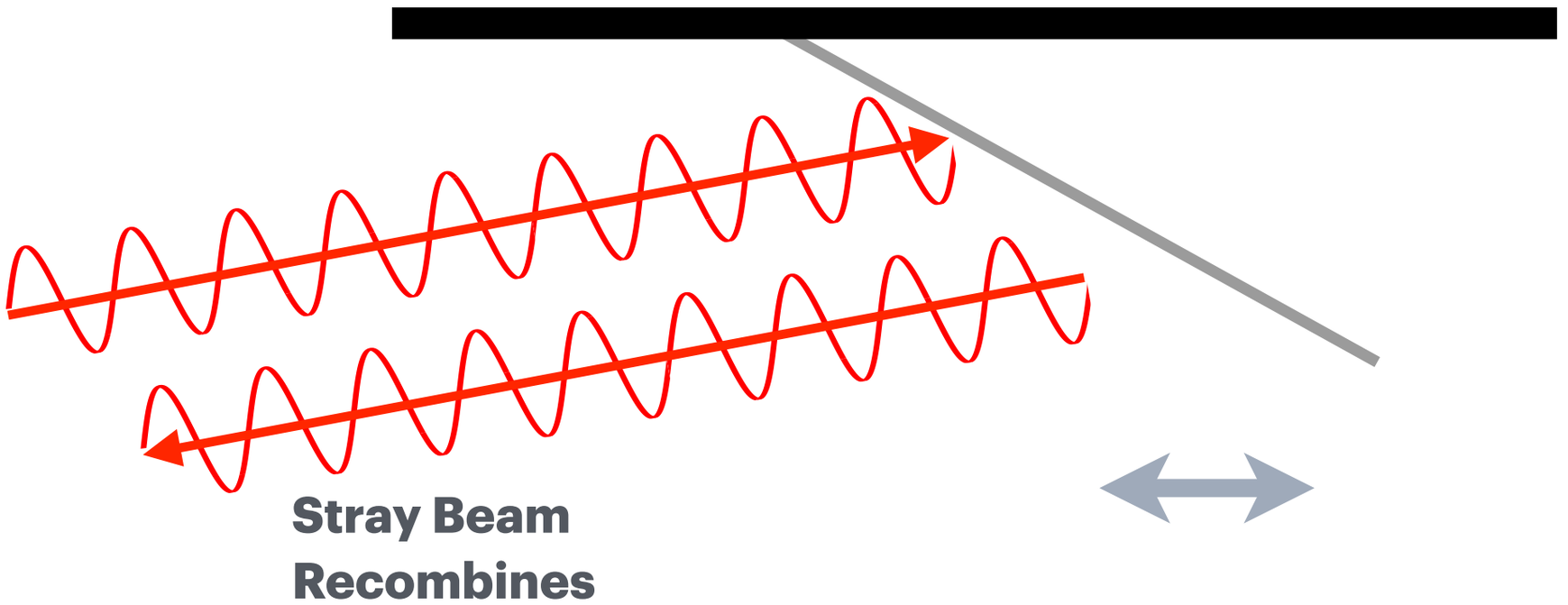
- Types of noise we model
  - Baffle Backscatter
  - Baffle Diffraction
  - Beamtube Forescatter
  - Beamtube Backscatter

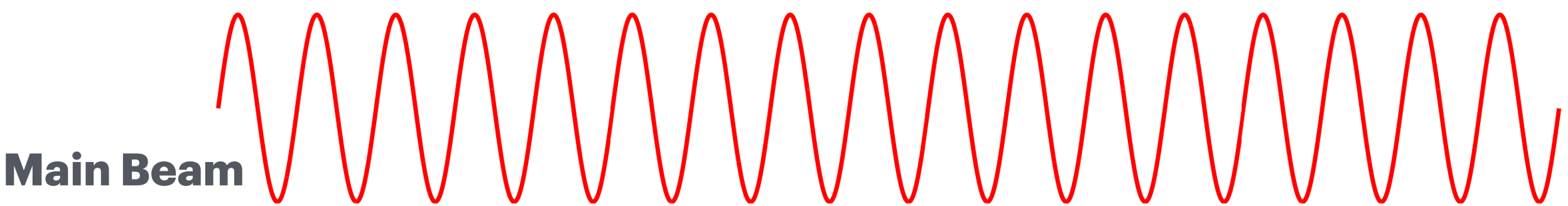


# A bit more "detail"

- Baffle Backscatter



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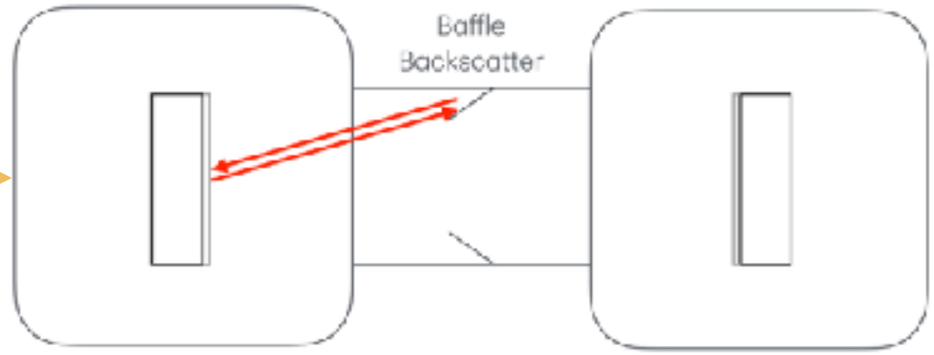
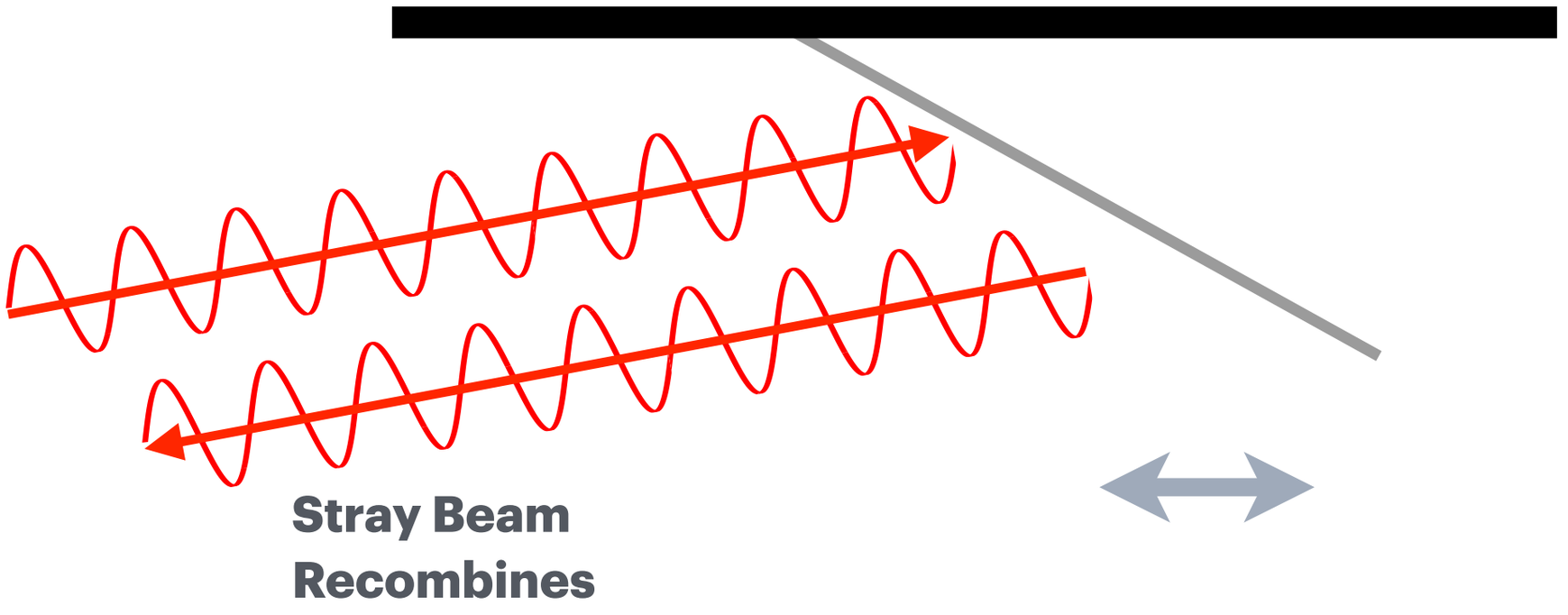
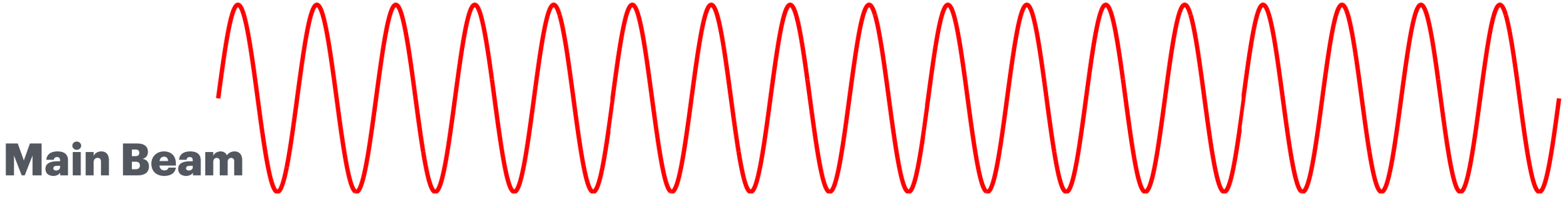
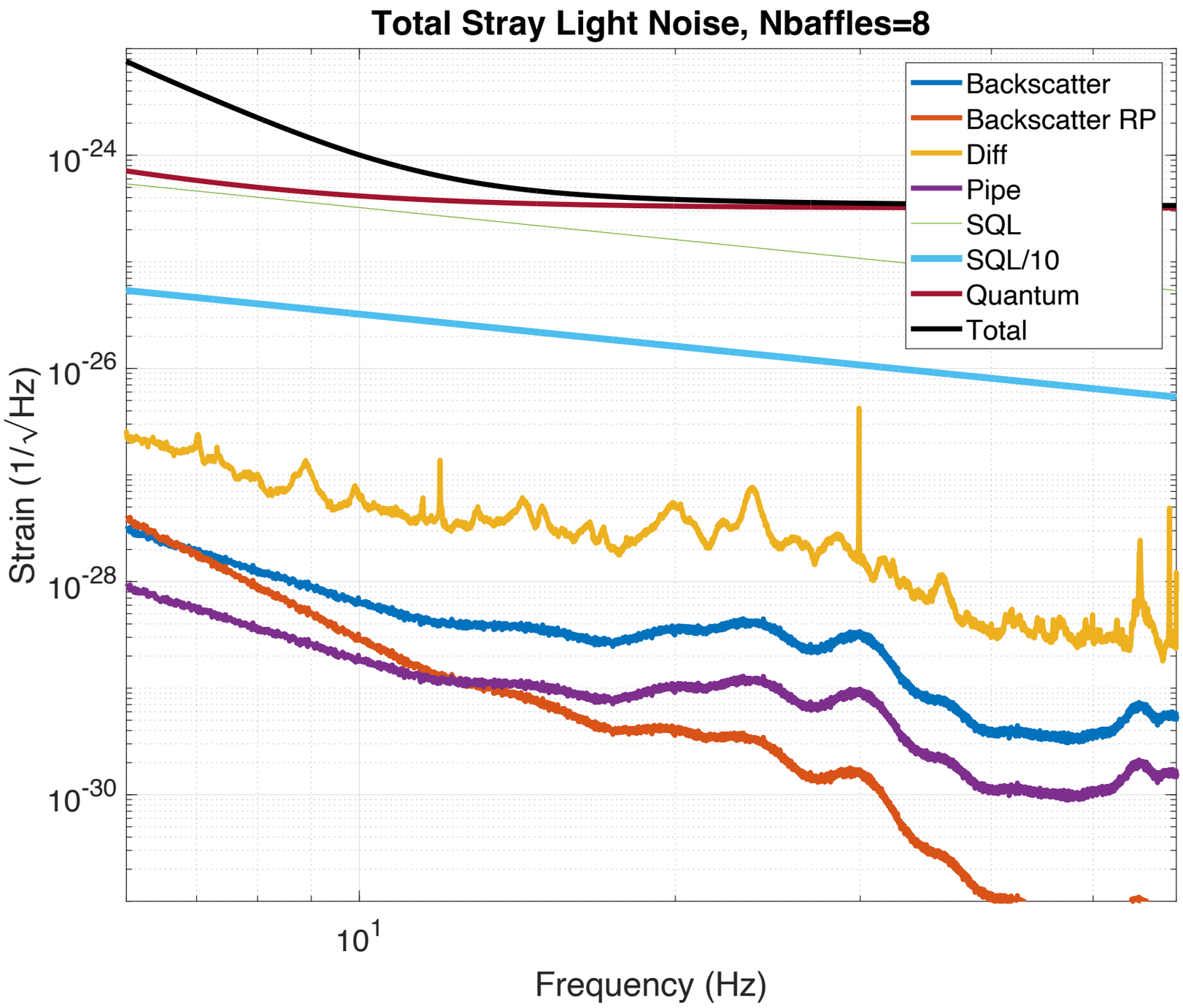


# We make Noise Estimations Like So

- As long as our model tells us we are away from the sensitivity of CE, we are good.



