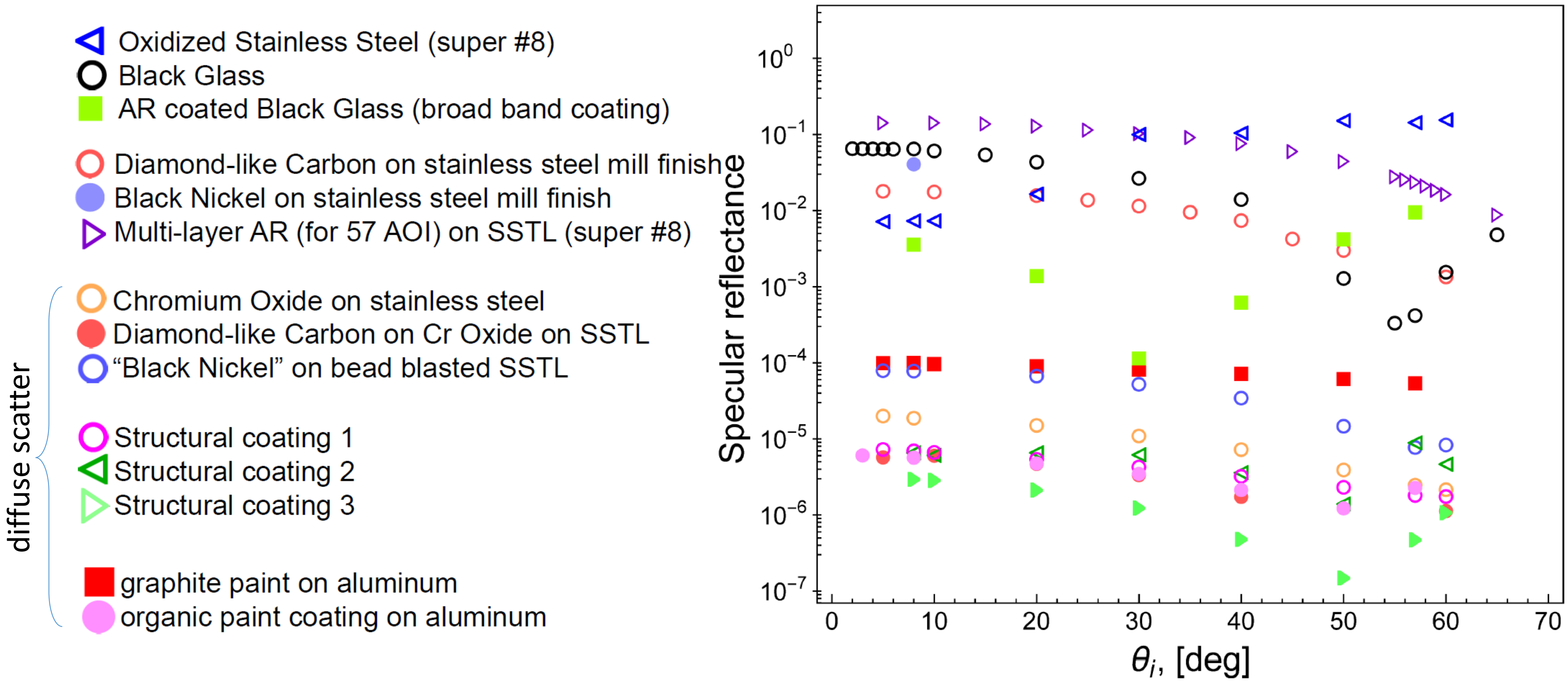
Stray light control upgrades for LIGO 4th Observation run

Alena Ananyeva on behalf of LIGO stray light team

- Baffles materials currently used at LIGO
- Overall baffles design methods we use (raytracing, CAD imaging, apertures rules, damping)
- What`s new for O4

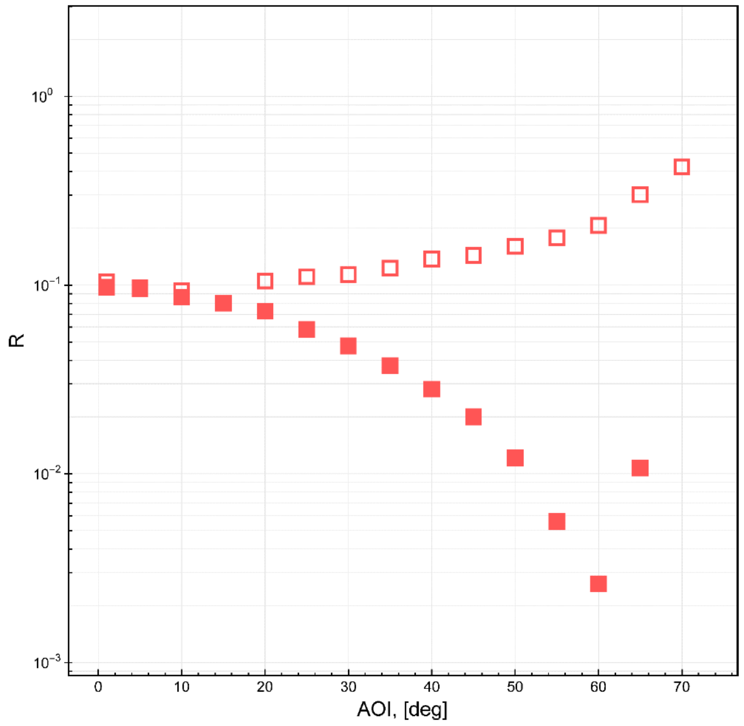
Baffle material research since 2017 (LIGO O2 and later)

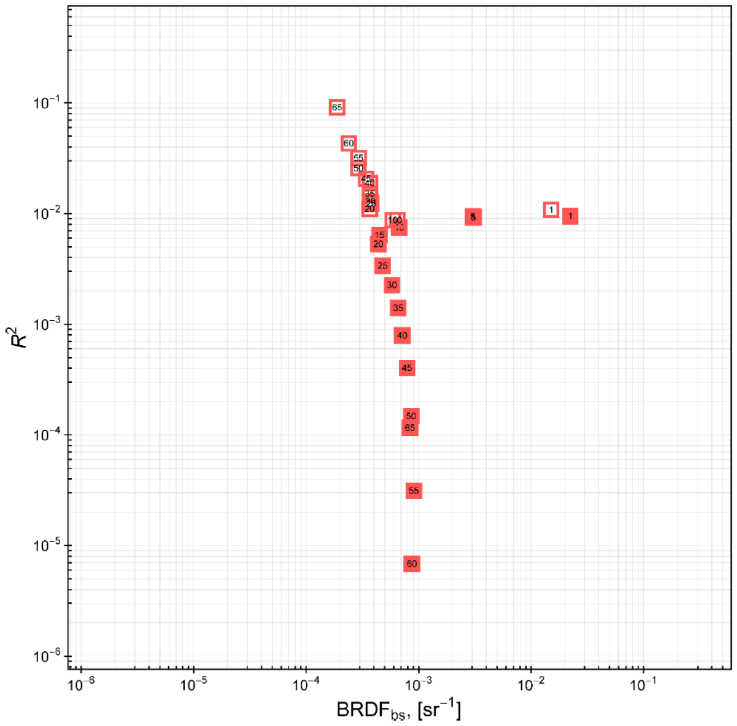


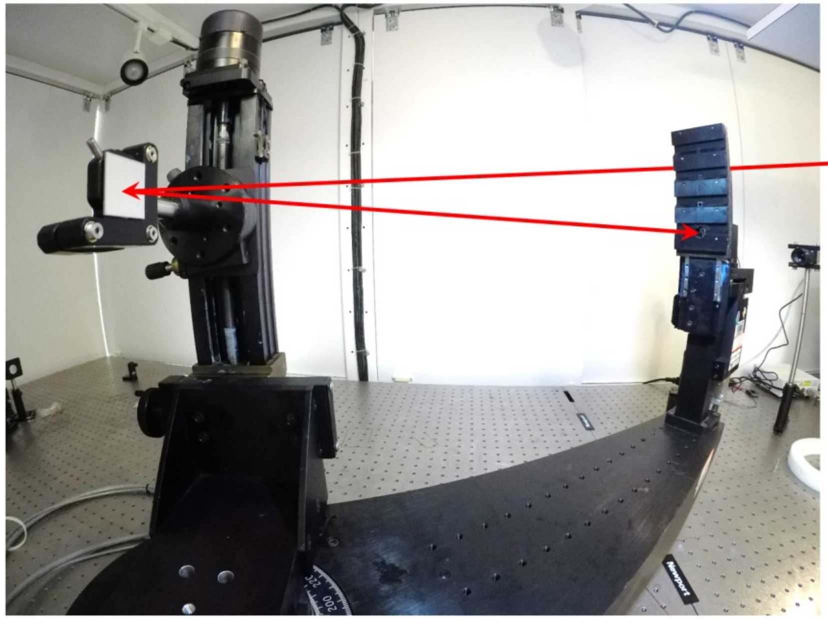
https://dcc.ligo.org/LIGO-G1700379

Diamond-like carbon on super#8 non-directional SSTL 304

P-polarization
S-polarization







1064 nm
Ø4mm
1.2 mW

Measurements were performed at Caltech using CASI scatter meter at 1064 nm

https://dcc.ligo.org/LIGO-T1700128/public

Materials comparison: robustness and availability vs performance

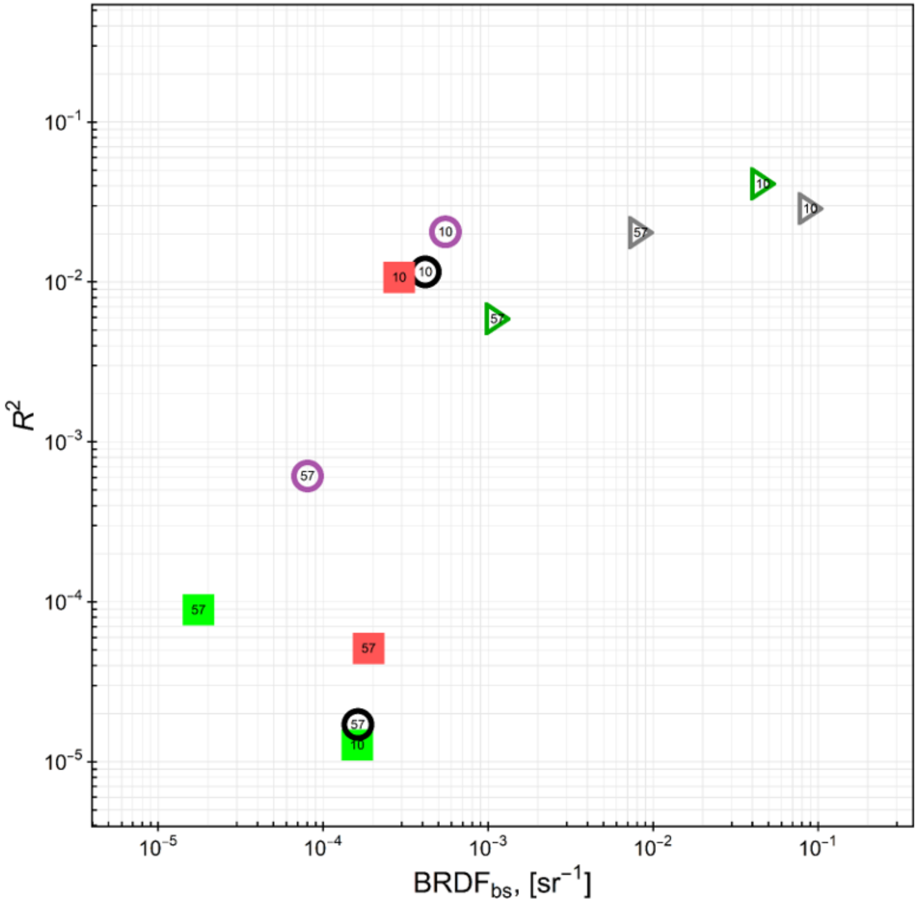
Material		Handling	Price	Lowest BRDF 8º AOI	Lowest BRDF 57 º AOI	Specular 8º AOI	Specular 57 º AOI
Oxidized Stainless Steel (super #8)		Robust	$	9×10^{-3}	9×10^{-3}	5×10^{-2}	1×10^{-1}
Black Glass		Brittle/delicate	$$	3×10^{-5}	1×10^{-5}	5×10^{-1}	2×10^{-4}
AR coated Black Glass (broad band coating)		Brittle/delicate	$$$	2×10^{-5}	1×10^{-5}	3×10^{-2}	5×10^{-3}
Diamond-like Carbon on stainless steel mill finish	✓	Robust	$	1×10^{-3}	1×10^{-3}	2×10^{-2}	1×10^{-3}
Black Nickel on stainless steel mill finish		Robust	$	2×10^{-4}		3×10^{-2}	
Multi-layer AR (for 57 AOI) on SSTL (super #8)	✓	Robust	$$	1×10^{-4}	1×10^{-5}	1×10^{-1}	1×10^{-2}
Chromium Oxide on stainless steel		Brittle/delicate	$$	2×10^{-2}	2×10^{-2}	2×10^{-5}	2×10^{-6}
Diamond-like Carbon on Cr Oxide on SSTL		Brittle/delicate	$$	6×10^{-2}	6×10^{-2}	4×10^{-6}	1×10^{-6}
“Black Nickel” on bead blasted SSTL	✓	Robust	$	7×10^{-4}	5×10^{-4}	8×10^{-5}	8×10^{-6}
Structural coating 1	✗	Handling only with special tooling	$$$$	1×10^{-2}	1×10^{-2}	5×10^{-6}	2×10^{-6}
Structural coating 2	✗	Handling only with special tooling	$$$$$	1×10^{-3}	1×10^{-3}	5×10^{-6}	2×10^{-6}
Structural coating 3	✗	Handling only with special tooling	$$$$$	9×10^{-4}		2×10^{-6}	2×10^{-7}
graphite paint on aluminum	✗		$	1×10^{-2}	1×10^{-2}	2×10^{-4}	5×10^{-5}
organic paint coating on aluminum	?	Robust	$	5×10^{-3}	5×10^{-3}	5×10^{-6}	2×10^{-6}