# Relevant Parameters for Stray Light

Beamtube wall material, radius, and shape

Baffle locations, material, mounting, and shape

Vacuum System Design

Coupling of seismic activity to the tube and baffle

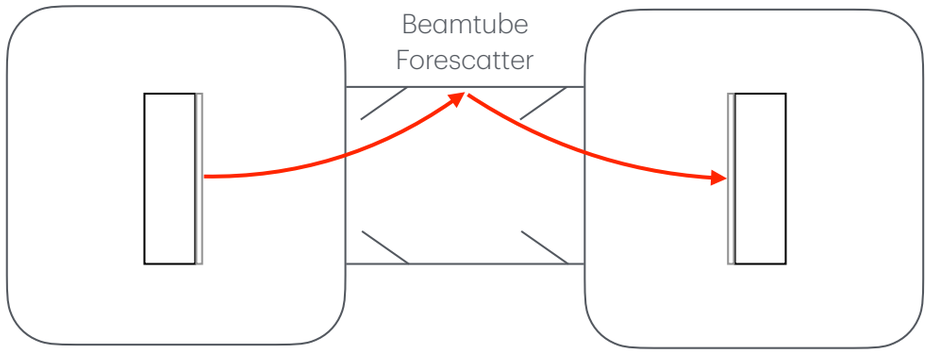
Seismic Activity at LOW AND HIGH frequencies

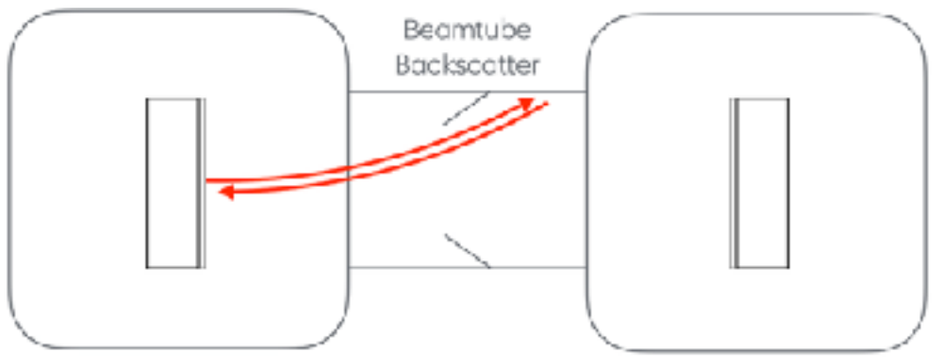
Beamtube alignment tolerance
and other non-ideal considerations

# Relevant Parameters for Stray Light

Beamtube wall material, radius, and shape

- Wall Type → forward and back scatter → baffle shielding requirement
- Wall Radius → Baffle height/inner radius → Number of baffles
- …

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**Side note: There are no measurements at the low/high angles required for our models**

**E. Noise Spectrum for Light Backscattered from Bare Tube Wall**

As was noted in Sec. I.A, the wall's backscatter probability $dP/d\Omega_{\rm bs}$ is not known at the small incidence/backscatter angles $\theta$ of concern to us. Accordingly, we shall explore the consequences of two possibilities:

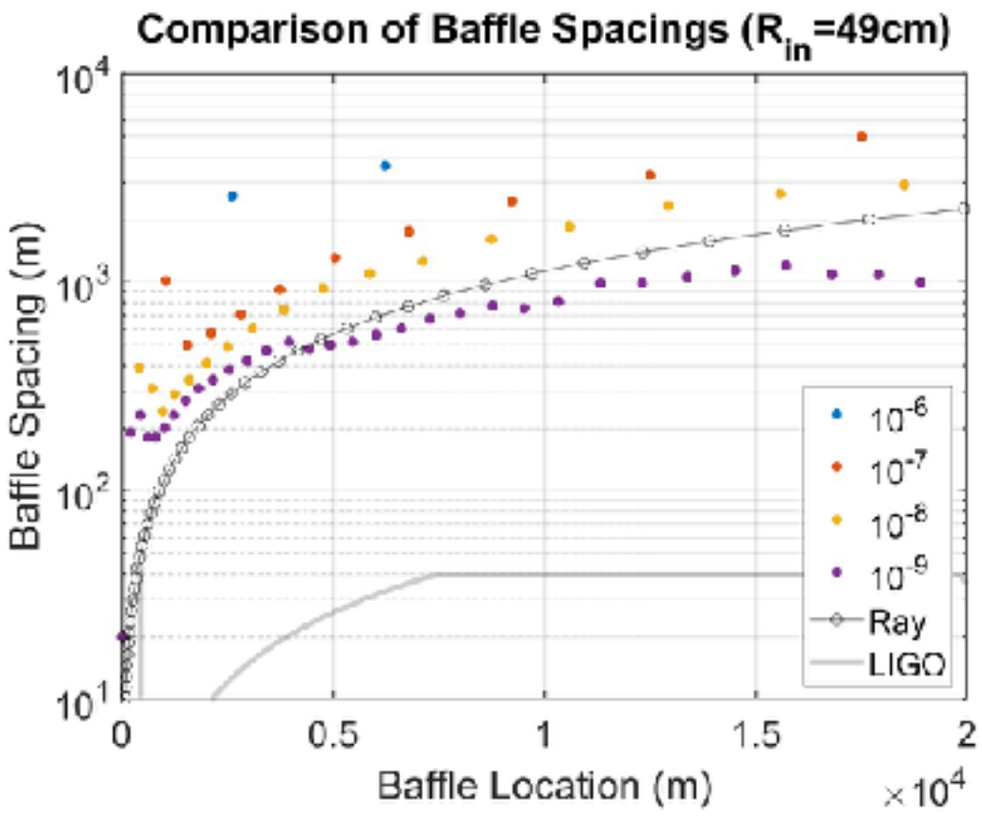
$$\frac{dP}{d\Omega_{\rm bs}} = \beta = 0.01 \quad \text{"pessimistic,"} \tag{32}$$

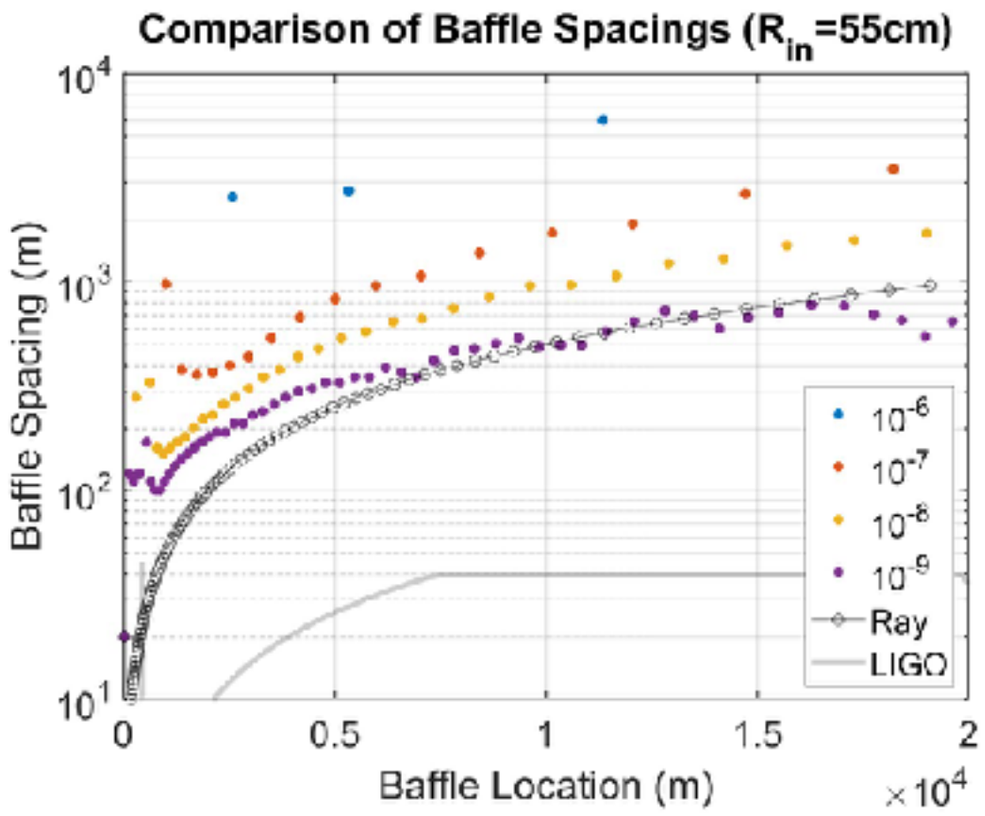
$$\frac{dP}{d\Omega_{\rm bs}} = \beta\theta = 0.01\theta \quad \text{"optimistic."} \tag{33}$$

# Relevant Parameters for Stray Light

Baffle locations, material, mounting, and shape

- Assuming we pick one type of baffle.
- Locations depends on inner radius.
- Locations depend on allowable power on beam tube.
- Geometrical vs Wave approach.

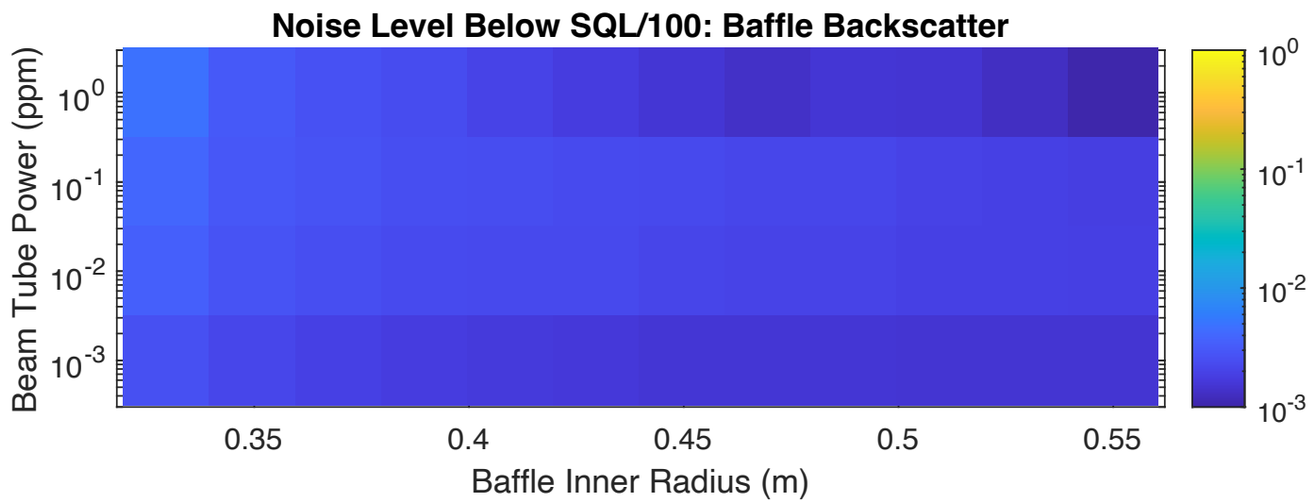


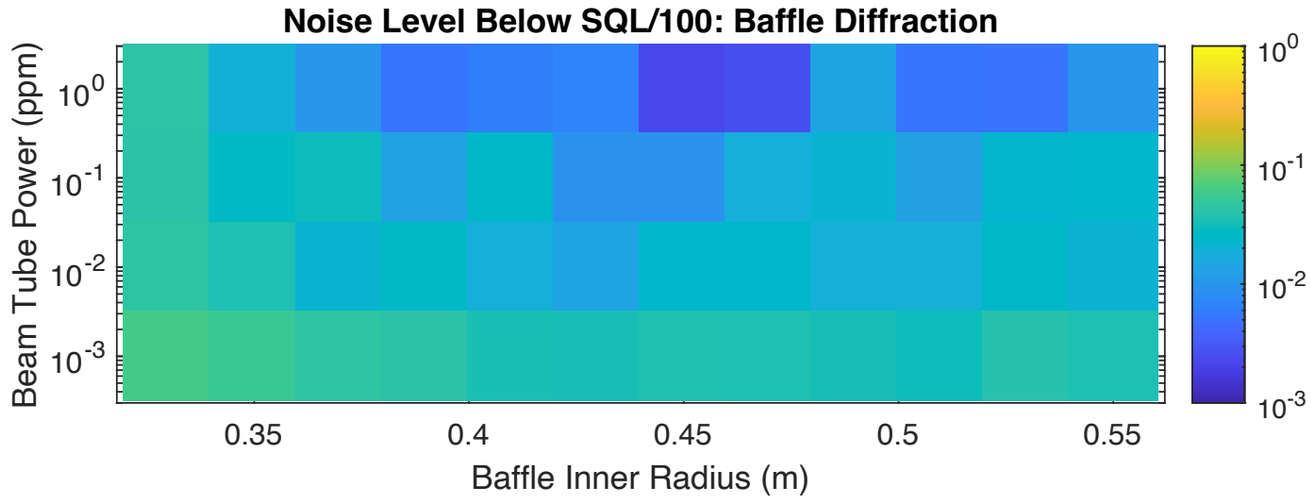



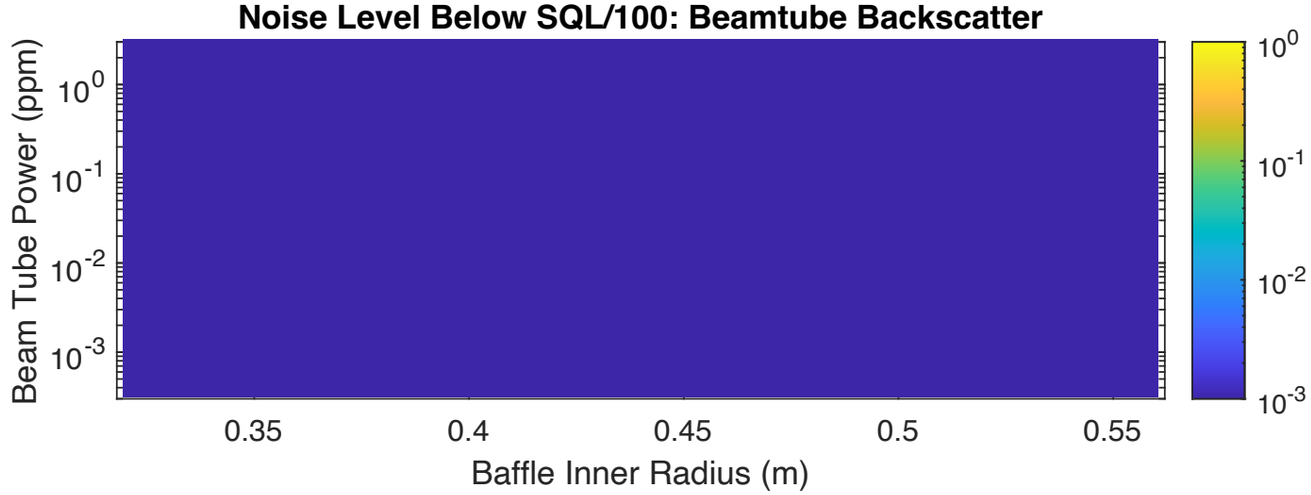
# Distributed Power Configuration

Baffle locations, material, mounting, and shape

- Main takeaway is that too many baffles only increase diffraction noise...
- Baffle Backscatter Noise is less dependent on beamtube coverage and their radius



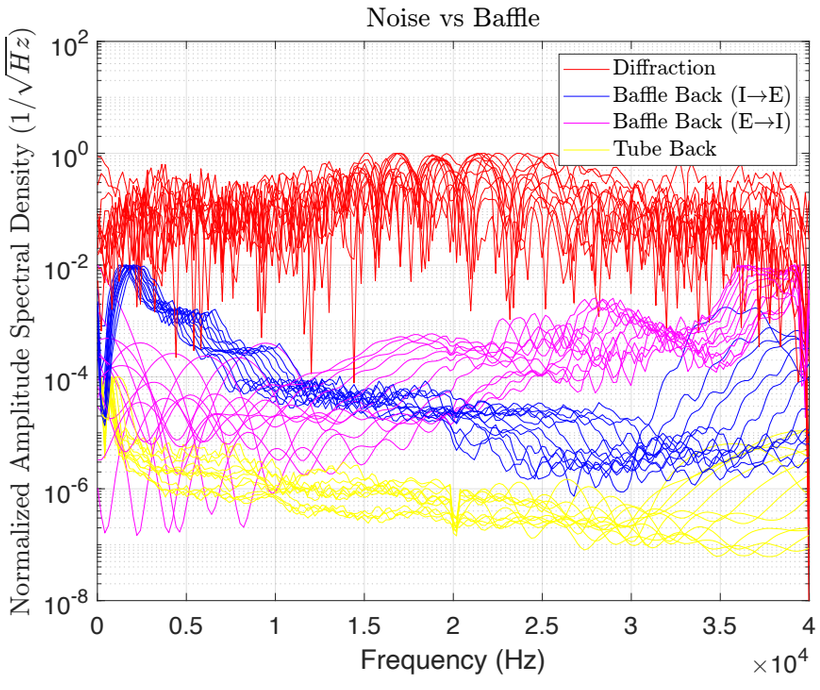



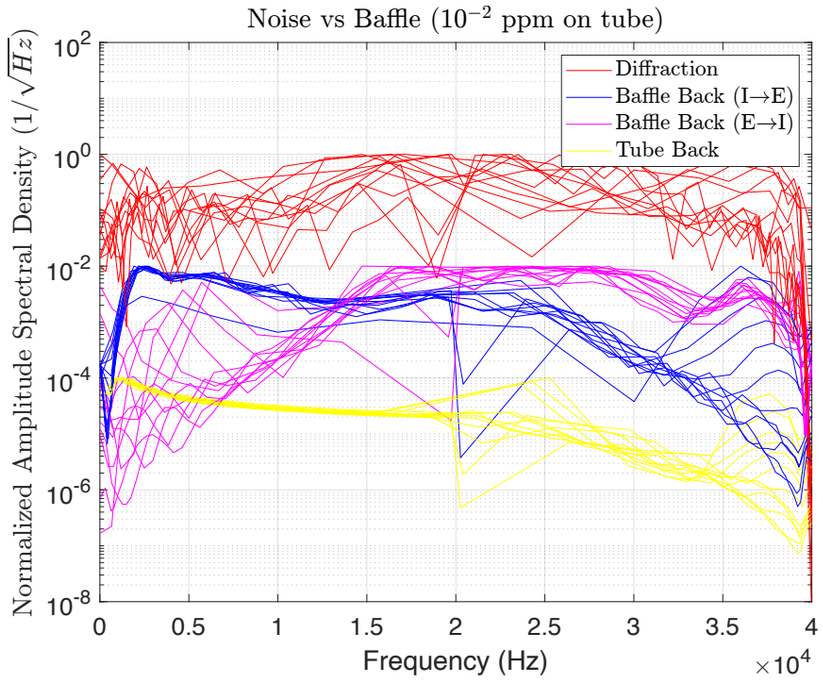



# Noise vs Baffle

## Main takeaways

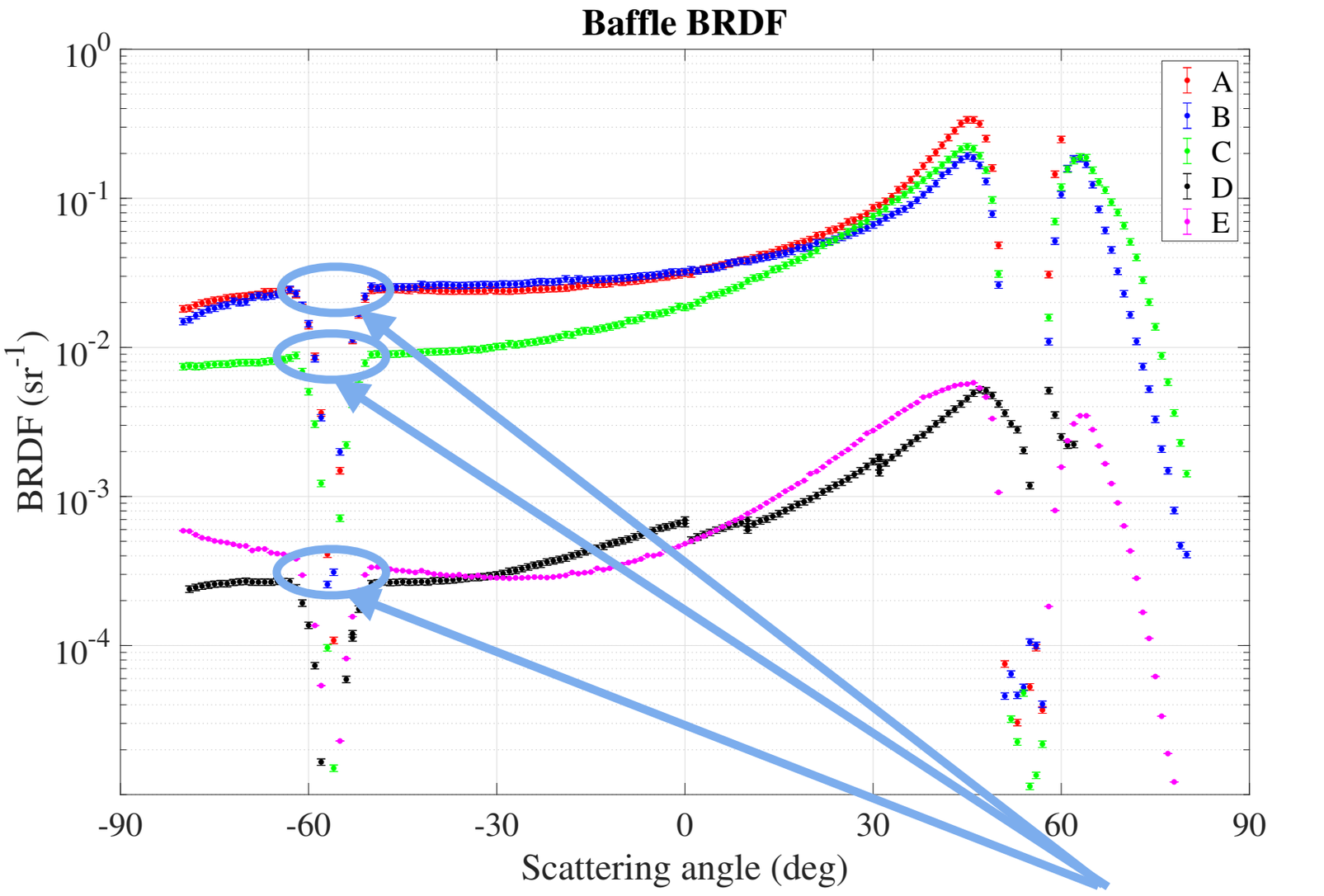
- Main takeaways is independent of the case studied.
- Diffraction noise peaks in the middle section, but dependence on location is relatively weak.
- Backscatter noise peaks close to the test mass, but when considering both test masses, backscatter becomes weakly dependent on location.