Robust | Brittle/delicate | Handling only with special tooling

IR absorbing low scatter coatings choses vs oxidized SSTL

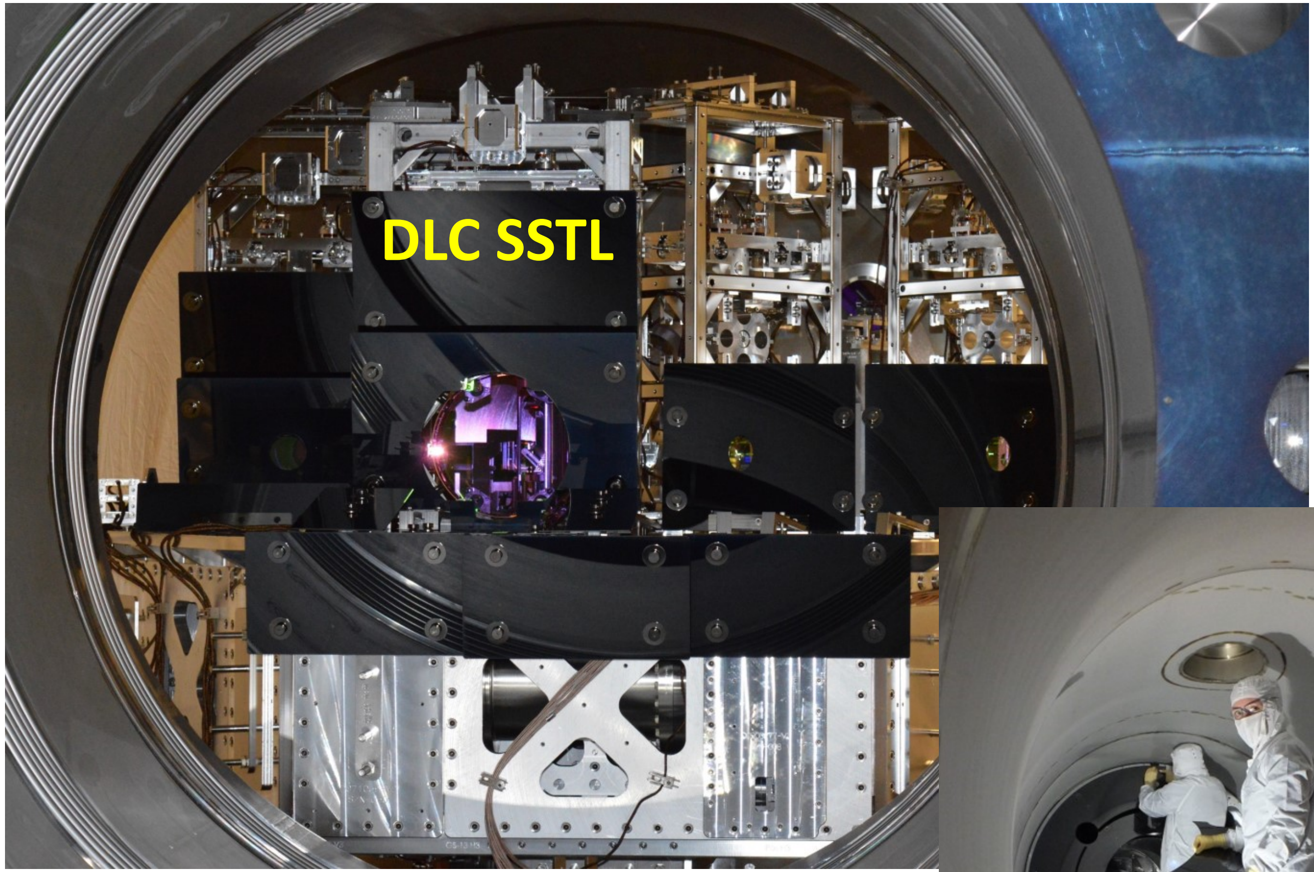
- Oxidized Stainless Steel (super #8)
- Black Glass
- AR coated Black Glass (low AOI coating)
- DLC on Super#8 large parts (like p-cal baffles)
- DLC on Super#8 medium size parts (SUS baffles)
- Black Nickel on Super#8

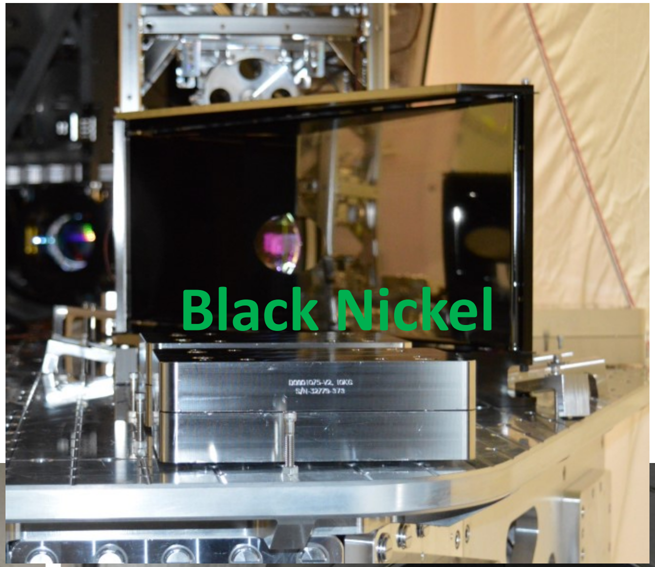
P.S. All of the new coatings are much more uniform compared to oxidized SSTL



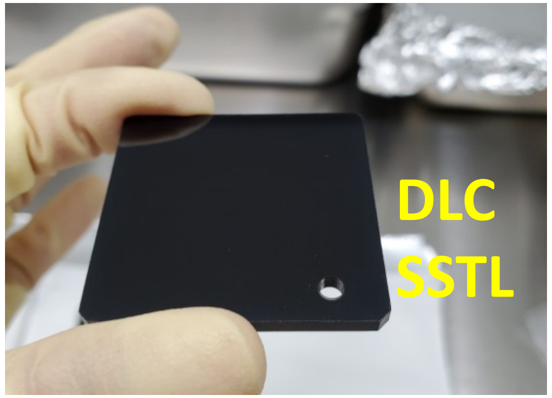
Multi bounce approach is an option instead of AR coating!

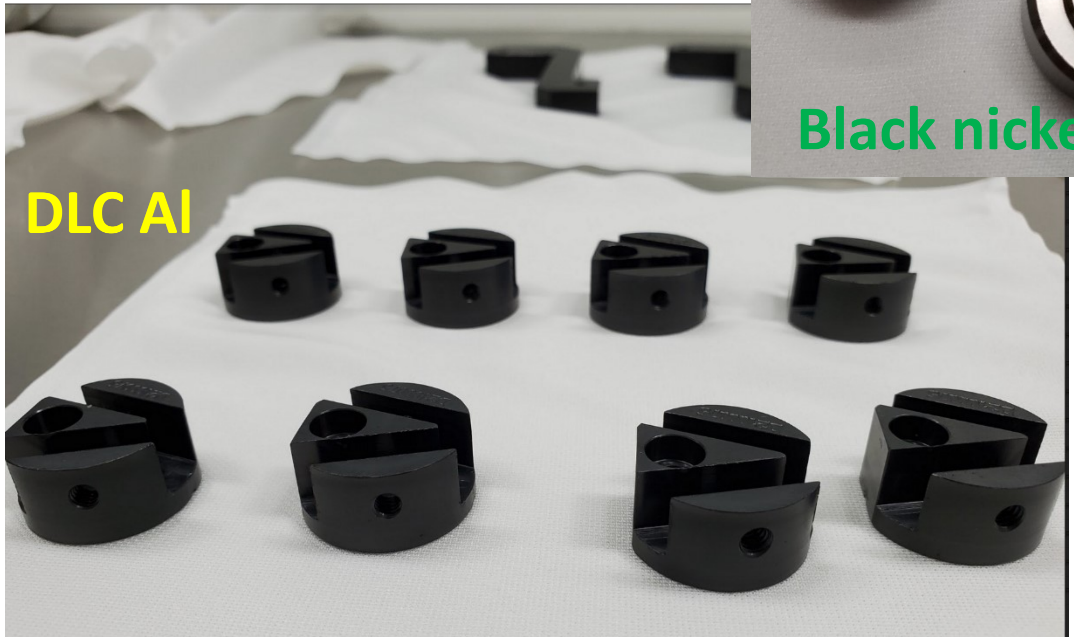
O2&O3 baffles made with new coatings!





Mounts and hardware are successfully coated with DLC and black nickel!



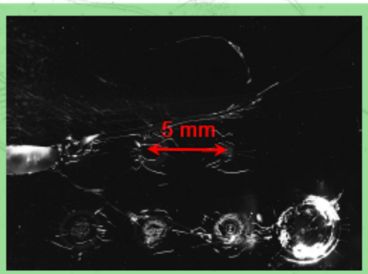


Pliable 1145-0 Al coil (thick foil 0.003”) is considered for wrapping objects in-situ
LIGO-T2000608

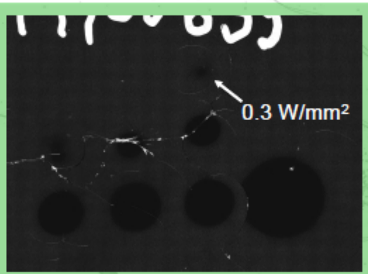
Laser Damage investigations of 1064 nm absorbing materials in vacuum

A. Ananyeva, D. Coyne, C. Torrie, E. Sanchez

G1800420



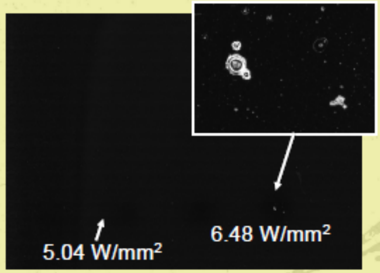
AR coated blk glass sample S1700635



Uncoated black glass sample S1700633

At around 0.3 W/mm² uncoated and coated black glass started to melt and to break. Cracks occurred in a similar patter which was presumably defined by the method the sample was mounted on the holder`s plate.

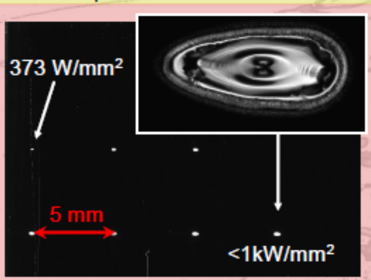
<1.5 W/mm²



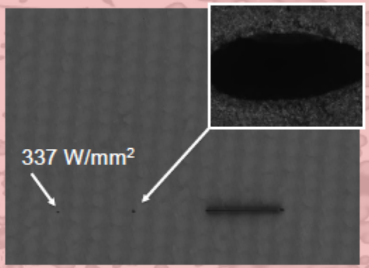
DLC sample S1800001

The DLC sample has been irradiated using the same pattern as black glass at first which did not result in any damage. Then the power range was increased. The picture on the left shows the sample surface after irradiation. Ten points have been irradiated with power density of 0.30, 0.63, 1.46, 2.18, 2.9, 3.61, 4.33, 5.04, 5.76, 6.48 W/mm², 5 min per point. At around 5.04 W/mm² (31.8 W total power) darkening of the coating was observed. Discoloration of the coating started to occur at 6.48 W/mm². No coating cracking or pilling off could be observed.