# Backscatter from Various Materials

Baffle locations, material, mounting, and shape



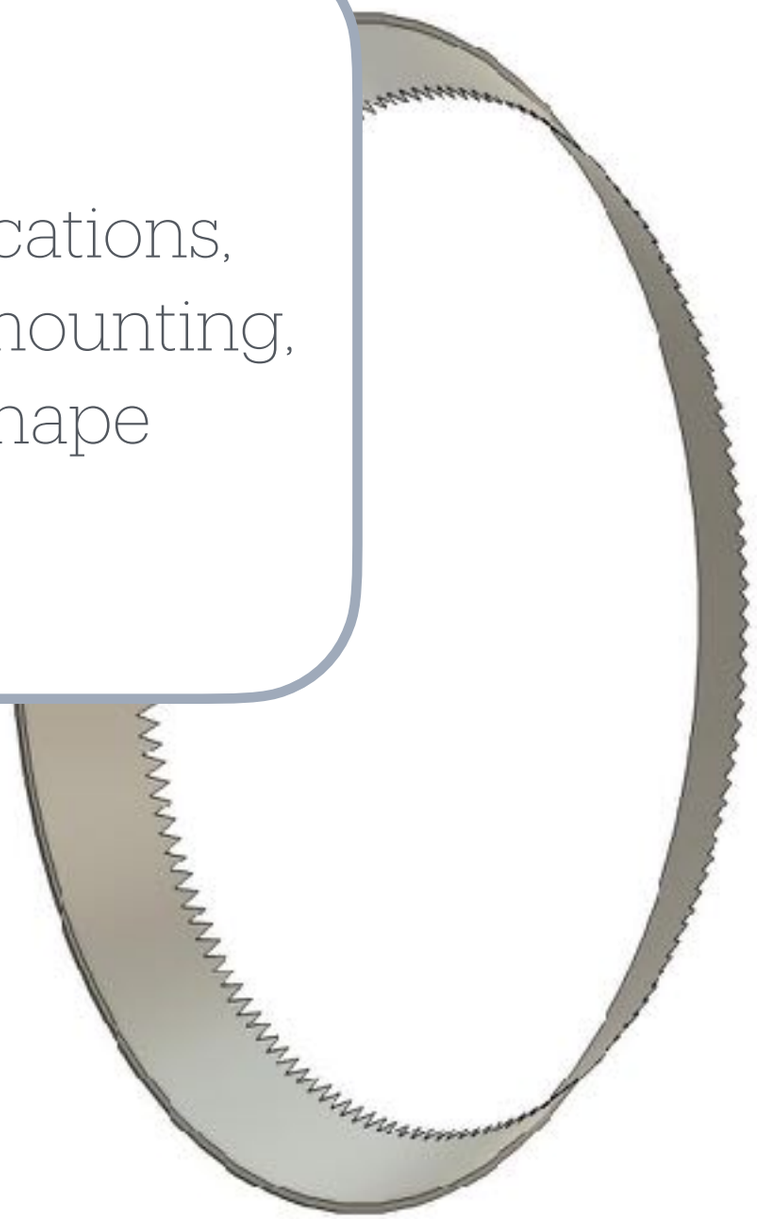

We are interested in these values

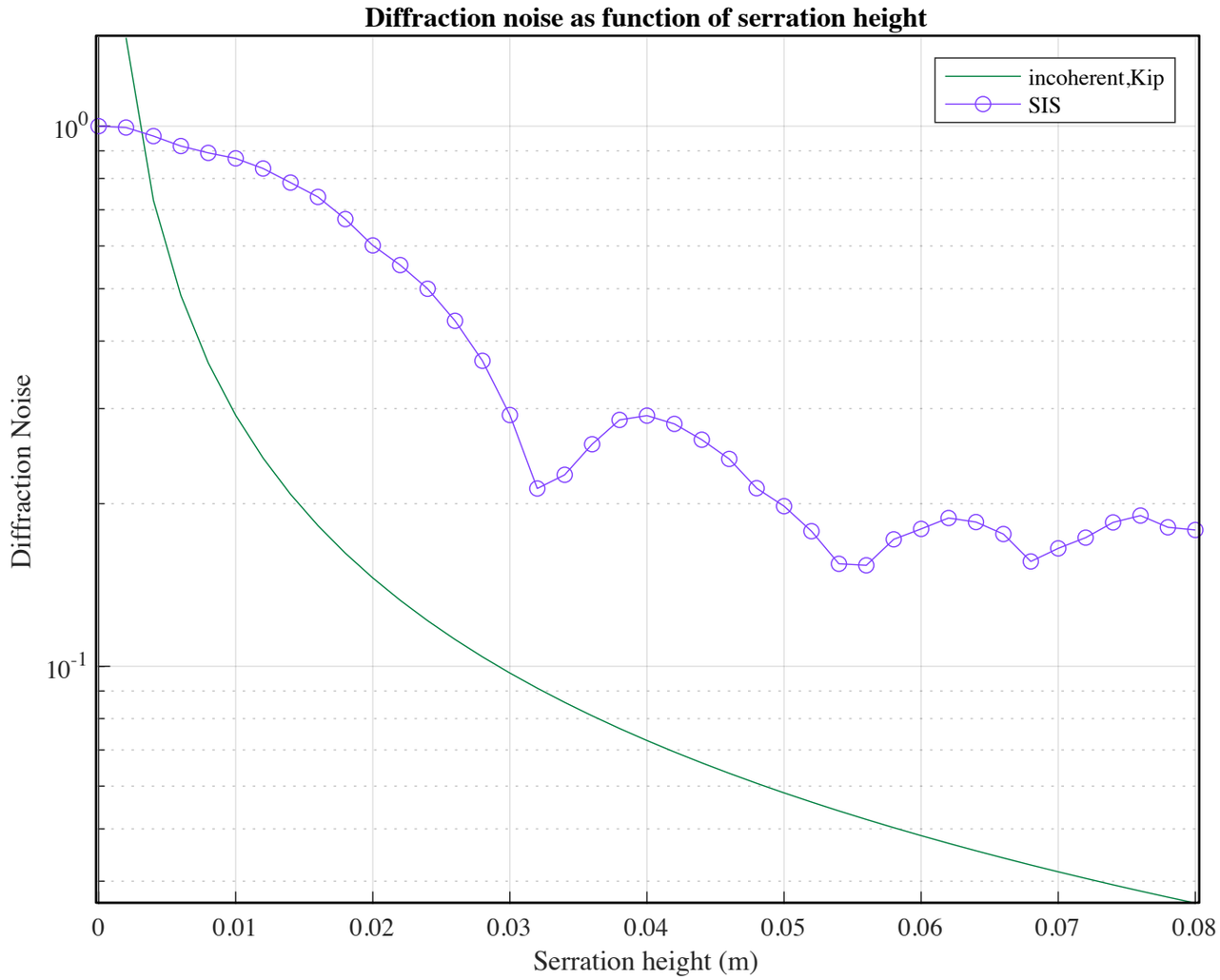


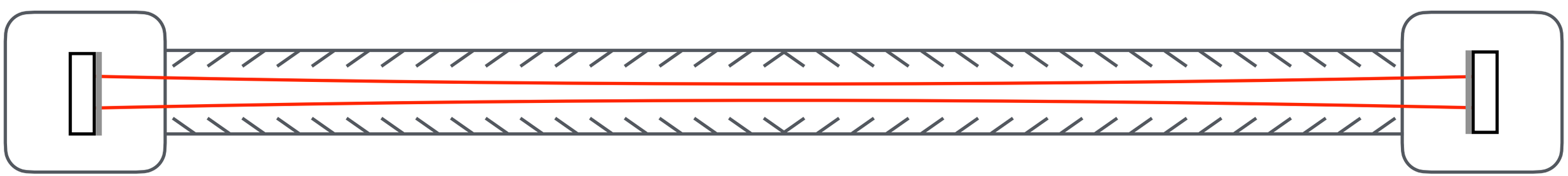


# Serration for Good

Baffle locations, material, mounting, and shape





# Relevant Parameters for Stray Light

Beamtube wall material, radius, and shape

Baffle locations, material, mounting, and shape

Vacuum System Design

Coupling of seismic activity to the tube and baffle

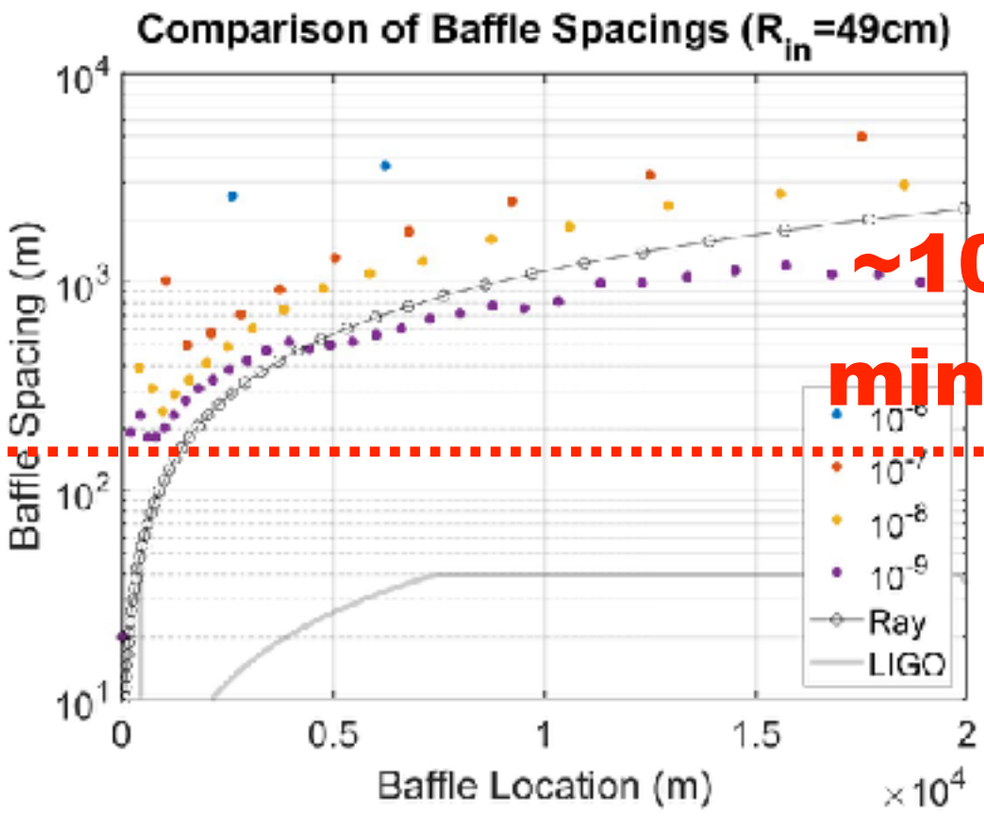
Seismic Activity at LOW AND HIGH frequencies

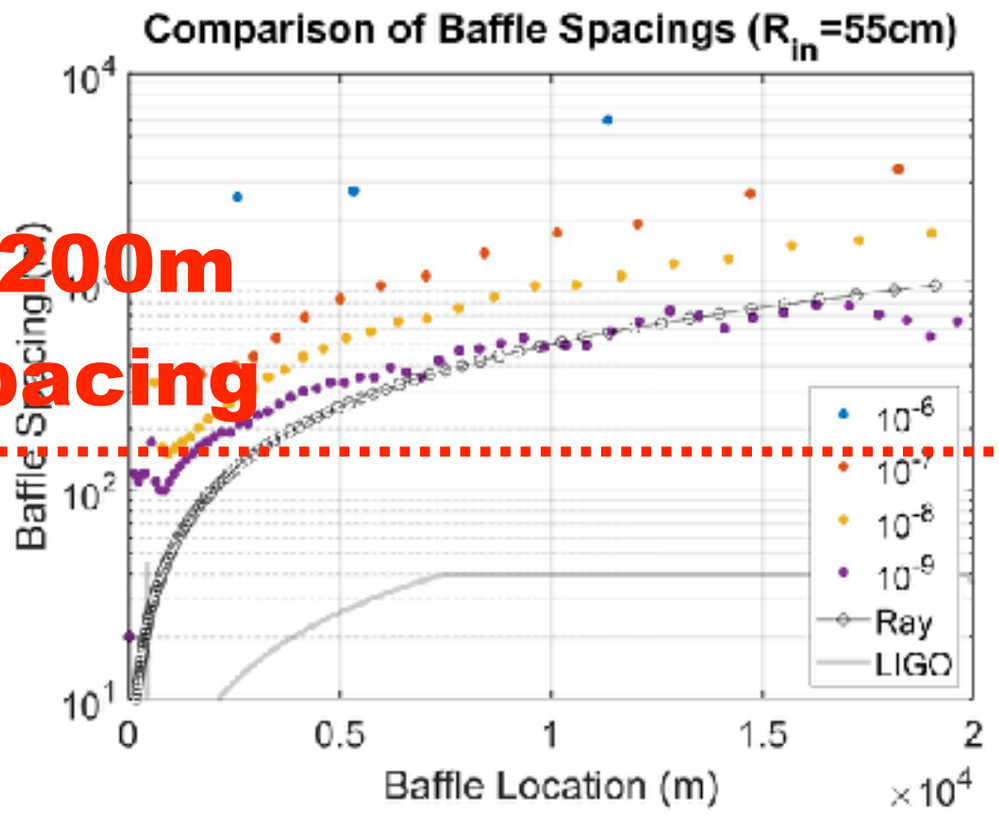
Beamtube alignment tolerance
and other non-ideal considerations

# Relevant Parameters for Stray Light

Vacuum System Design

- Nearly all calculations point to a 100-200m minimum separation between baffles.
- If cryo-pumps are placed every 200-250m, and each of them requires some baffling, then it's possible it is all we need.

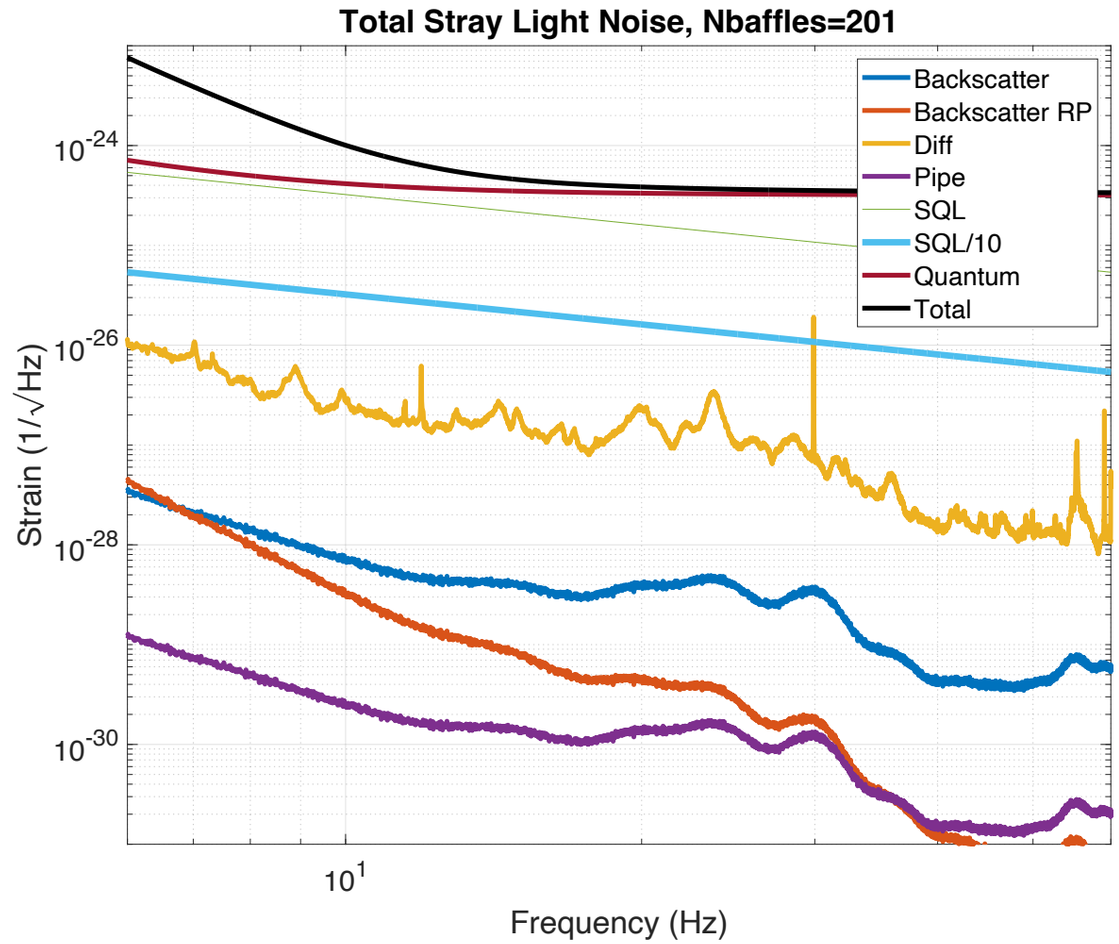


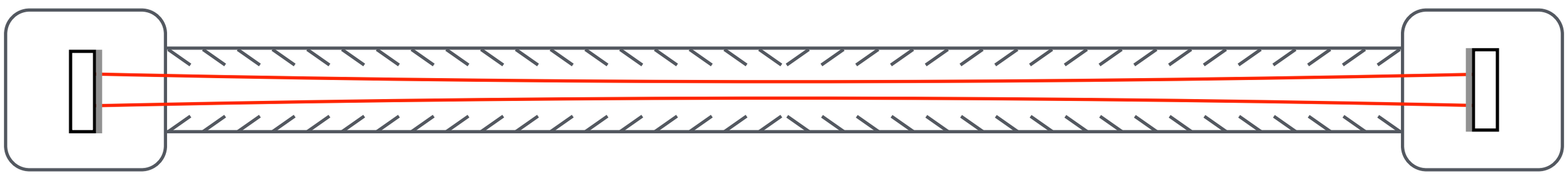

**~100-200m min spacing**

# Standard Simple Configuration

Vacuum System Design




Constant 200m baffle spacing

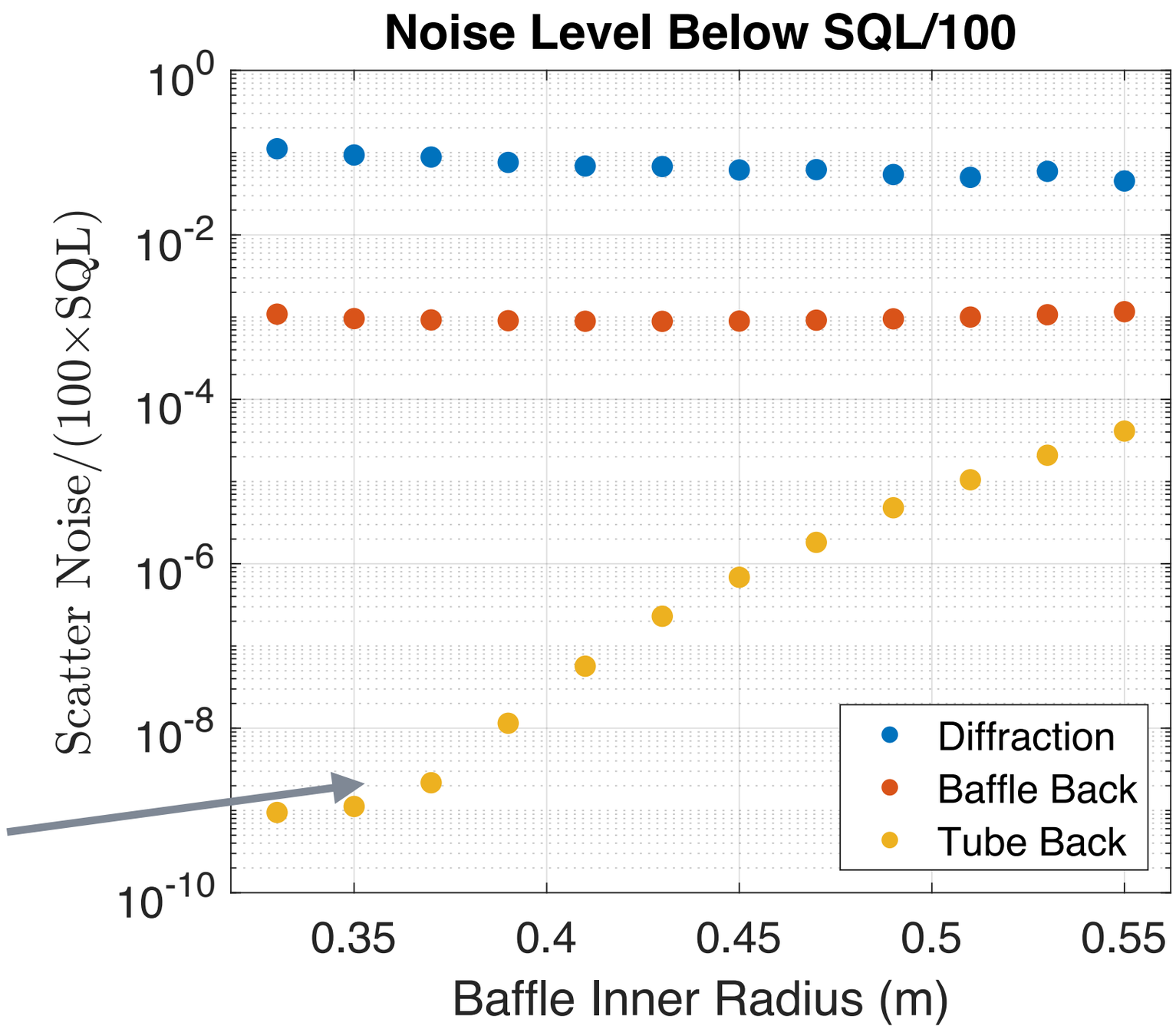


# Standard Simple Configuration

Vacuum System Design

Very low angle tube backscatter a relative unknown

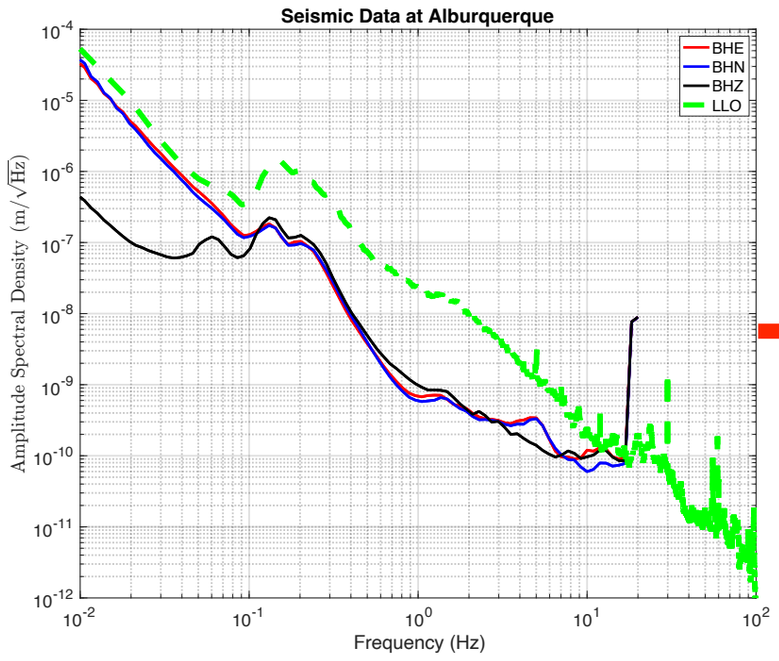
## Noise vs Baffle Inner Radius



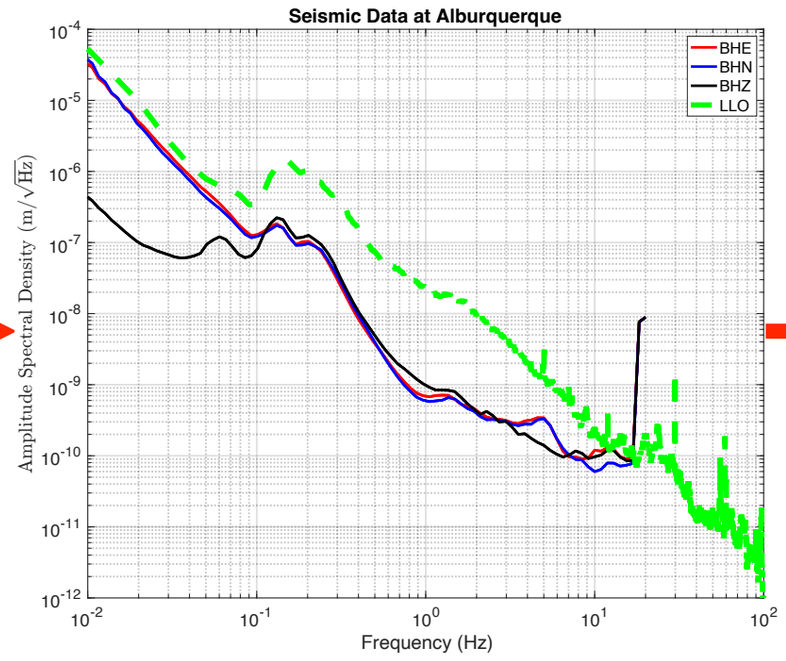
# Relevant Parameters for Stray Light

Coupling of seismic activity to the tube and baffle

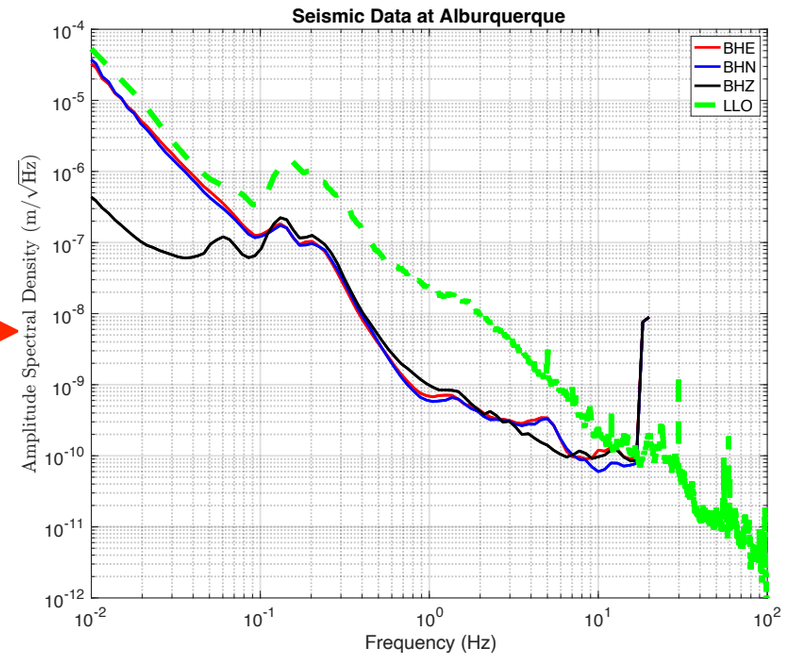
- We assume that the ground motion transfer directly to the baffle
- Mounting will determine resonances and damping




Ground




Tube



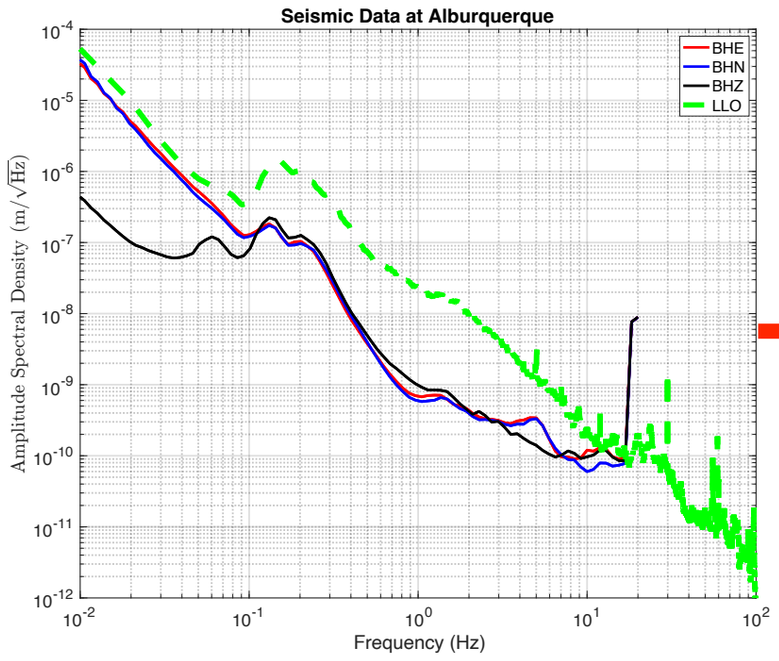

Baffle

# Relevant Parameters for Stray Light

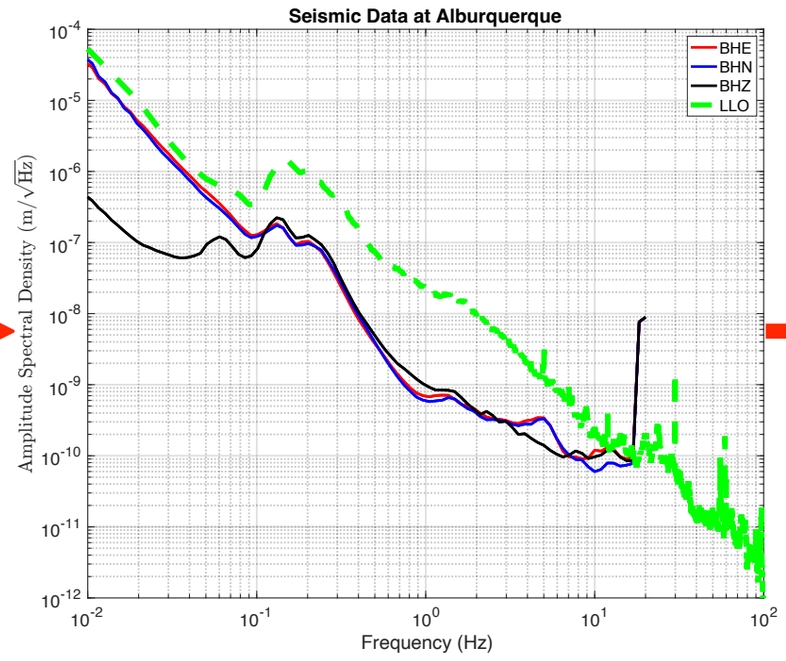
Coupling of seismic activity to the tube and baffle

**We care both for the low frequencies and the high frequencies, due to fringe wrapping**

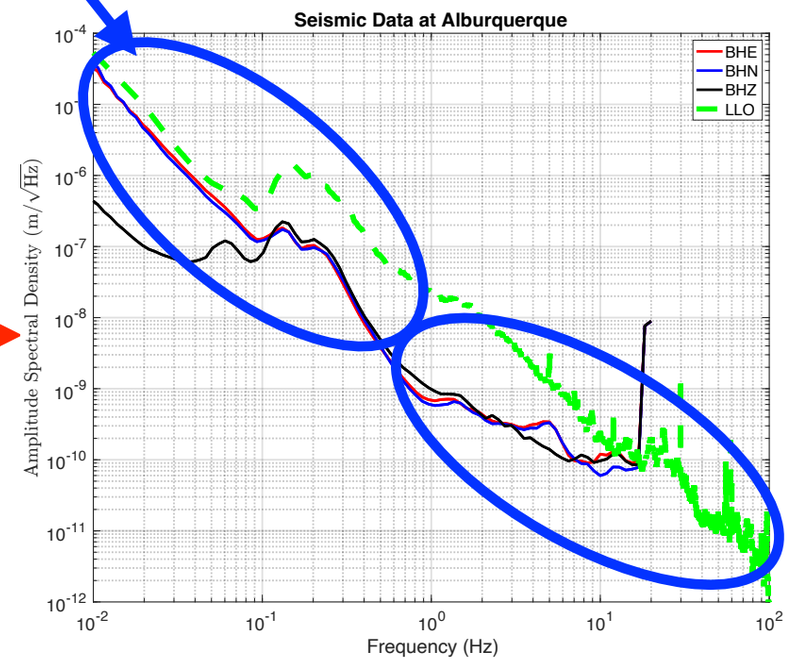
- We assume that the ground motion transfer directly to the baffle
- Mounting will determine resonances and damping