<6.5 W/mm²



Silicon sample S1800012



Sintered silicon carbide S1700637

Silicon and silicon carbide samples were first irradiated with low power levels equivalent to those used on the previous black glass and DLC samples. None of the two runs resulted in damage. The figures on the left show surfaces of the samples after irradiation at ten points at incremental power densities up to 1102.80 W/mm². Silicon started to damage at 371.13 (16 W total power) and silicon carbide at 736.97 W/mm² (37.05 W total power). The samples did not crack or break.

<1.1 kW/mm²

Poster LVC 2018

LIGO-G1800420

Laser damage threshold of the five materials was evaluated against their optical properties at 1064 nm. Sintered silicon carbide has the highest laser damage threshold but also very high scatter due to high porosity of the surface. It is recommended to be used only at the areas with power densities higher than 100 W/mm² and only for "V"-type of beam dumps. Silicon is recommended to be used instead in high power areas. For dumping beams with up to 1 W/mm² DLC coated polished SSTL is more preferable due to lower reflectivity and lower cost. DLC coating is also very durable and easy to handle. Black glass is recommended to be used only for close to normal incidence situations when reflectivity is important and only below 0.1 W/mm² power density. In this case an AR coating is required.

Material	Cost	Lead time for 20 beam dumps	Reflectivity at 57° deg AOI	BRDFbs	Laser Damage Threshold W/mm²
Black glass uncoated	$$	< 2 weeks	~ 4%	~ 2×10^{-4}	0.24 - 0.30
DLC coated SSTL	$$	2-3 weeks	~ 6%	~ 2×10^{-4}	4.33 - 5.04
Silicon	$$$$	3-4 weeks	~ 10%	~ 8×10^{-5}	249.20 to 371.13
Sintered SiC	$$$	4-5 weeks	Diffuse	High	615.02 to 736.97

General Requirements Document - Stray Light Improved Control (SLiC) LIGO-E1600332

LIGO	LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY	E1600332 Document No	-v4 Rev
	REQUIREMENTS DOCUMENT	Sheet 4	
General Requirements Document - Stray Light improved Control (SLiC)			

Aperture Size

For all baffles with an aperture the base-line requirement is as follows: -

The beam size ω (aka w) values quoted in D0902828-v5 are the 1/e^2 radii (see section 1.2 of T1000581-v1 and Table 2 of T0900043-v11). Peter suggested/requested a 10x factor on the size of the baffle apertures. Consequently:

D_b = Min{ D_o, 20 * w}
D_b = Baffle Aperture Diameter
D_o = Optic Diameter
w = 1/e^2 beam size (radius)

^Note if e.g. EQ stops are in the 20w path then consideration will need to be given to adjust this requirement. Refer to image in appendix 1 below. Any other objects in front or behind a baffle especially those which are within the laser path and within the baffle diameter are required to be moved away or replaced with a coated version or require its own baffle (example: LIGO-D1700261 aLIGO, SLiC, BALLAST MASS BAFFLE)

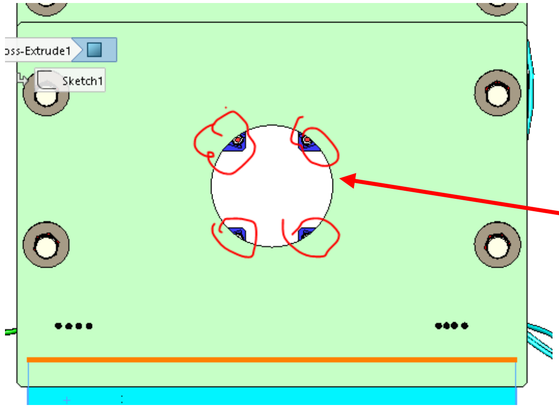
Size (Global)

HAM ISI "baffles" should extend across all of the cages from the HAM ISI table (including the suspension spacer) up to (and including) coverage of the suspended intermediate mass. Consideration up to 20w should be investigated for areas with large beams e.g. PR3 and SR3. (*All with unique spacers (in height) that are LLO and LHO specific.)

Size (Local)

The following detail assumes the SLiC baffles will be made from a couple of sections per suspension "cage" structure or per assembly. The size all comes down to the limitation of the coating chamber, depending on the coating technique used:

1. **DLC coating:** the substrate can be a big as ⌀35"(diameter) - LIGO-C1700089-v2;
2. **Black Ni coating:** the substrate can be a big as 48" x 30" - LIGO-C1700090-v3;
3. **AR coated Black Glass:** segments no bigger than 9" x 24" - LIGO-L1500091;
4. **Uncoated black glass** comes in sheets 4' x 4' and the baffle size is limited by practicality



The aperture is usually defined as 20w of the beam or as large as the optic (for large beams). Hardware within the aperture needs to be covered or coated

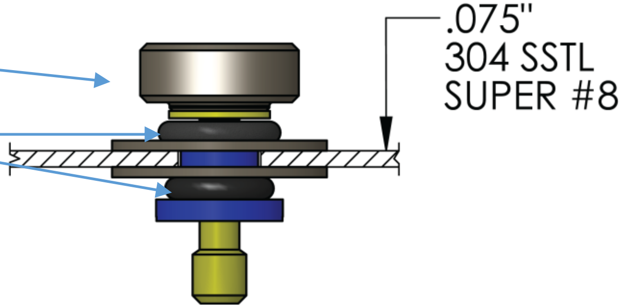
Apertures / Holes

Consideration needs to be given to the finish of the apertures / holes for the laser beam. Refer to OMC black glass shroud components LIGO-E1500047 for glass baffles. SSTL baffles are recommended to have a machined bevel on the back side (assuming the laser enters from the from side). Example for SSTL baffle with a beveled aperture LIGO-D1700296. Mounting holes can be water jet (for glass only) ot laser cut (for SSTL)

Damping

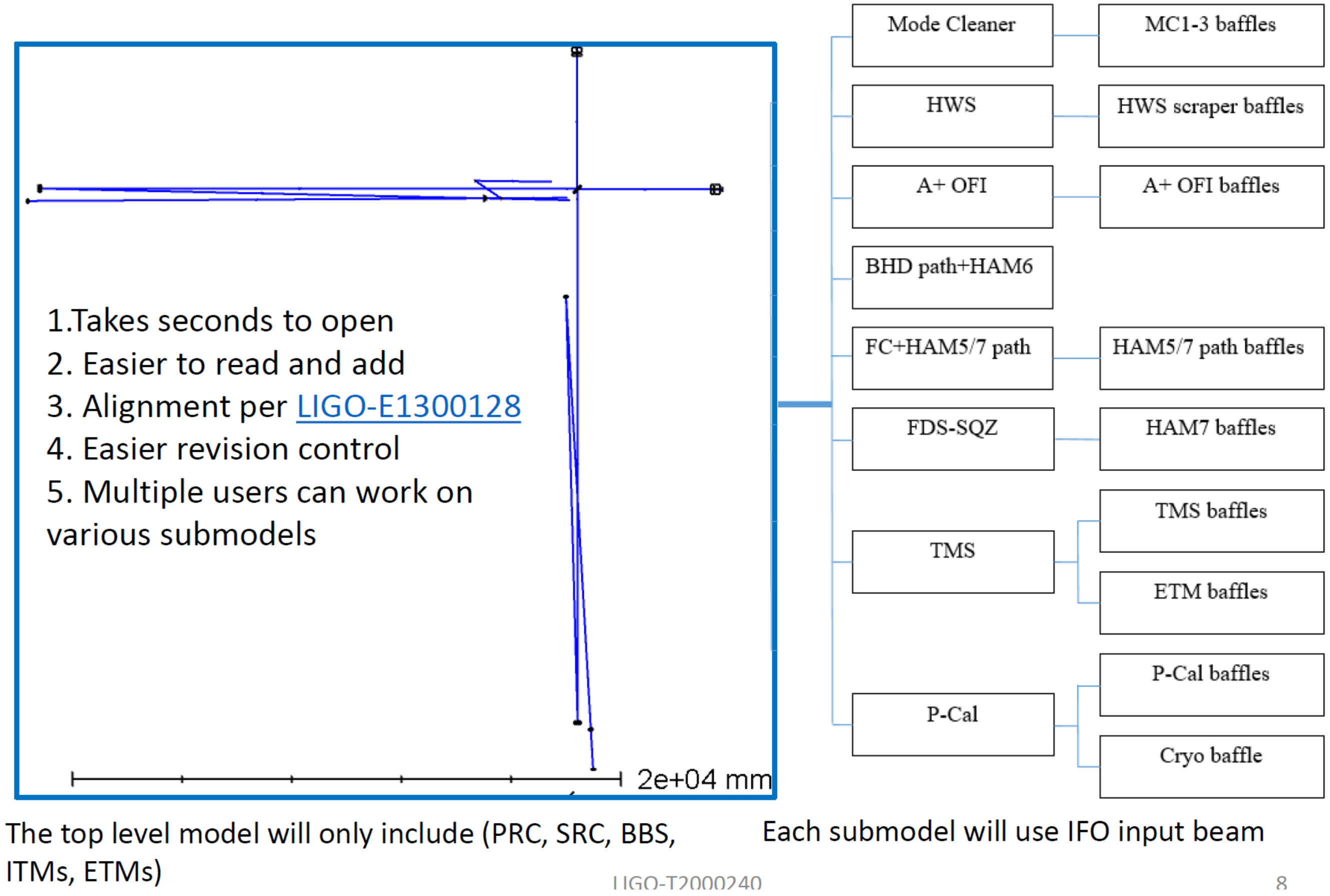
Local damping of individual segments of the baffle should be provided via o-rings at the mounting locations. Refer to LIGO-T1700511 *Assembly and Damping Guidelines for SLiC Baffles* [It should also be noted that global damping, in the form of 2x SUS cube dampers is also present on each HAM SUS "cage" structure.]

Coated crew cap
Viton o-ring
LIGO-D1700232



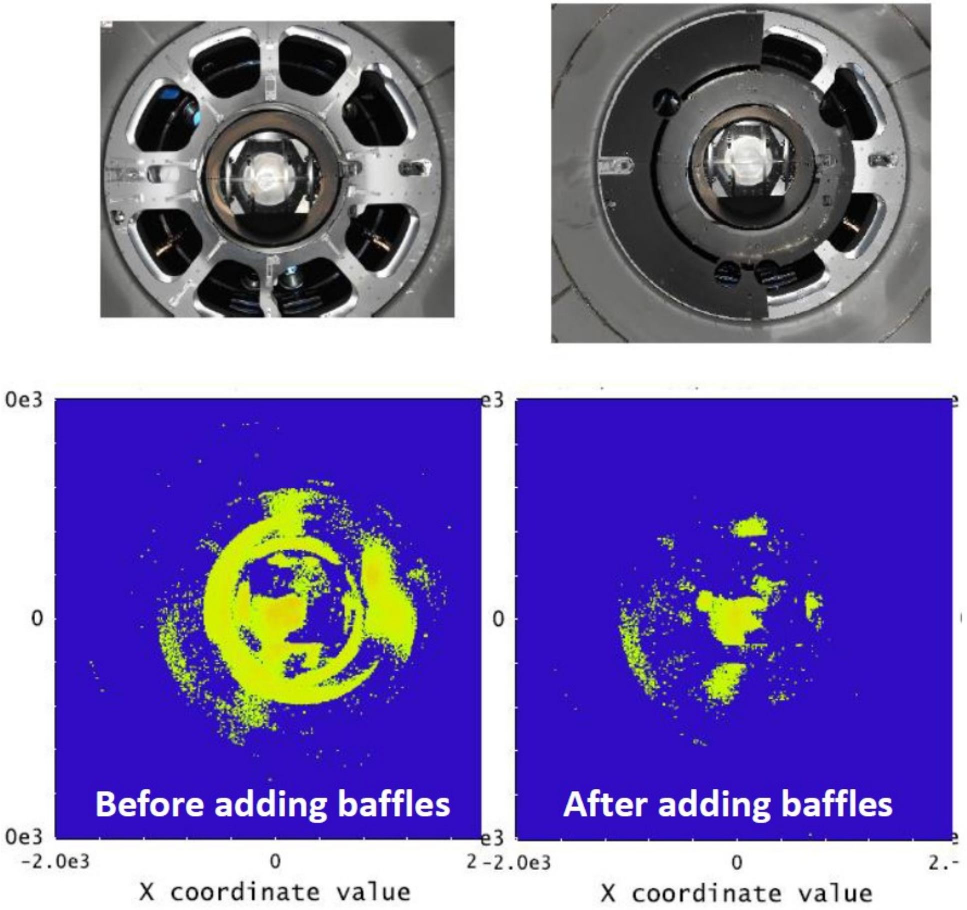
Zemax model of A+ configuration of LIGO

The model is used for beam preparation, ghost beams hunting and other stray light analysis. The beams can be exported as a step file and added to the solid works model which helps to position baffles apertures, check for beam clippings and etc



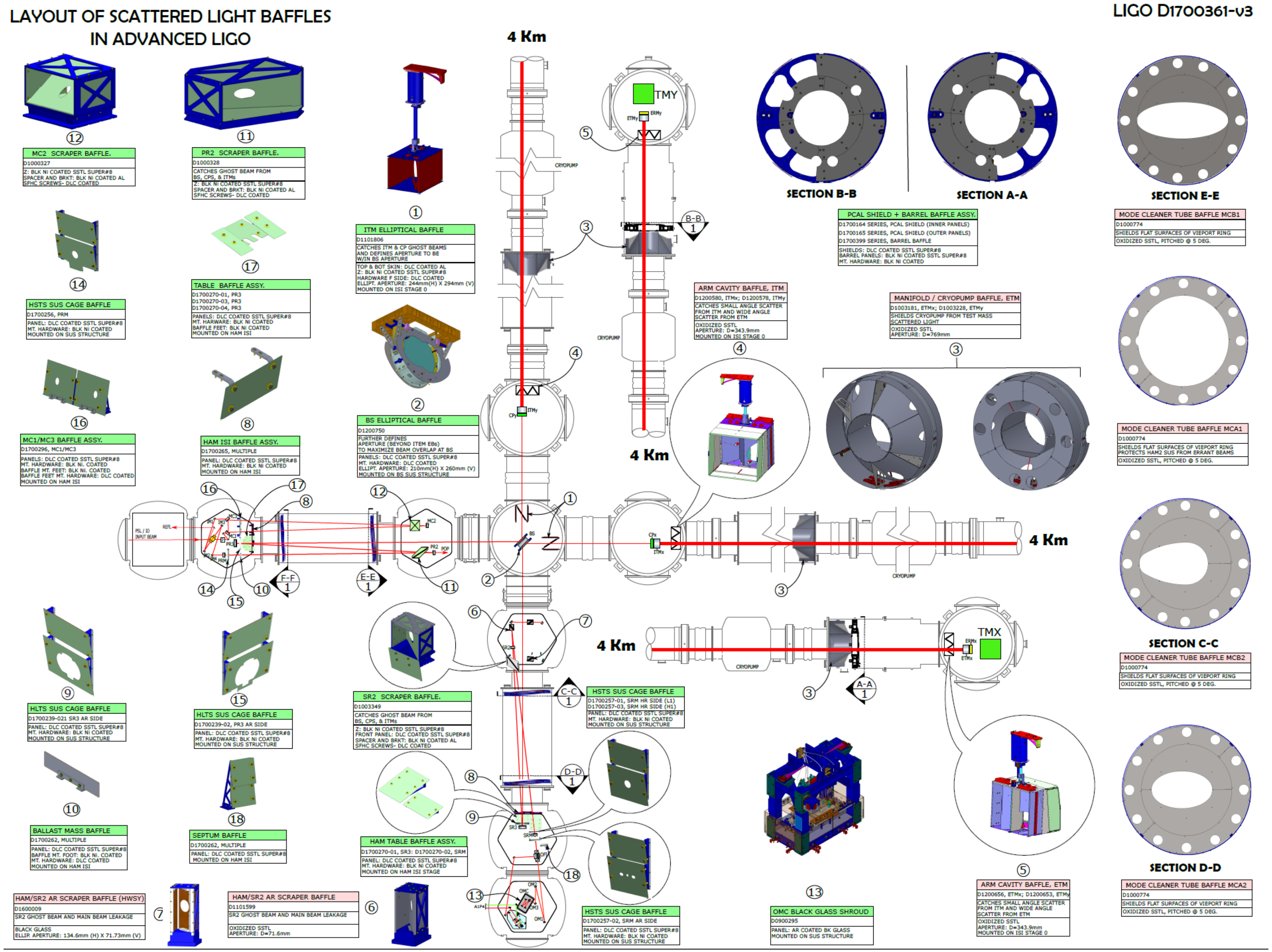
Tree structure Zemax model of the interferometer: (slide ref LIGO-T2000240). How to use the model LIGO-E2000223.

Zemax stray light analysis example:



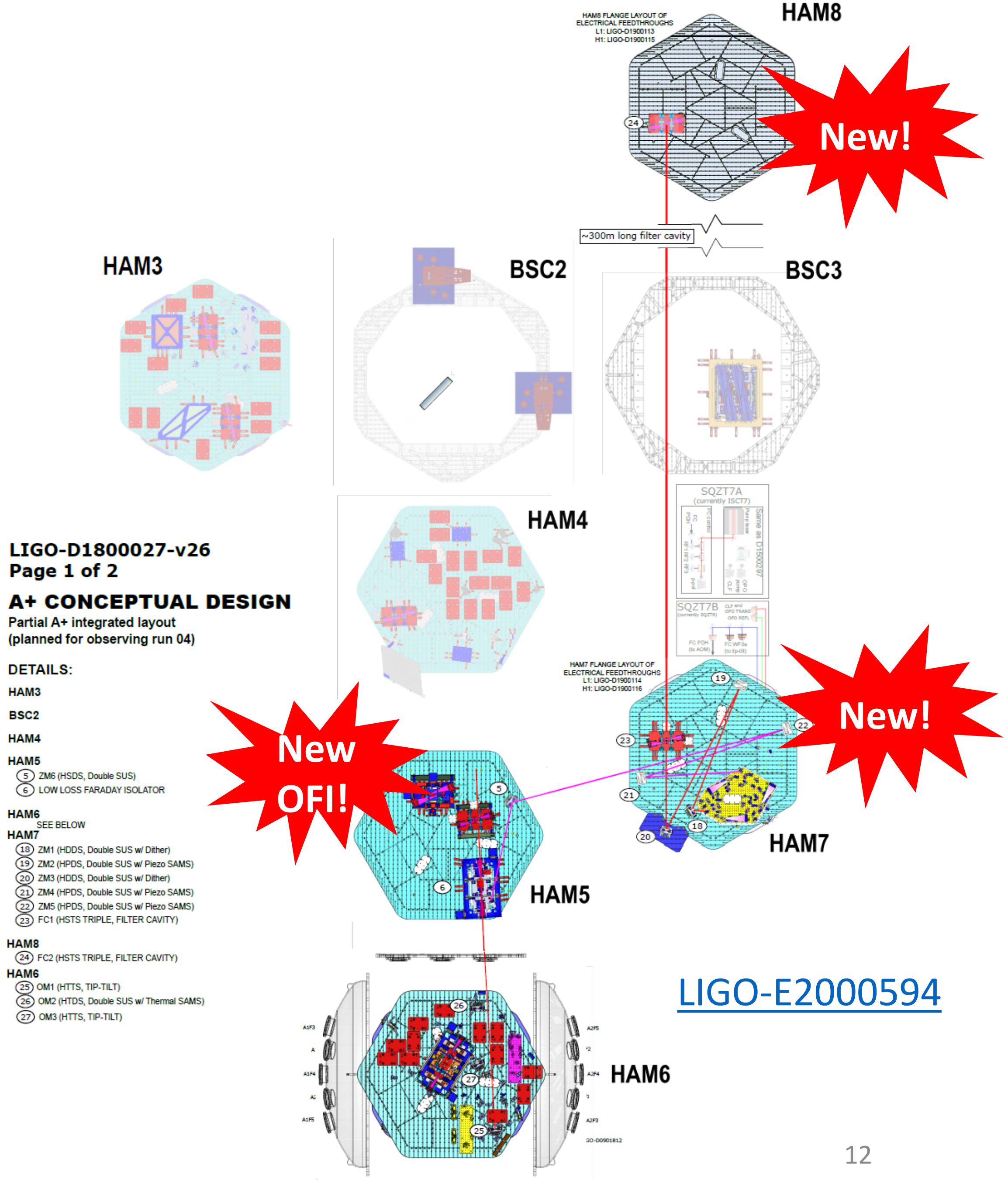
O2 baffles scope

[LIGO-D1700361]



A+ baffles scope and more

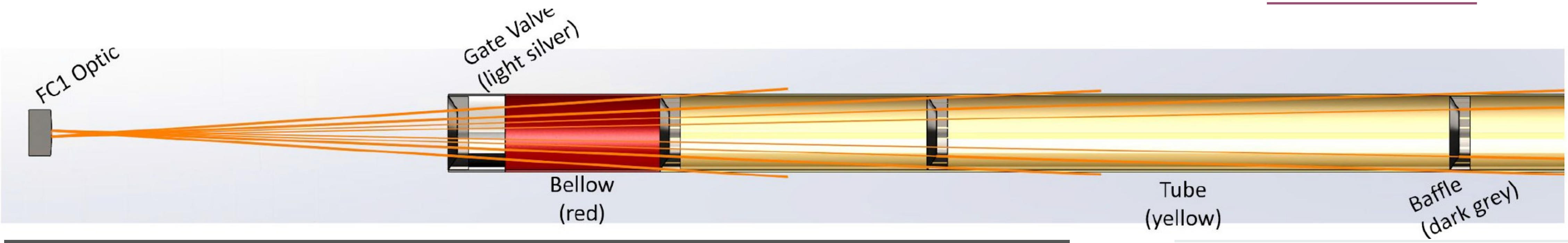
- Baffles in new chambers: HAM7 and HAM8
- Filter Cavity baffles
- Baffles for the new OFI in HAM5
- Other baffles in areas identified by commissioning