Ground




Tube



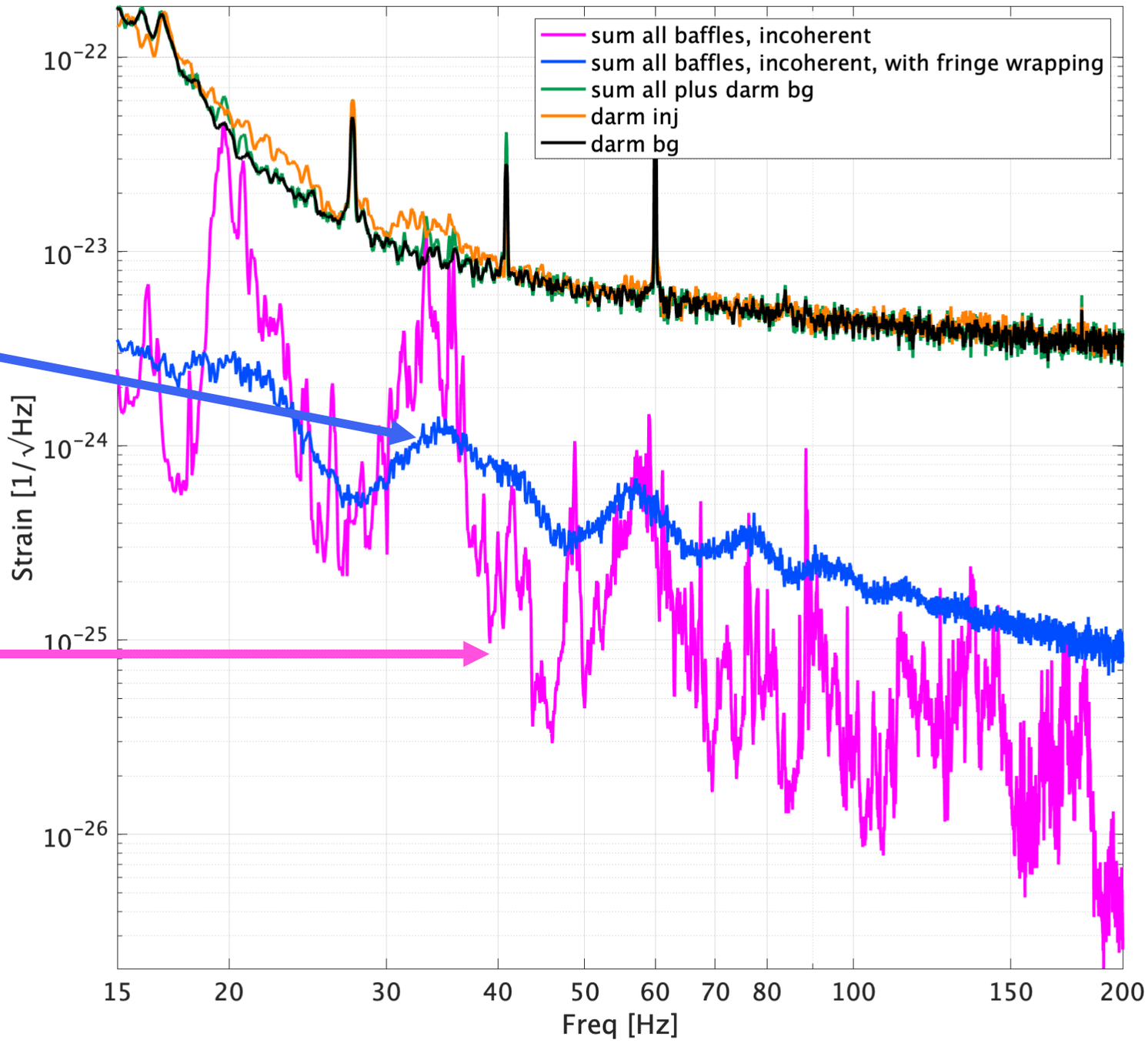

Baffle

# Model Validation

Anamaria Effler, Millie Chick

Fringe wrapping

No wrapping



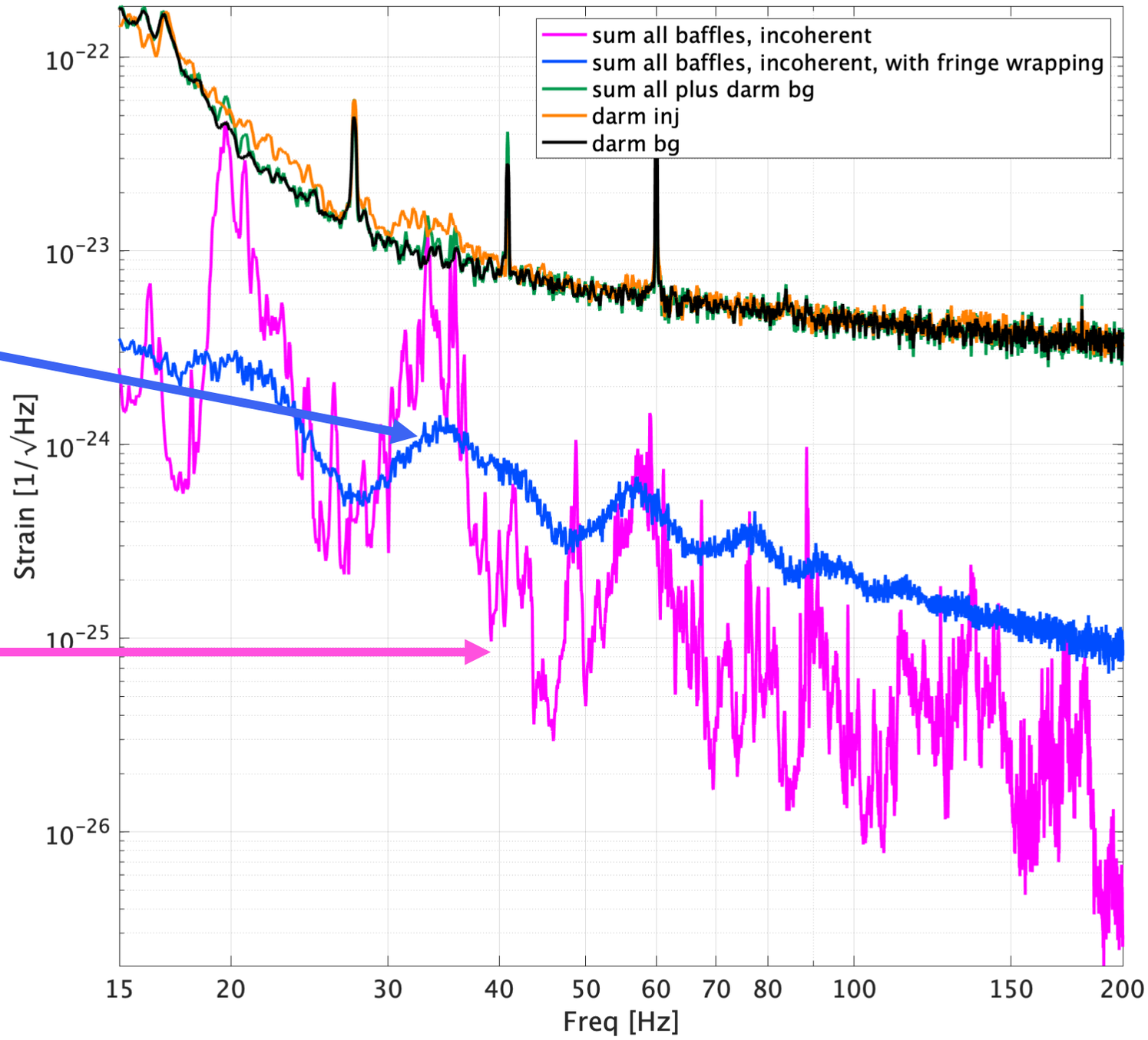
# Model Validation

Anamaria Effler, Millie Chick

**IS A FACTOR OF 10 SAFETY MARGIN ENOUGH?**

Fringe wrapping

No wrapping



# Key Takeaways

- More baffles, more diffraction noise.
- Baffle Backscatter noise doesn’t change much with config.
- Noise per baffle is “evenly” distributed across the tube.
- Beamtube scatter is a relative unknown.
- Noise estimates are generally favorable, but need to increase modeling confidence.

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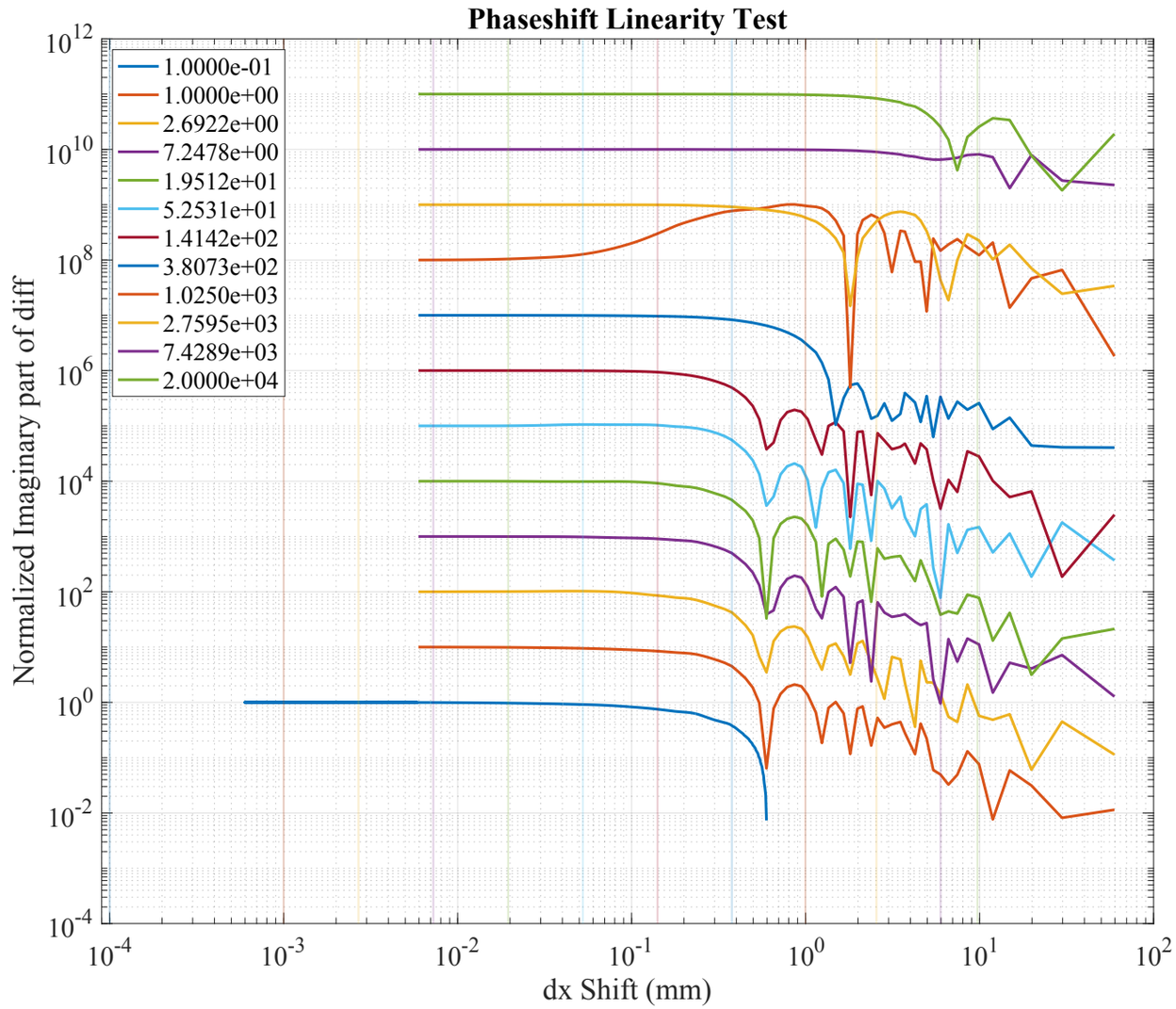
- Beamtube scatter is a relative unknown.
- Noise estimates are generally favorable, but need to increase modeling confidence.

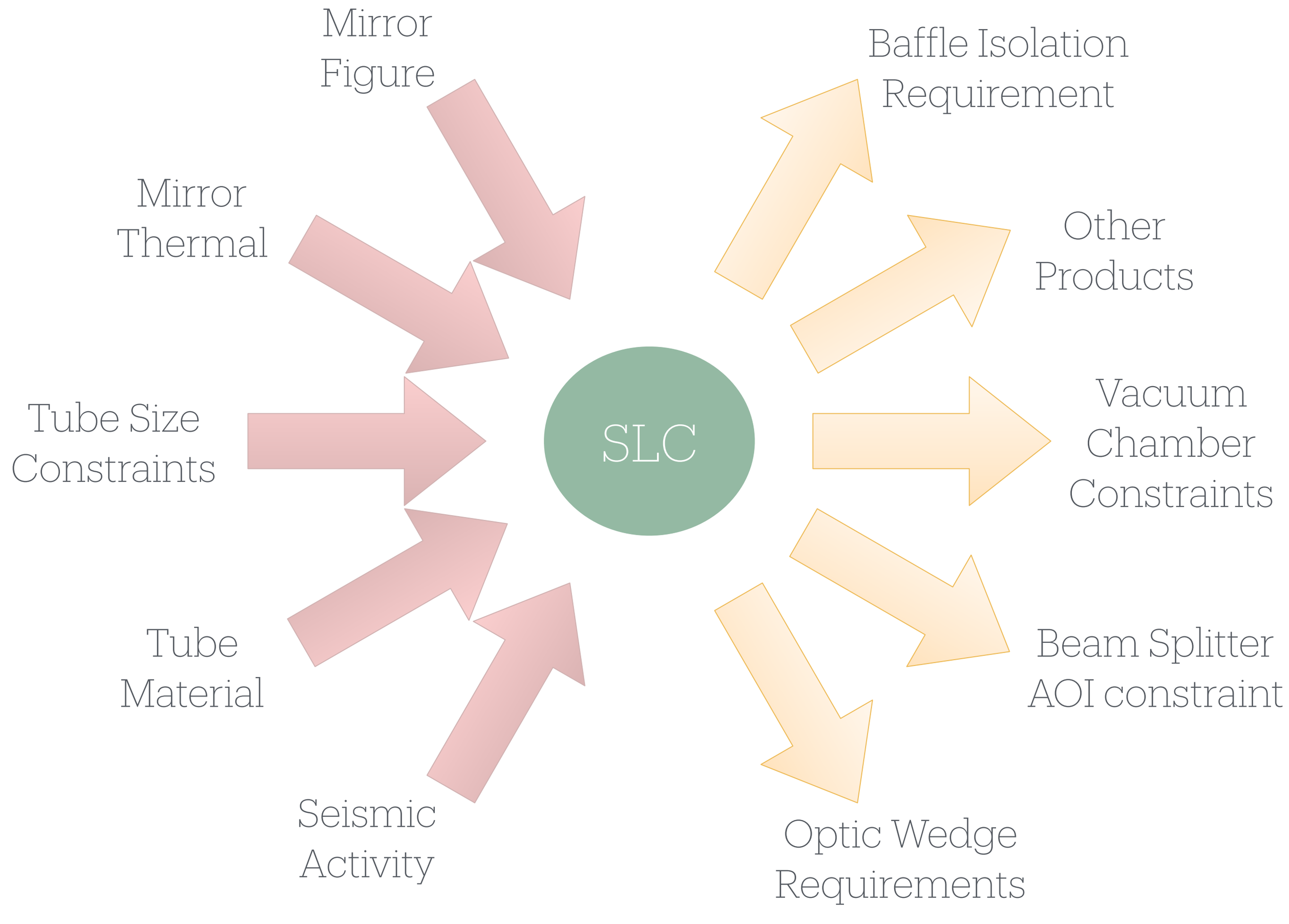
**Beamtube Diameter at ~122cm is ok from the Stray Light point of view**

# Thank you!

# Modeling Development

- Fringe wrapping is an important effect that is relatively easy to model for backscatter.
- Fringe wrapping on diffraction is less straightforward and not explored.
- Diffraction noise from low frequency beam motion.



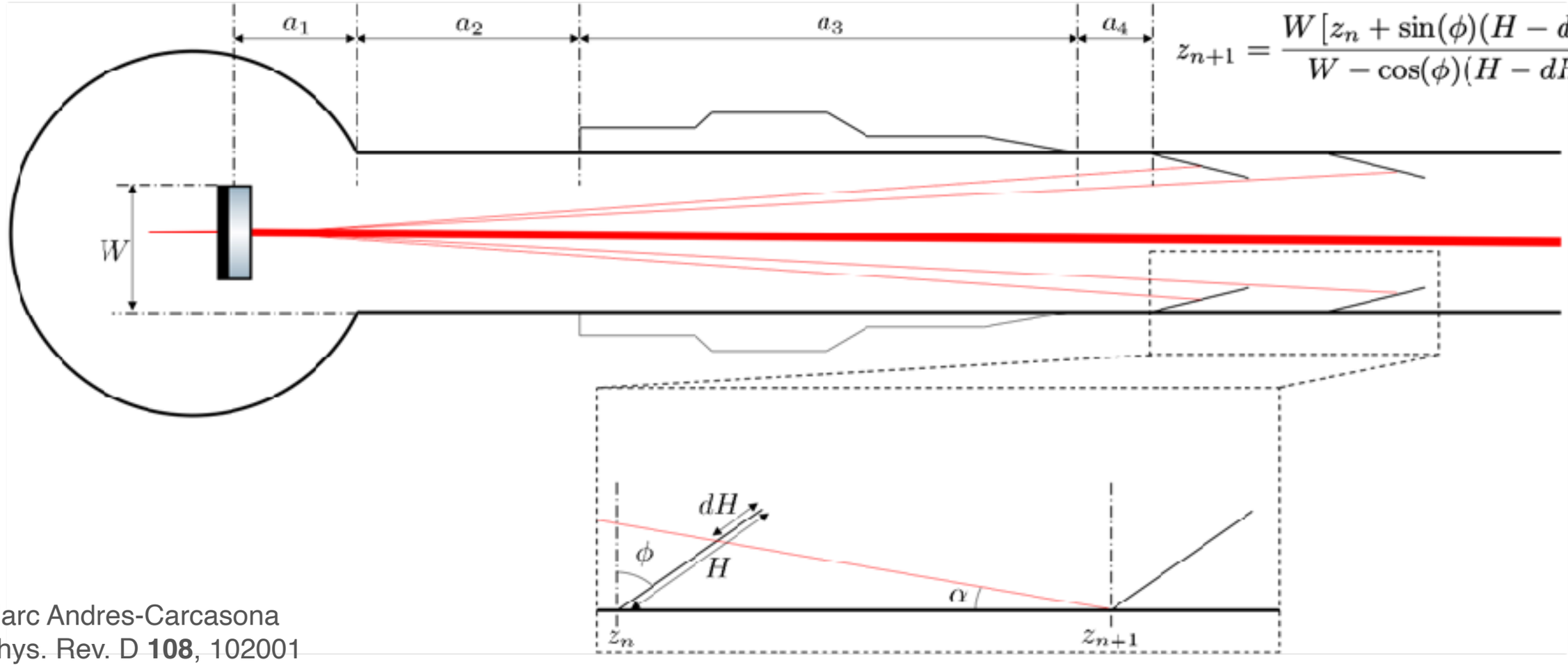

Mirror
Figure
Mirror
Thermal
Tube Size
Constraints
Tube
Material
Seismic
Activity
SLC
Baffle Isolation
Requirement
Other
Products
Vacuum
Chamber
Constraints
Beam Splitter
AOI constraint
Optic Wedge
Requirements

# Placing Beamtube Baffles

## Baffle Locations: Going beyond ray optics

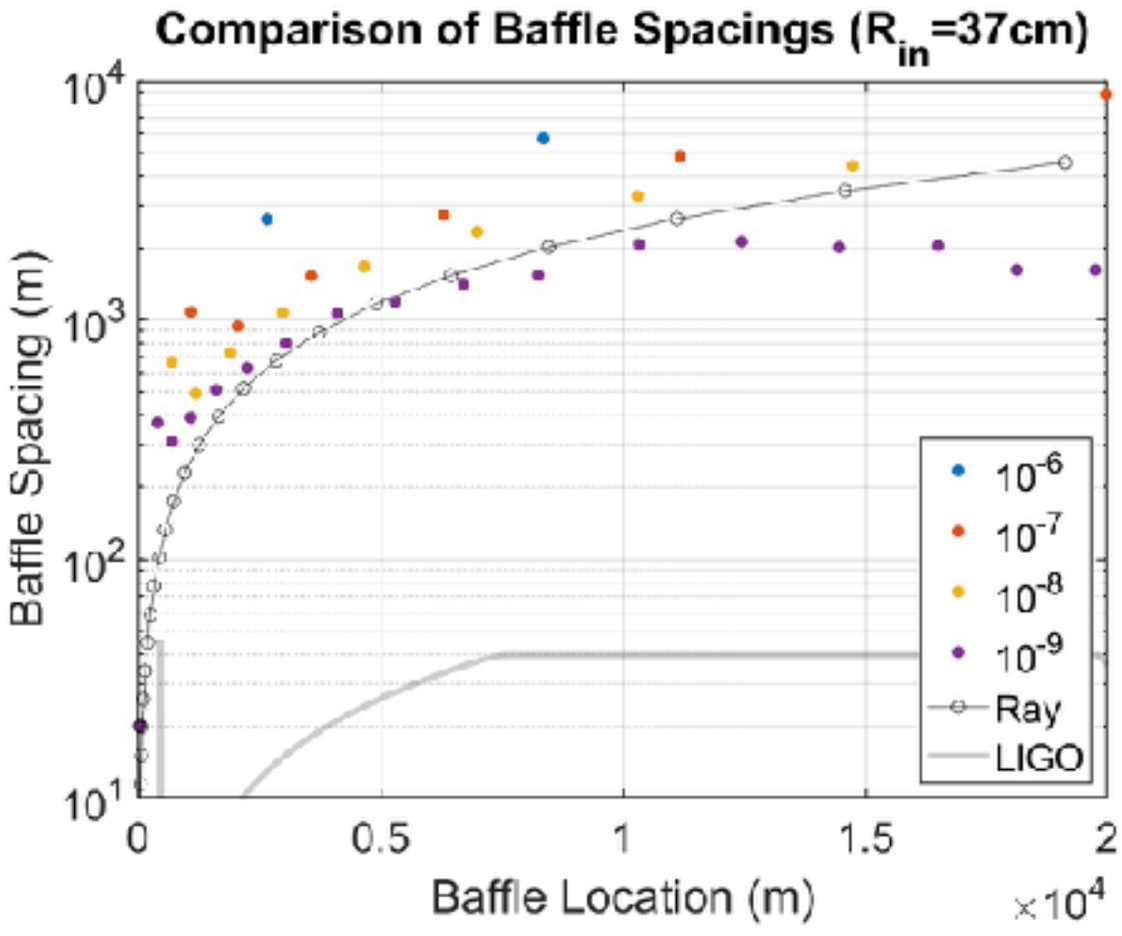
- Traditional approach to the placement of baffles is to use ray optics and try to shadow the entire beam tube.
- Another approach is to use SIS to calculate the wave propagation and calculate the power on the beam tube between baffles, and try to keep it below a given threshold

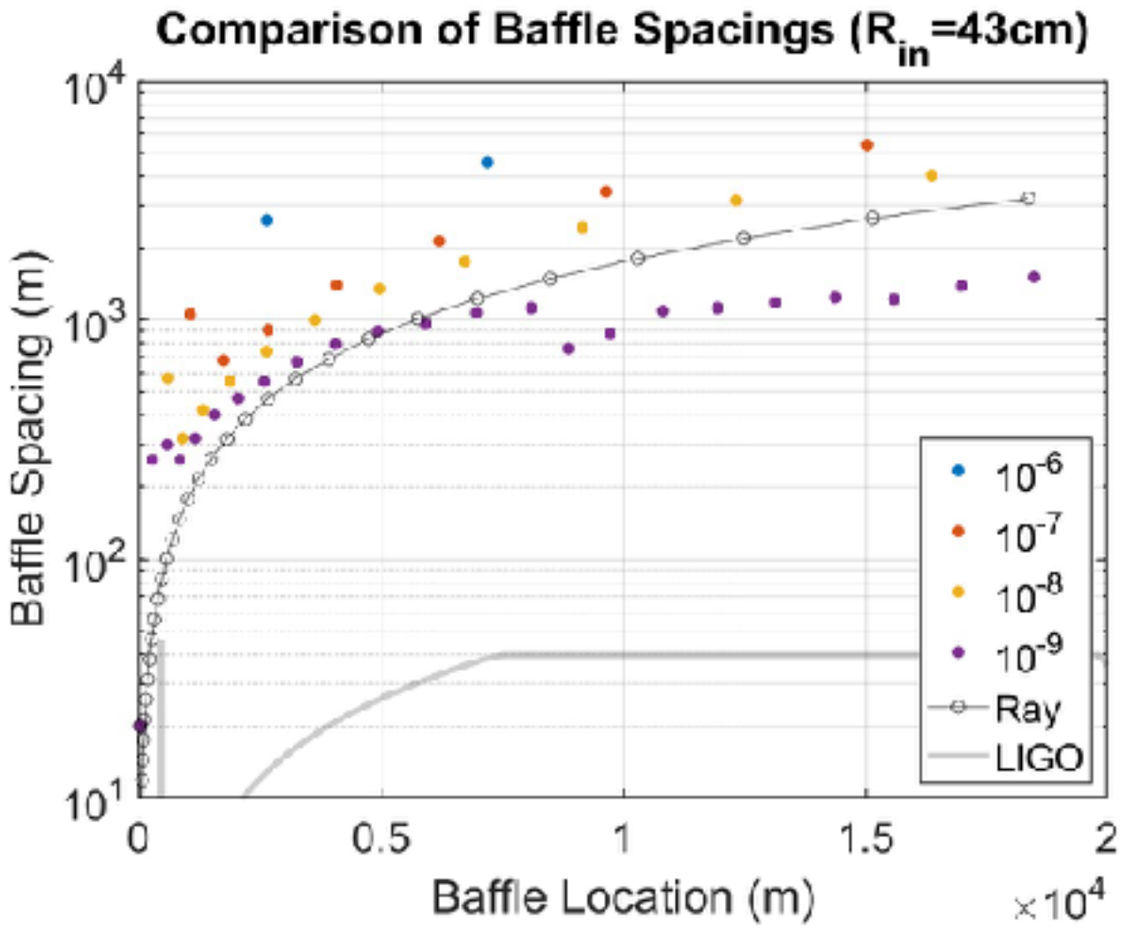
## Ray Optics

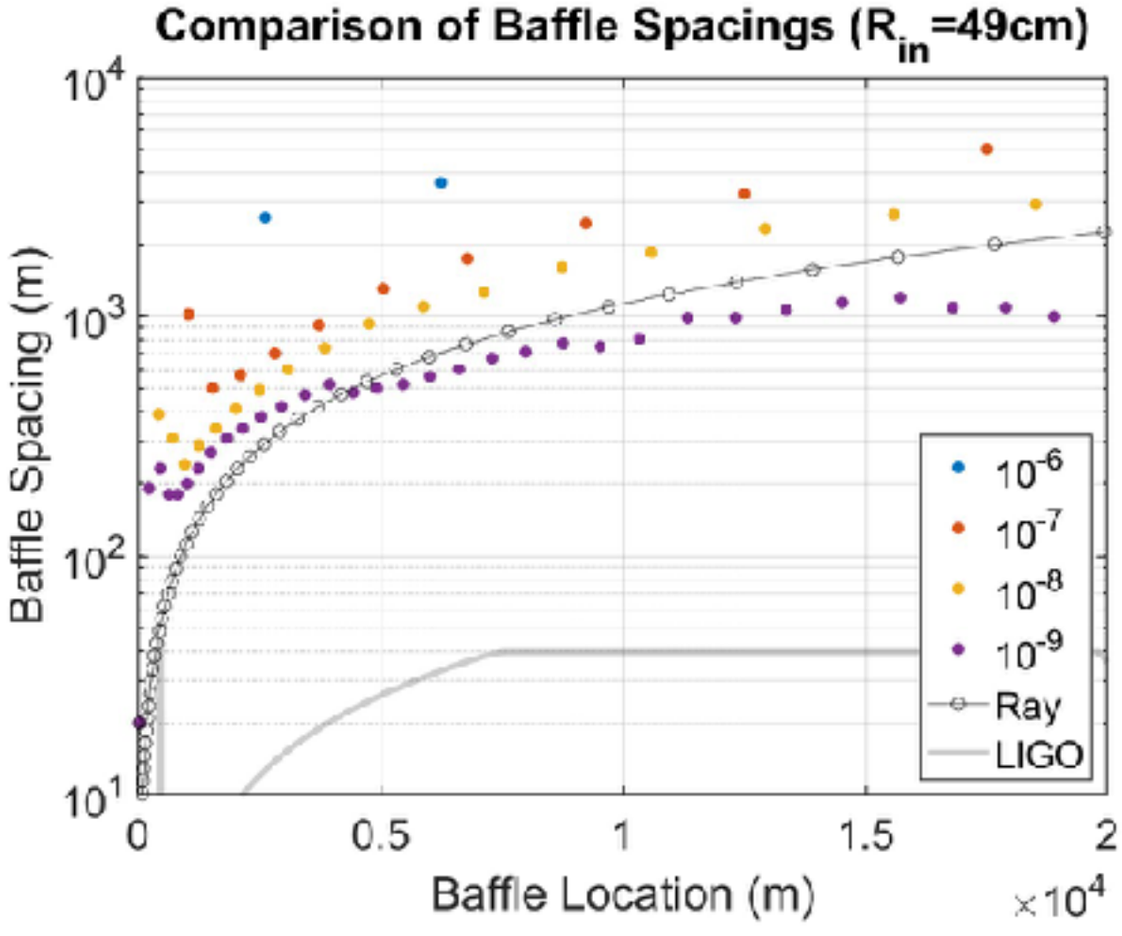


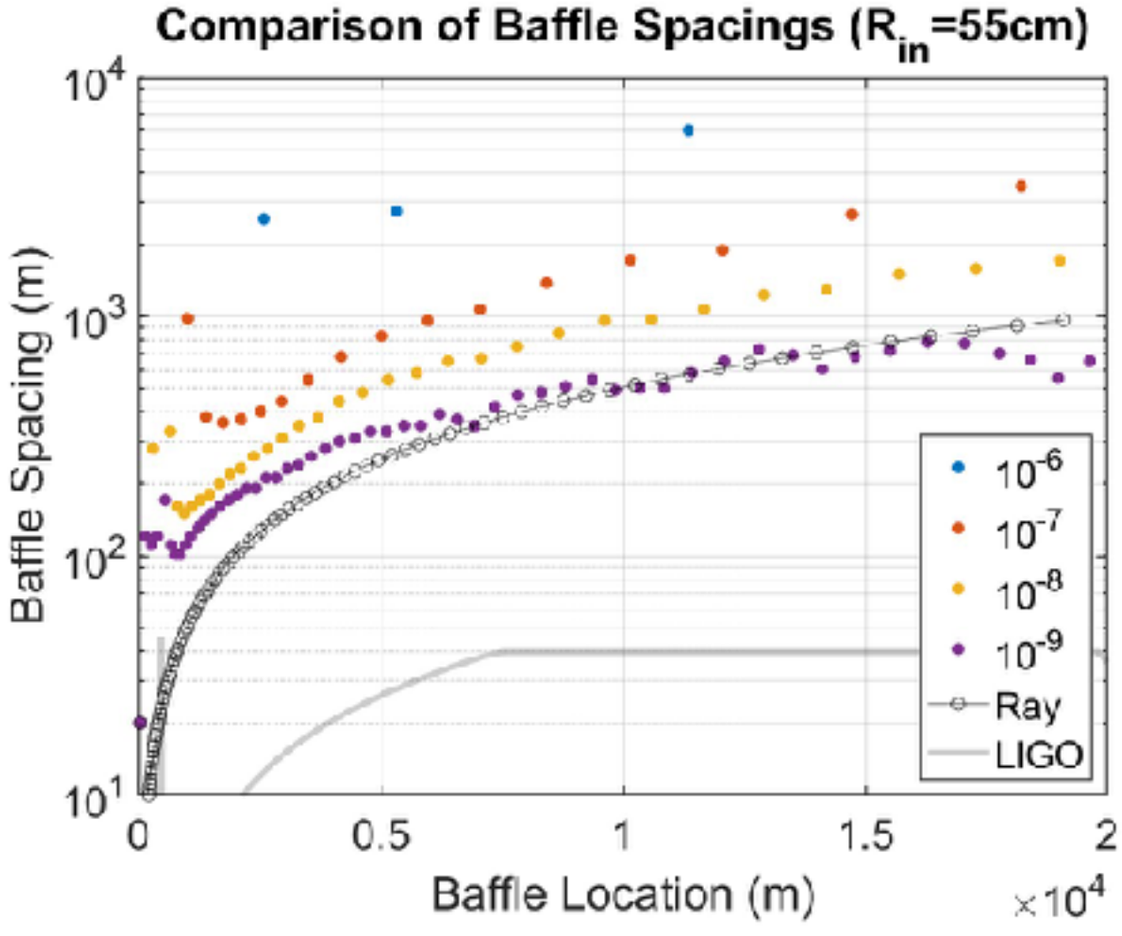

$$z_{n+1} = \frac{W\left[z_n + \sin(\phi)(H - dH)\right]}{W - \cos(\phi)(H - dH)}$$