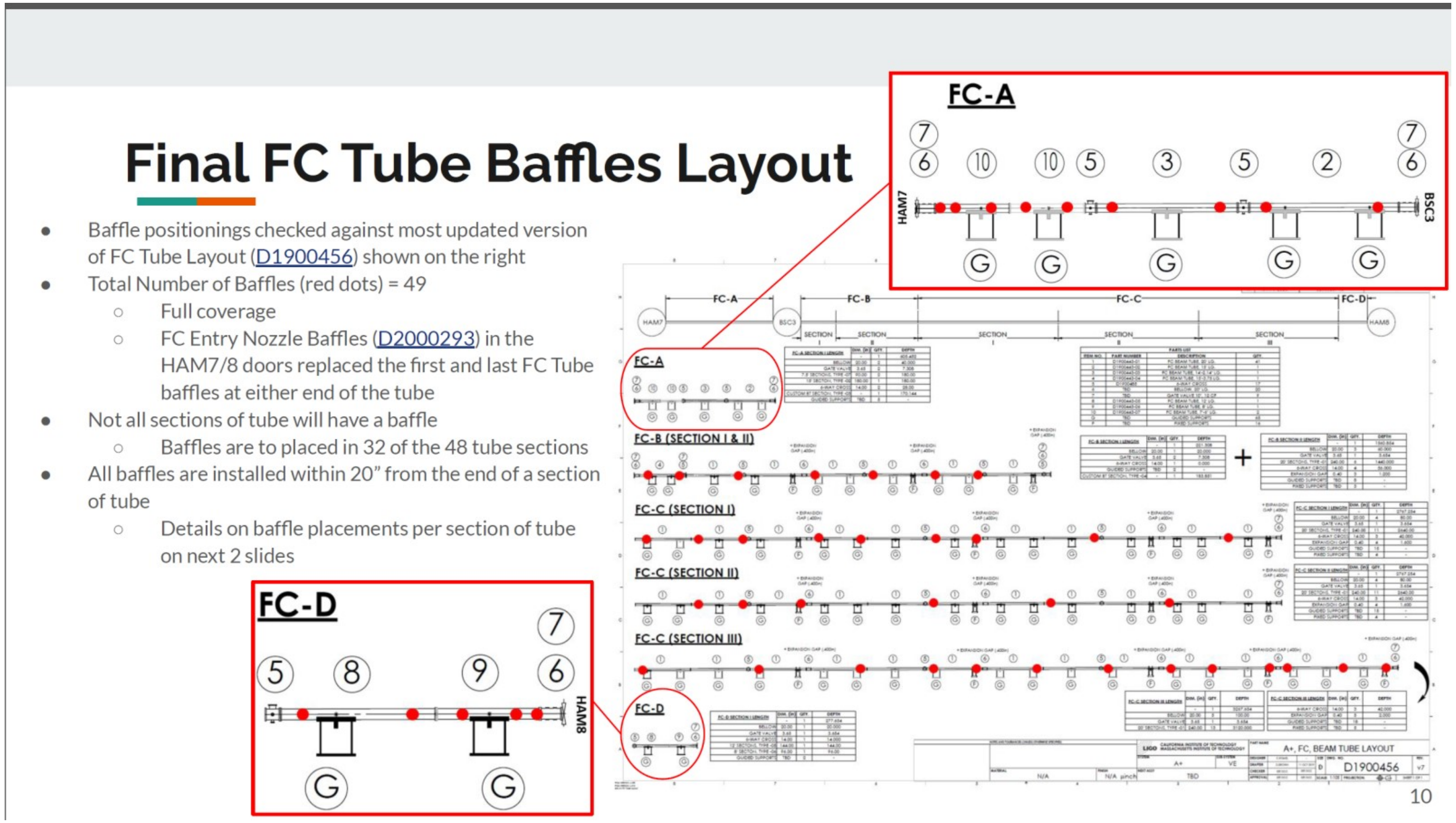


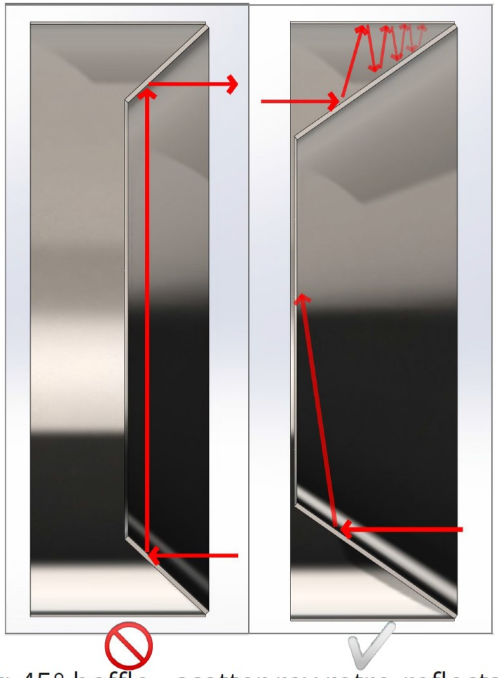
LIGO-E2000594

A+ baffles: filter cavity baffles

Danielle Petterson - FDR slides LIGO-E2000443





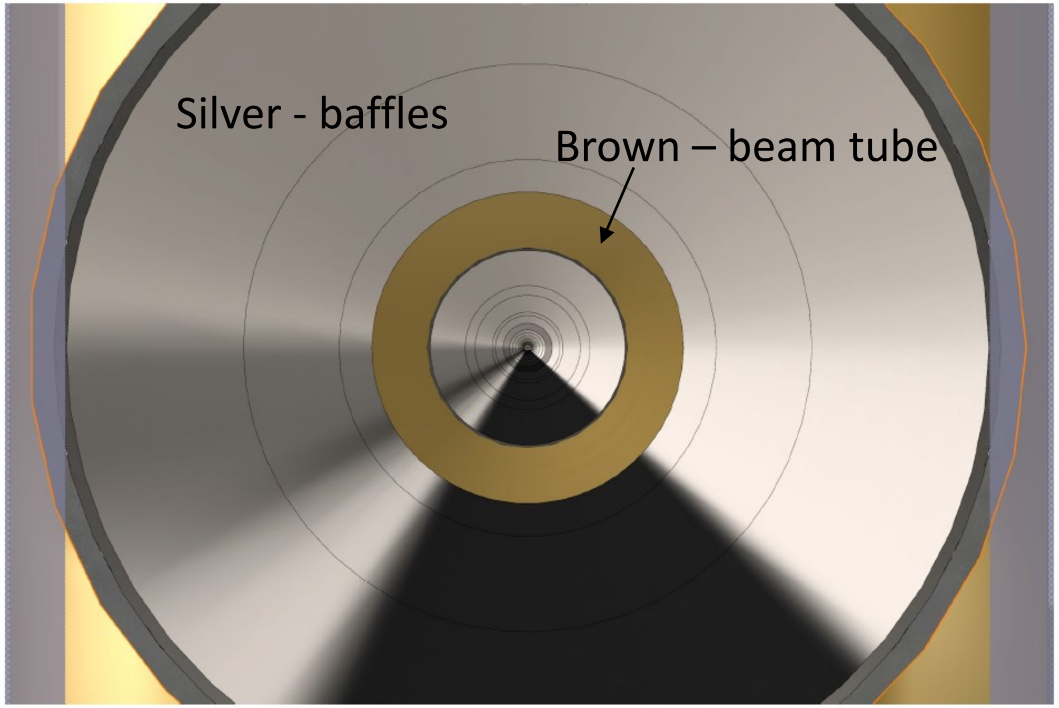


Near optic side

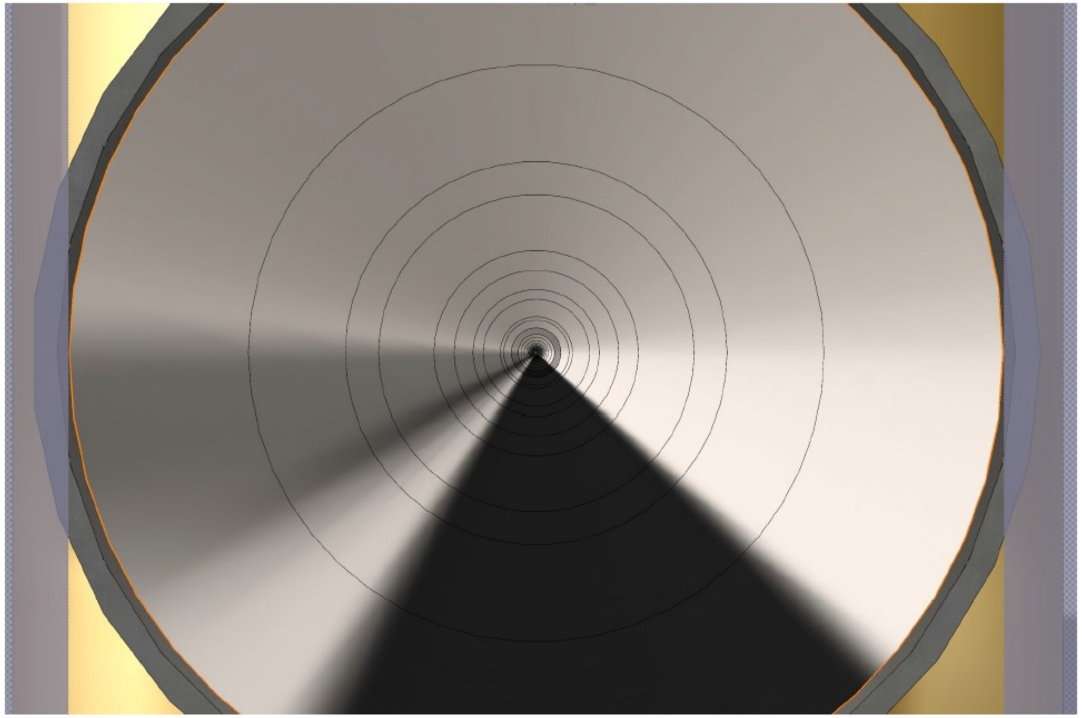
Left: 45° baffle - scatter ray retro-reflects back to the optic
Right: 35° baffle - scatter ray from near optic does not retro-reflect; scatter ray from far optic is trapped

A+ baffles: filter cavity baffles

With original configuration of beam tube section



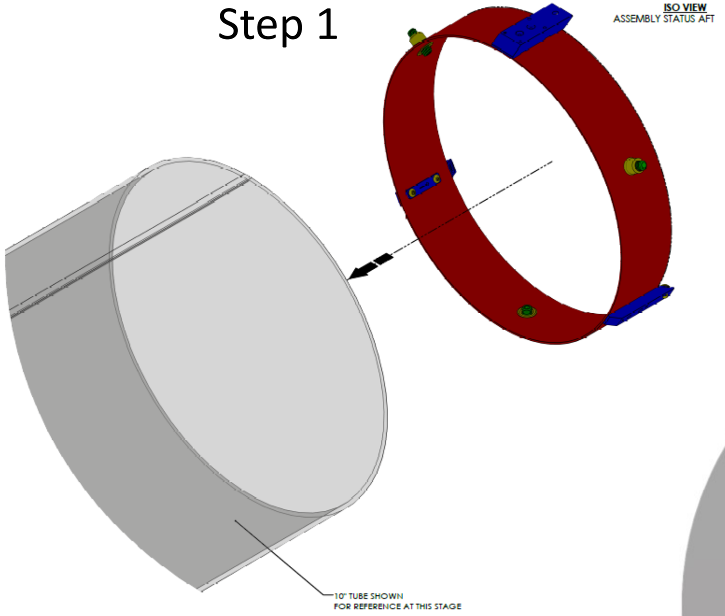
After splitting some tube sections to add baffles



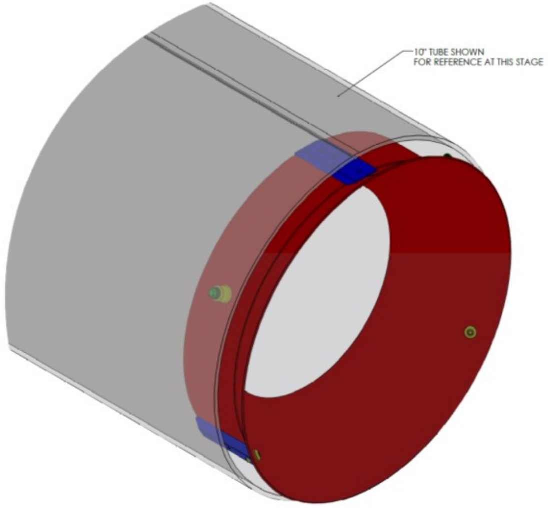
CAD camera view from FC1 to FC2 – tube baffles coverage check. Left: an area of the beam tube still exposed to optic, right: full coverage after splitting a tube section into 2 segments to allow additional baffles placement