Marc Andres-Carcasona
Phys. Rev. D **108**, 102001

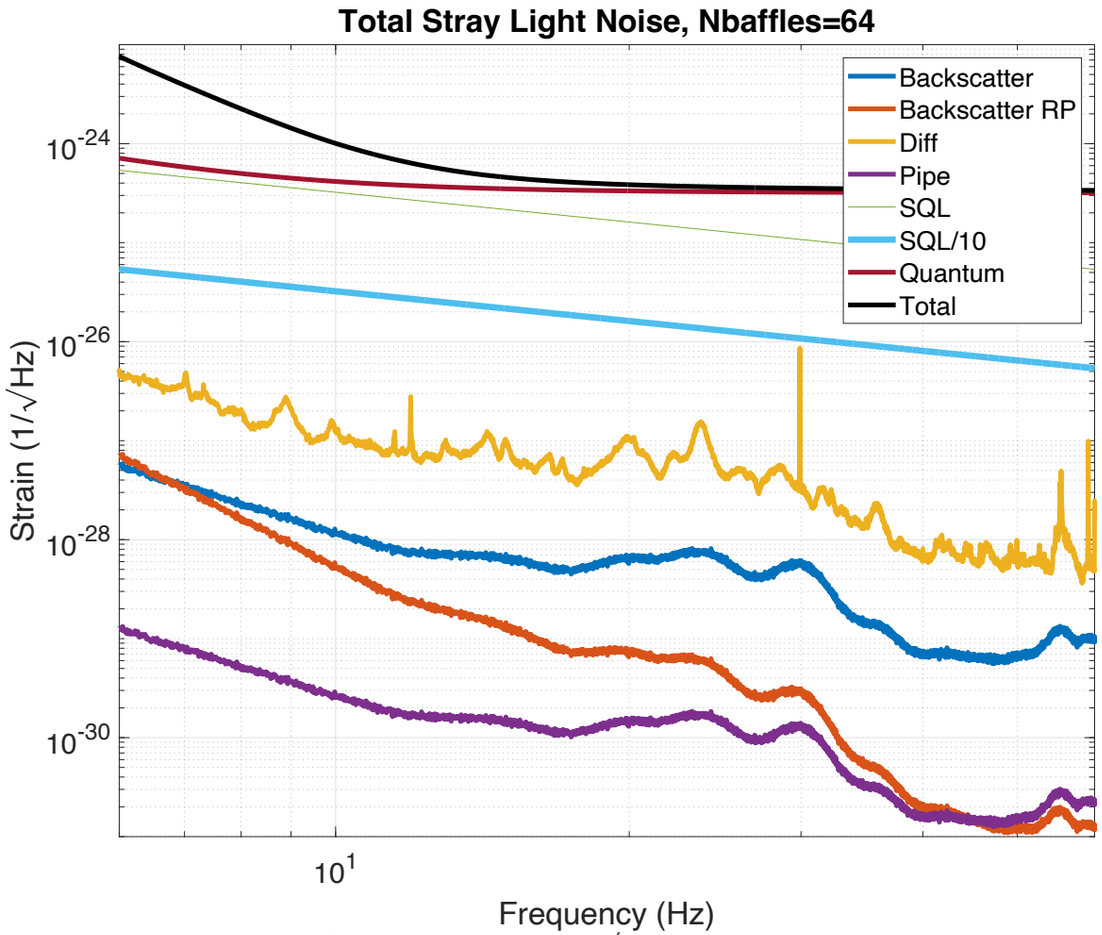

Comparison of Baffle Spacings ($R_{in}$=37cm)
Baffle Spacing (m)
Baffle Location (m)
$\times 10^4$
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
Ray
LIGO


Comparison of Baffle Spacings ($R_{in}$=43cm)
Baffle Spacing (m)
Baffle Location (m)
$\times 10^4$
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
Ray
LIGO

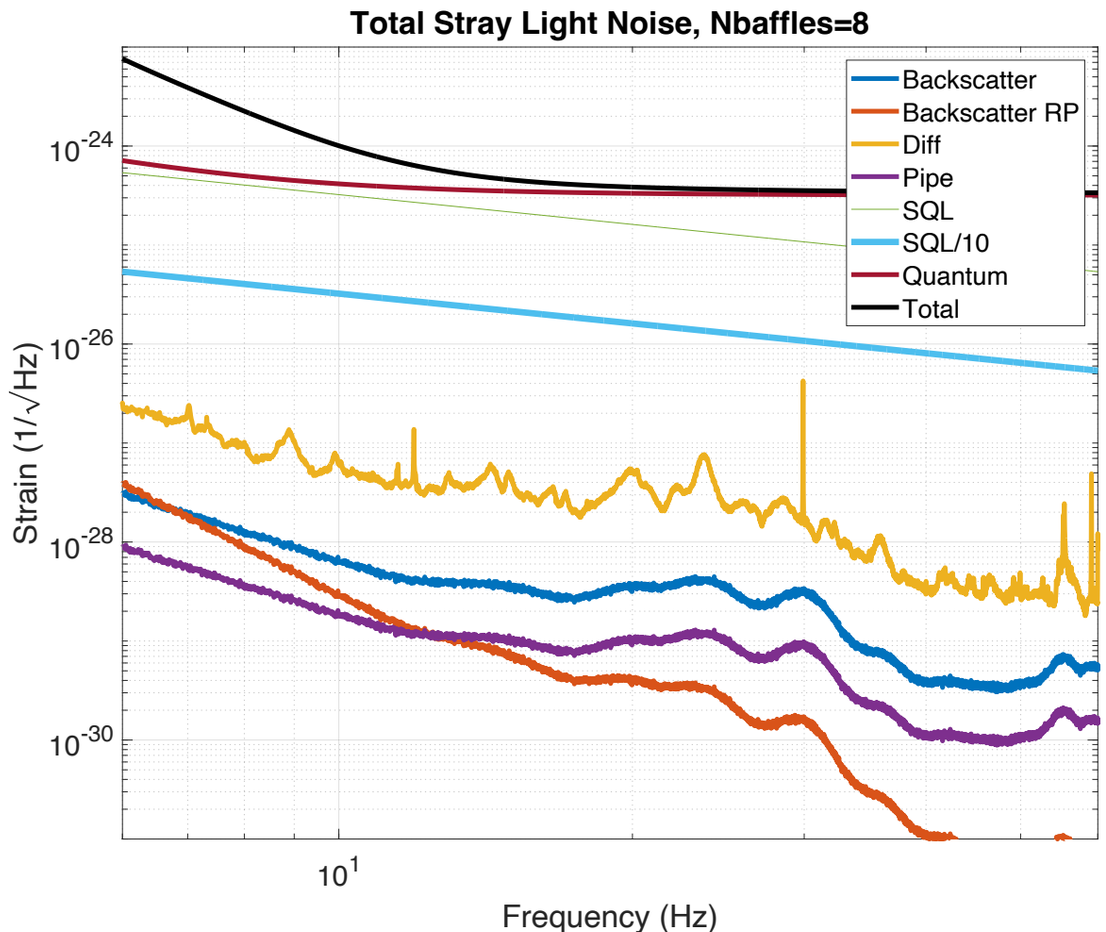

Comparison of Baffle Spacings ($R_{in}$=49cm)
Baffle Spacing (m)
Baffle Location (m)
$\times 10^4$
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
Ray
LIGO


Comparison of Baffle Spacings ($R_{in}$=55cm)
Baffle Spacing (m)
Baffle Location (m)
$\times 10^4$
$10^{-6}$
$10^{-7}$
$10^{-8}$
$10^{-9}$
Ray
LIGO

# Distributed Power Configuration

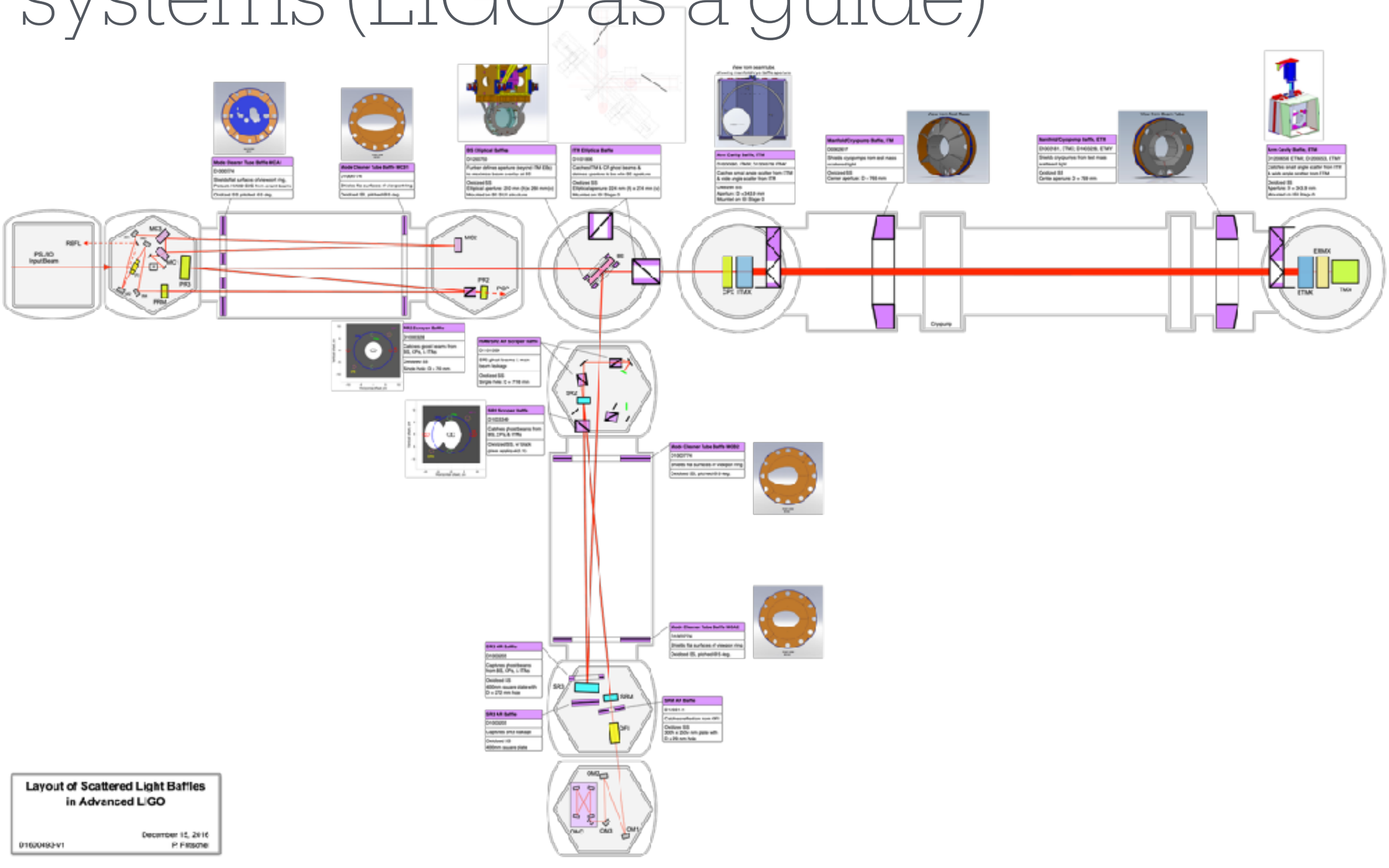



0.01ppm/section




1ppm/section

# Baffling strategy for other systems (LIGO as a guide)




Layout of Scattered Light Baffles
in Advanced LIGO

December 15, 2016

D1600493-V1

# SLC NSF Award — 3-Year Timeline

## Major Goals

- Report on Stray Light Noise Analysis for CE.
- Evaluation of Impact of Test Mass surface roughness to the overall Stray Light Noise.
- Baffles Conceptual Design for the 40 km beamtubes.
- Trade Study on Baffles Materials and Coatings with main focus on beamtube baffles.
- General requirements document - Stray Light Mitigation Strategy for core and auxiliary optics..

### Year 1

- Modeling tools development
- Modeling of beam tube stray light
- Modeling validation
- Baffle material measurements
- Ray trace modeling of other components
- Stray Light 3R doc

### Year 2

- Finalize Conceptual Design
- Exploration of non-ideal effects
- Support of other systems
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### Year 3

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- Non-beamtube related strategies
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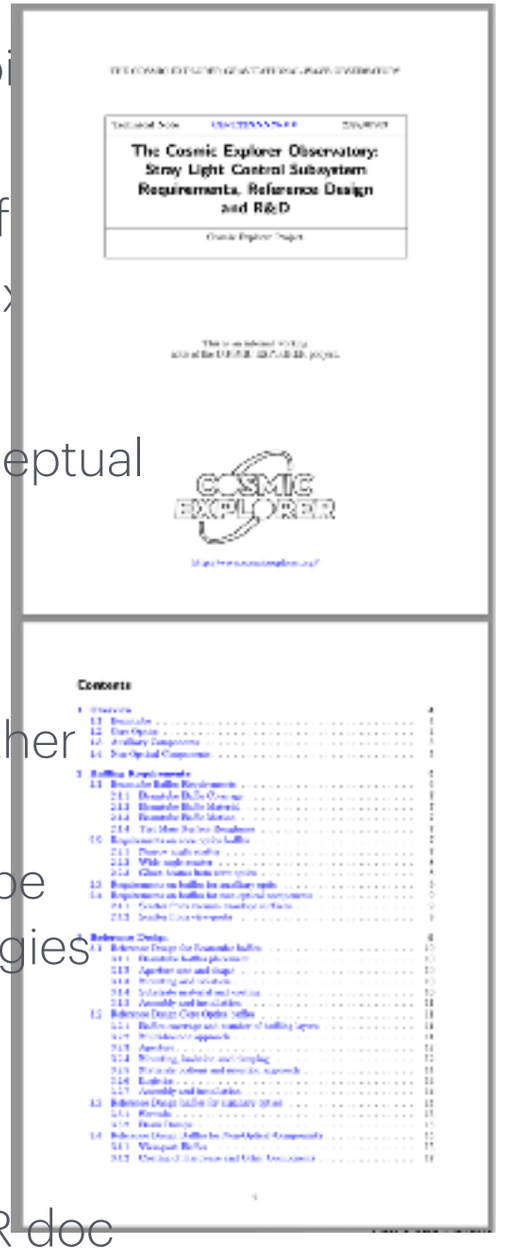
**3R DOCUMENT**

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**Year 3**

- Finalize Conceptual Design
- Support of other systems
- Non-beamtube related strategies
- 2 μm
- Stray Light 3R doc

# Forescatter from Various Materials

- Would be great if we had some low angle measurements for forward and backscatter (<1deg)

Interested in ~~these~~ values