A+ baffles: assembly and mounting

Step 1

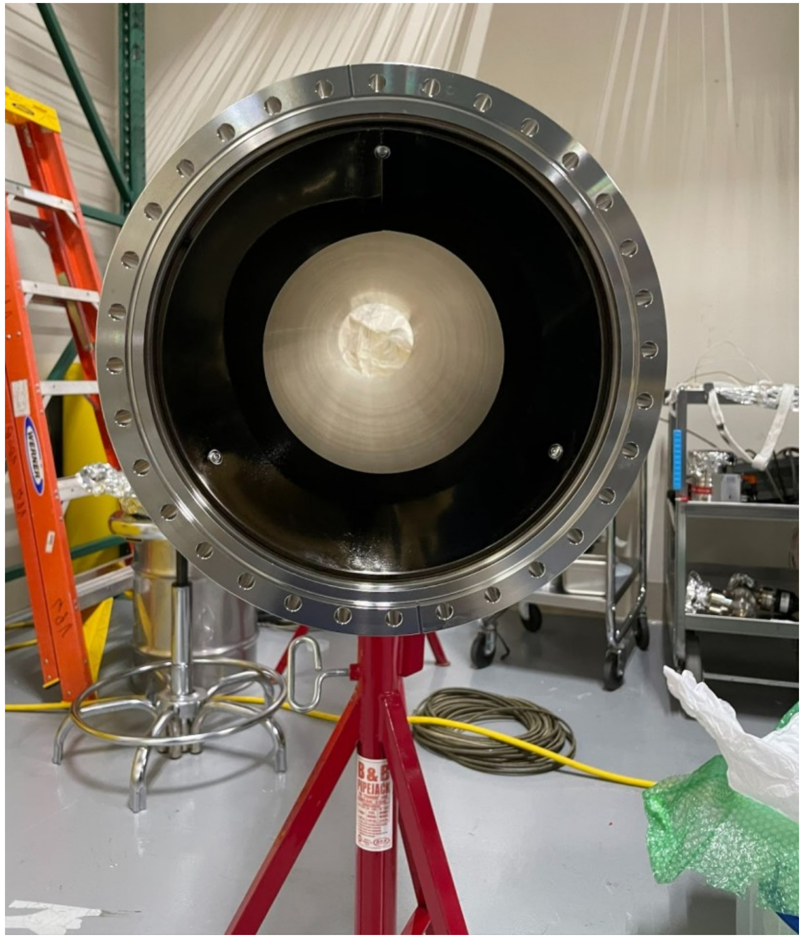


Step 2



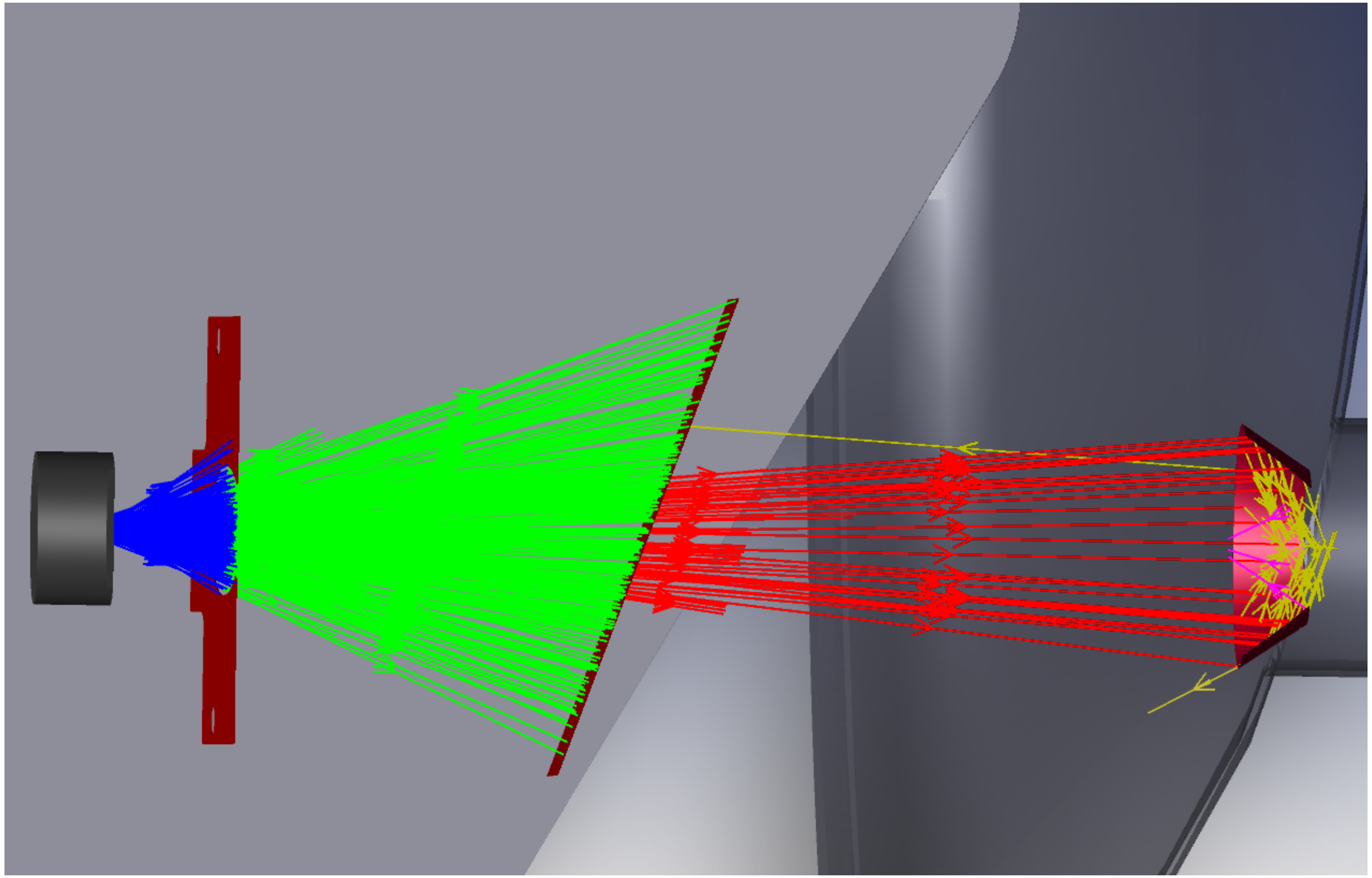
FC tube baffles consist of a mounting ring and a cone made of super#8 SSTL formed and black Ni coated. The mounting ring acts as a spring to provide damping.

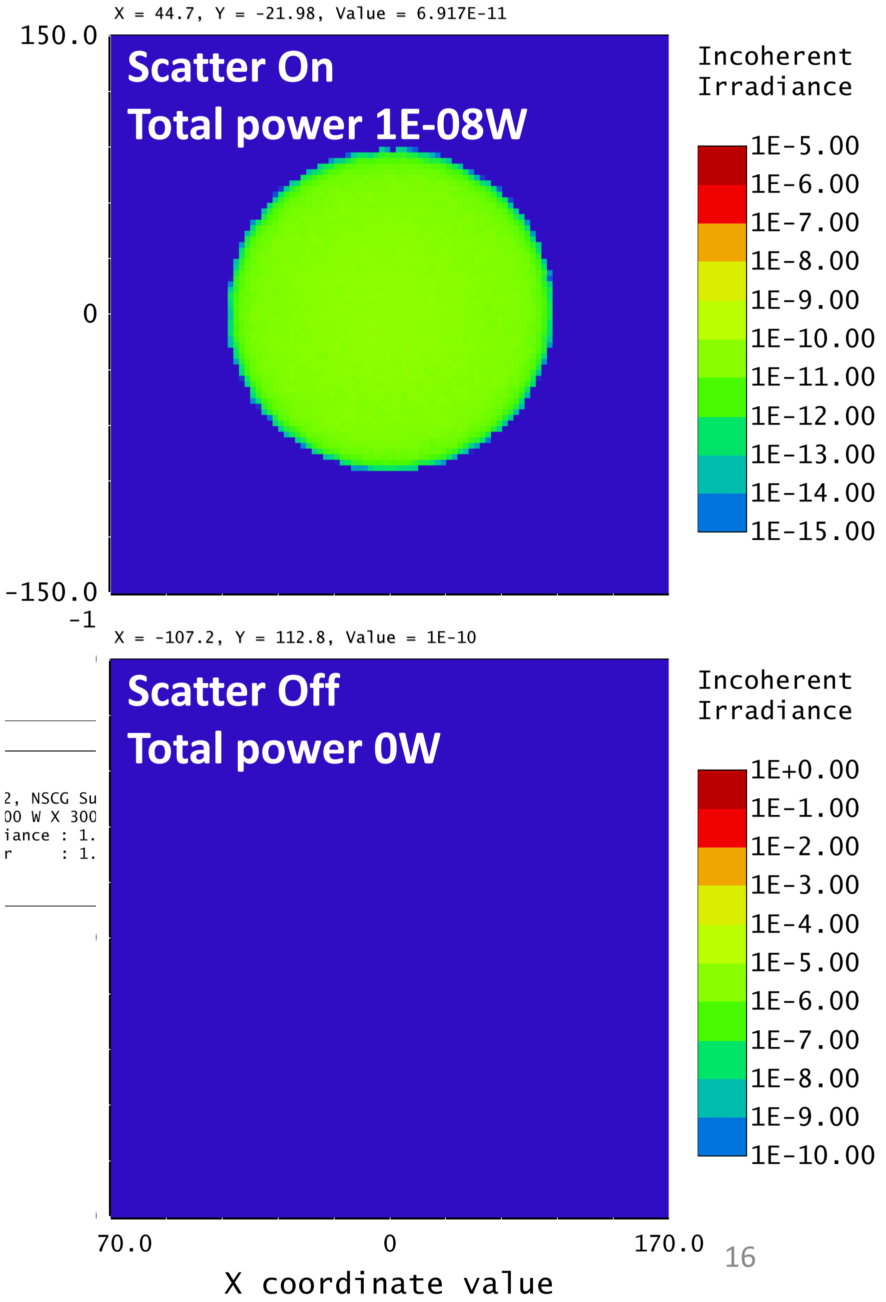
Filter cavity tube baffle fit check in a tube section: near optic view



https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=55721

HAM7 and HAM8 baffles: Back scatter from the nozzle baffle: 10 conical nozzle baffle

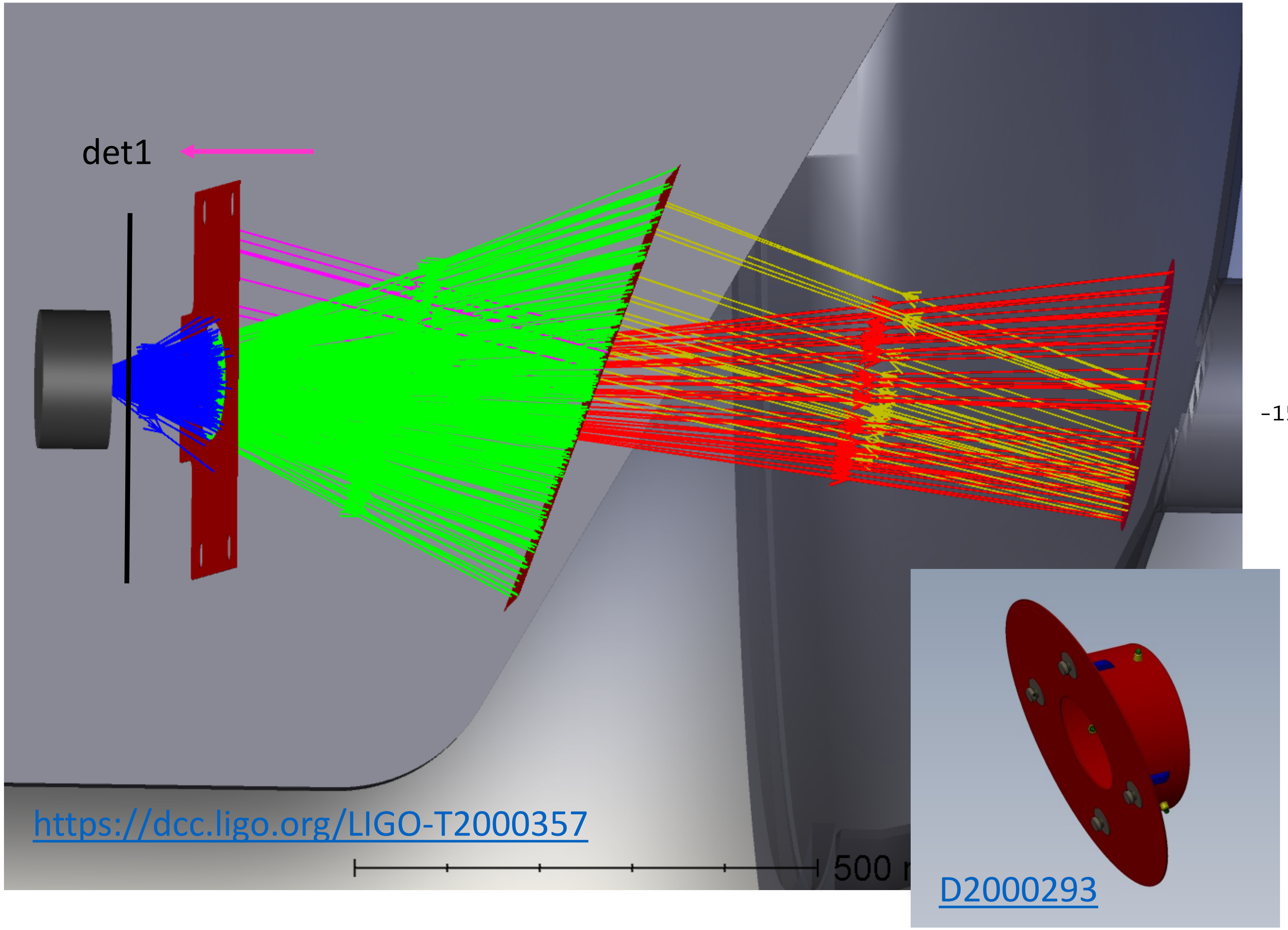




Even less scatter returns from the baffle to FC2 if the nozzle baffle is same as the cone part of FC tube baffles

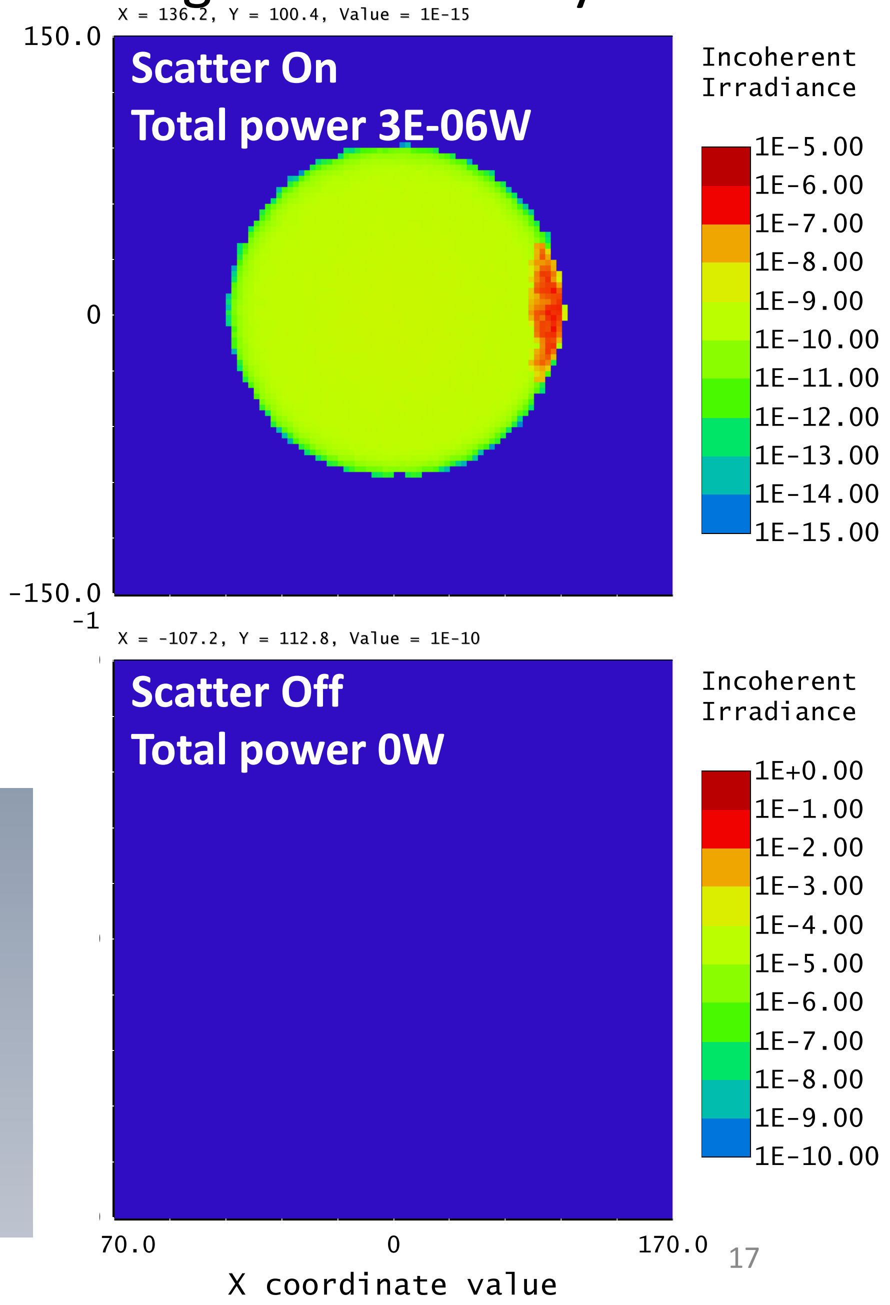
*back scatter will be lower as well

HAM7 and HAM8 baffles: Back scatter from the nozzle baffle: 10 deg nozzle baffle yaw



https://dcc.ligo.org/LIGO-T2000357

D2000293



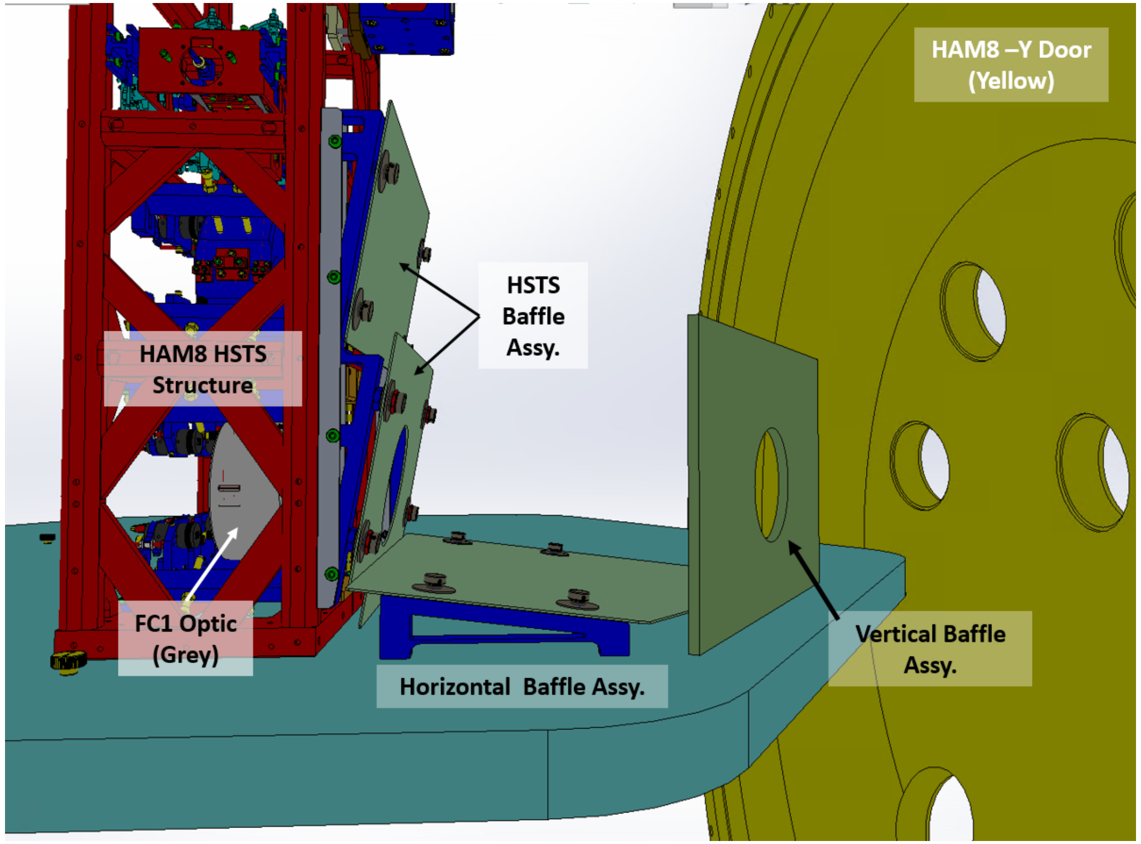
No specular reflection from the baffle returns to FC2 but some scatter does

HAM7 and HAM8 baffles: CAD model

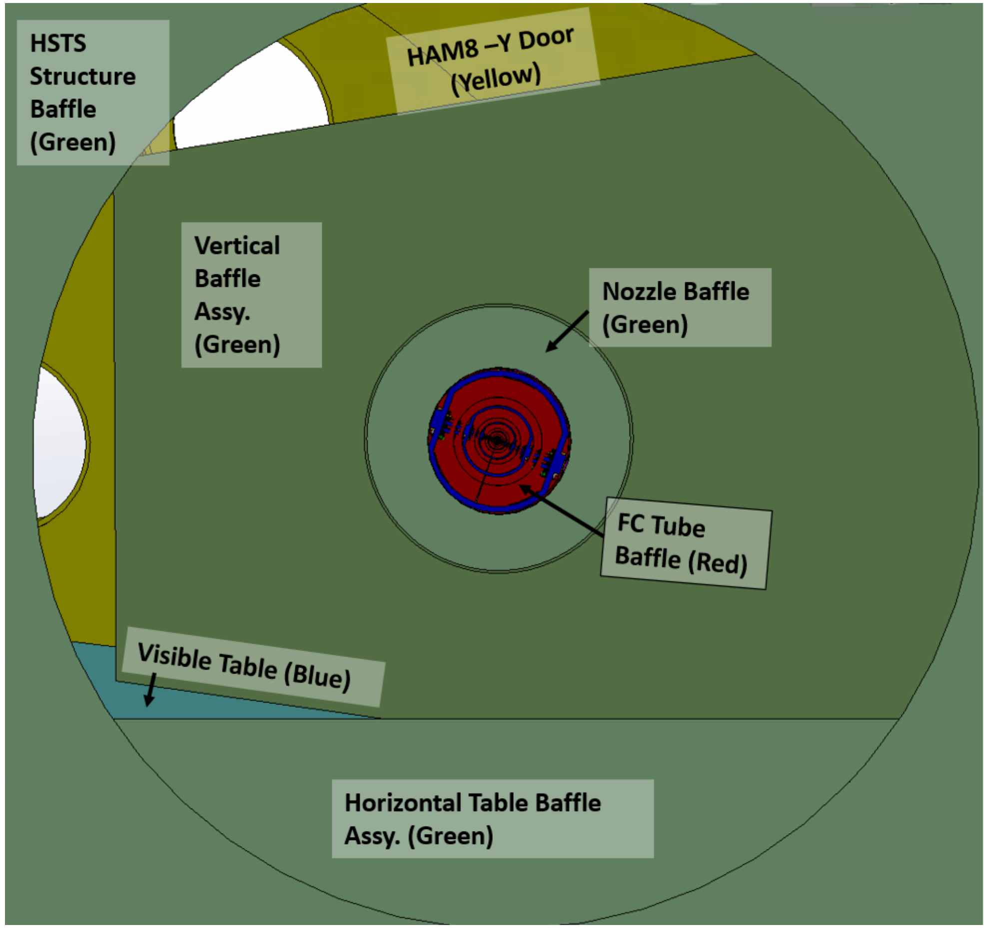
Multi layers baffles concept is used to allow relaxed baffles apertures:

- baffles on the structure to dump low angle scatter from the far optic
- Baffle on the table to provide second layer for scatter absorption
- Vertical baffle on the table covers the chamber`s door
- Nozzle baffle covers what table baffle could not cover

FDR slides https://dcc.ligo.org/LIGO-E2000441

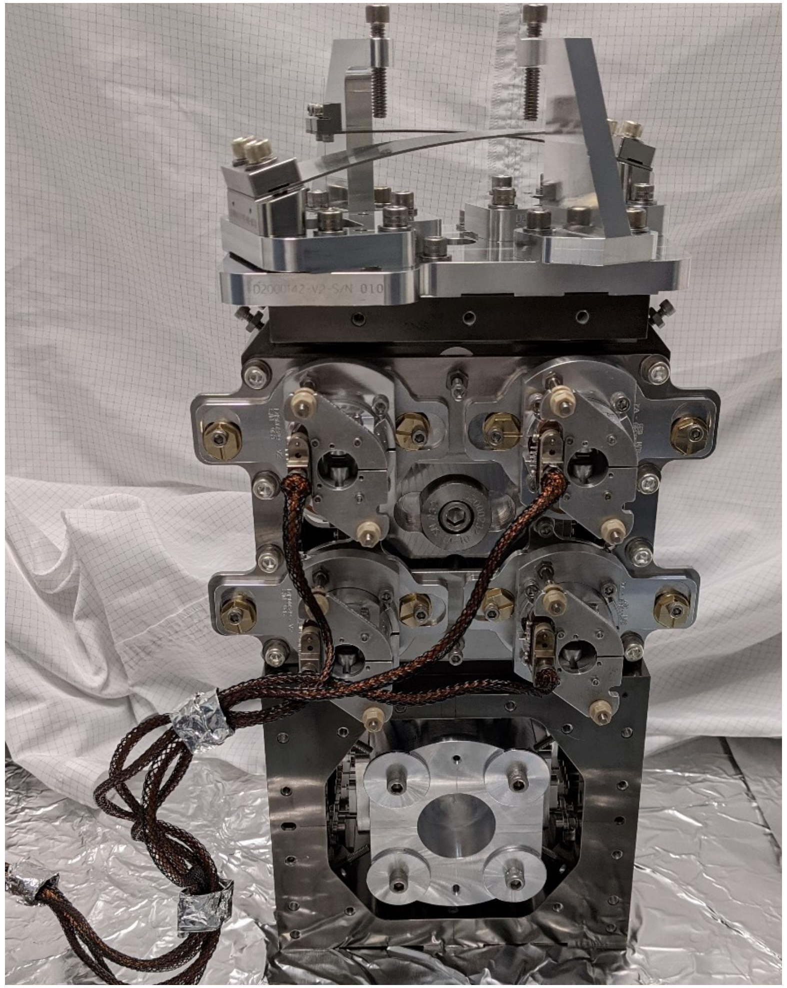


SW model borrowed from slide 35 CDR E2000177

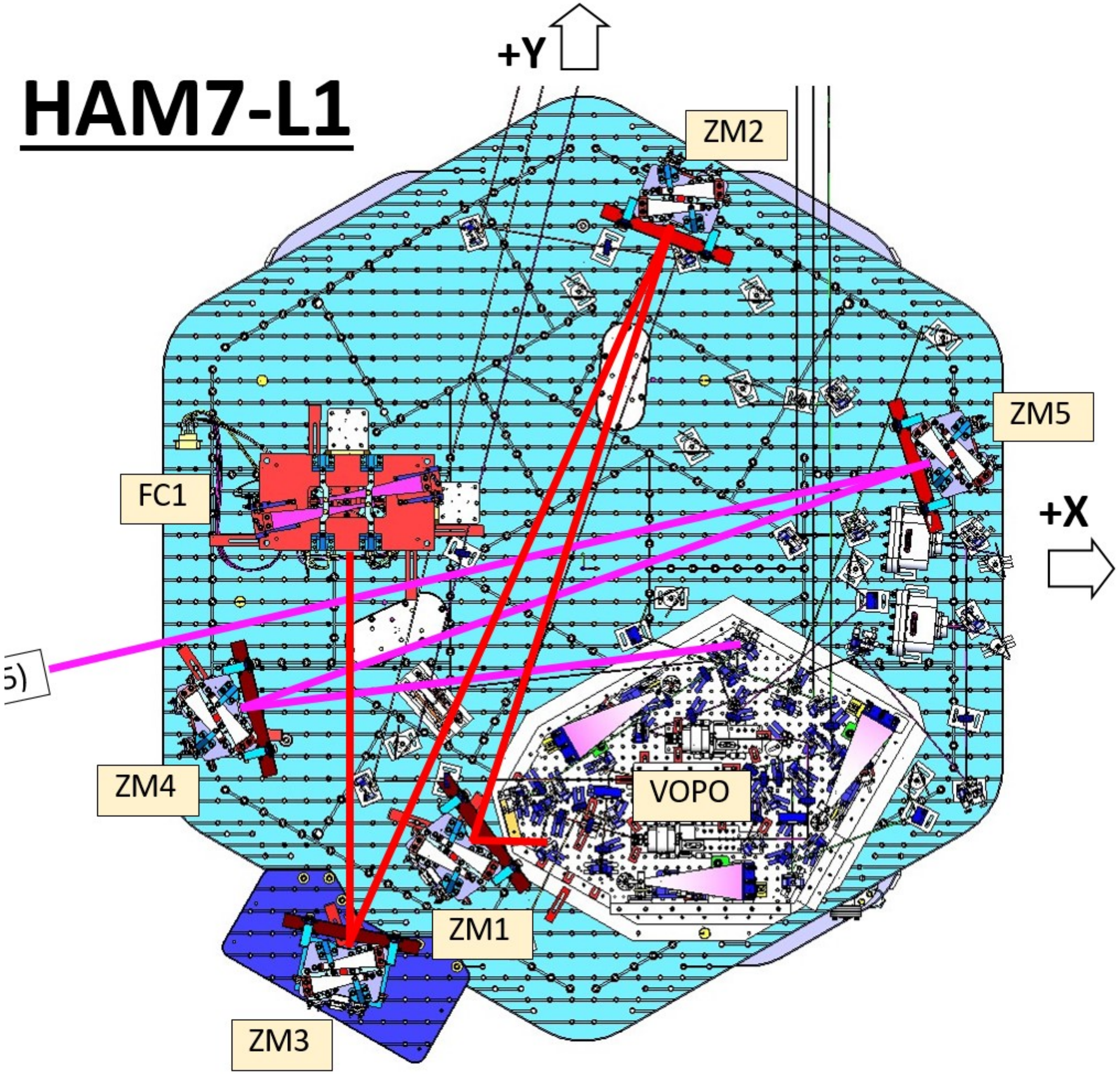


CAD camera view from FC2 toward FC1

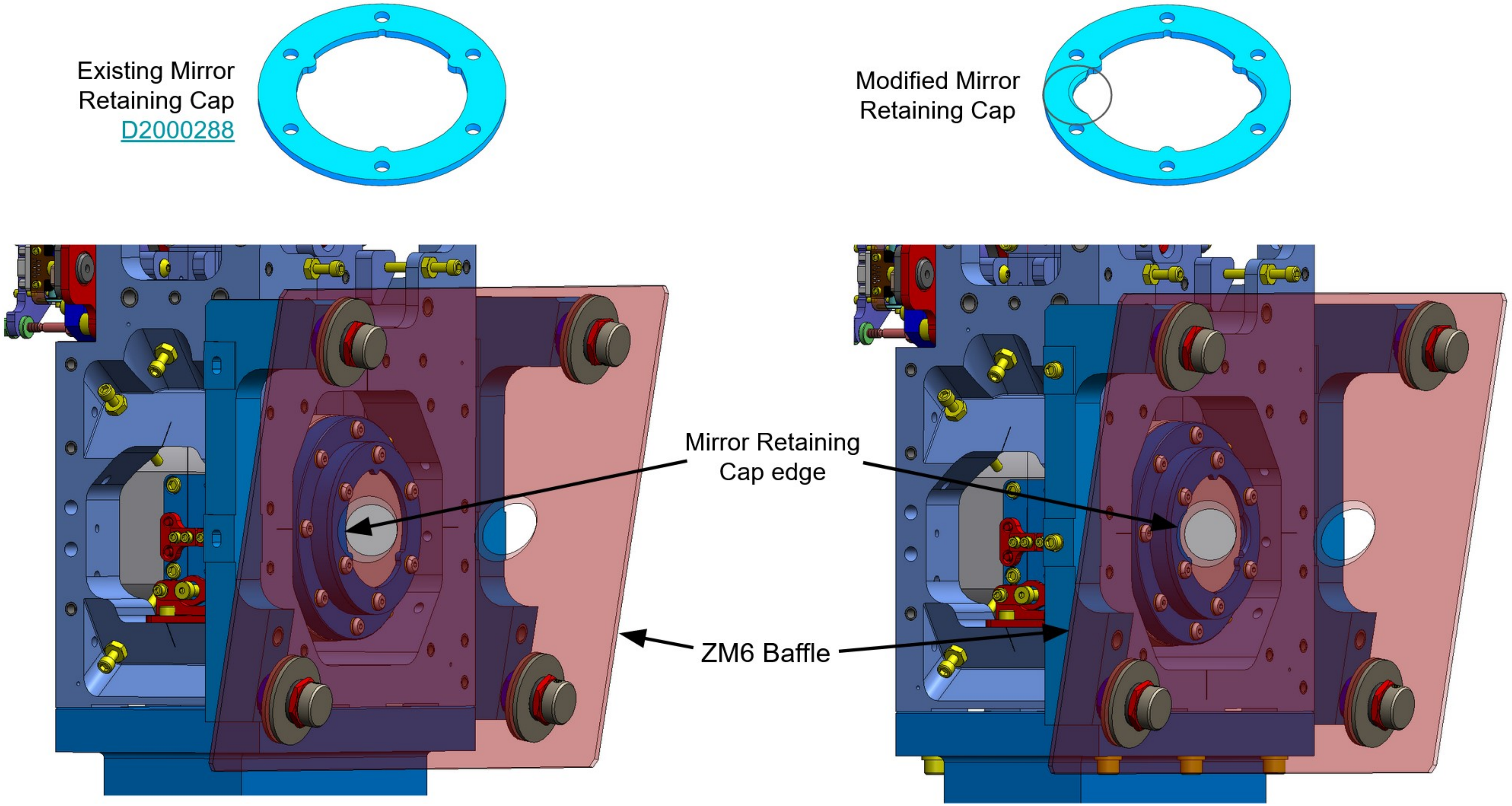
Squeezer path to HAM5: baffles for each ZM optics and coated HDS structures



An HDS structure test assembly with a coated structure at LLO https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=54506



ZM6 in HAM5: tricky AOI and required 20w clearance LIGO-G2100885



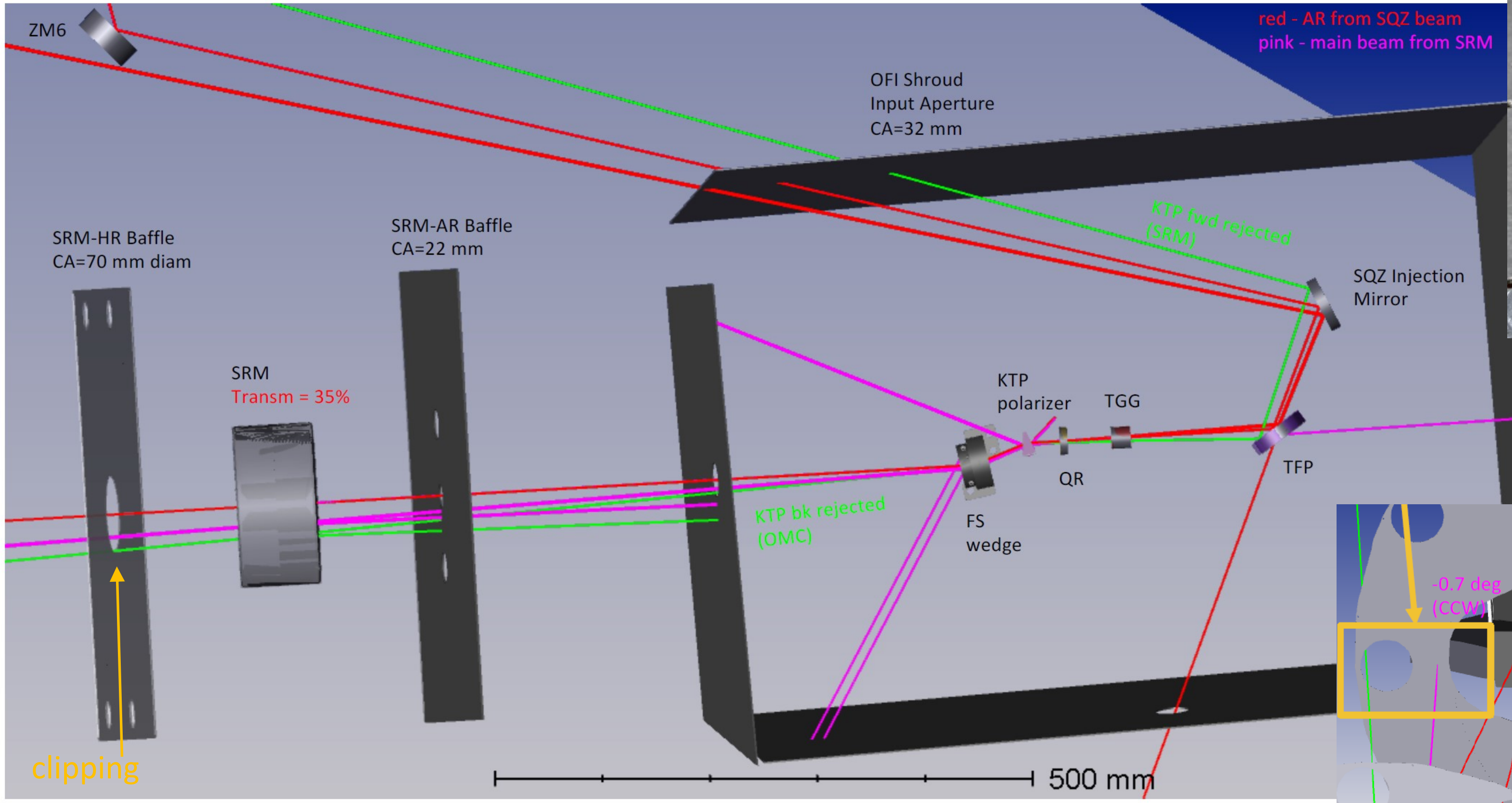
CAD camera view of ZM6 from OFI: A new type of baffles with in and out apertures due to high AOI. This example shows how “stay clear zones” are taken into account

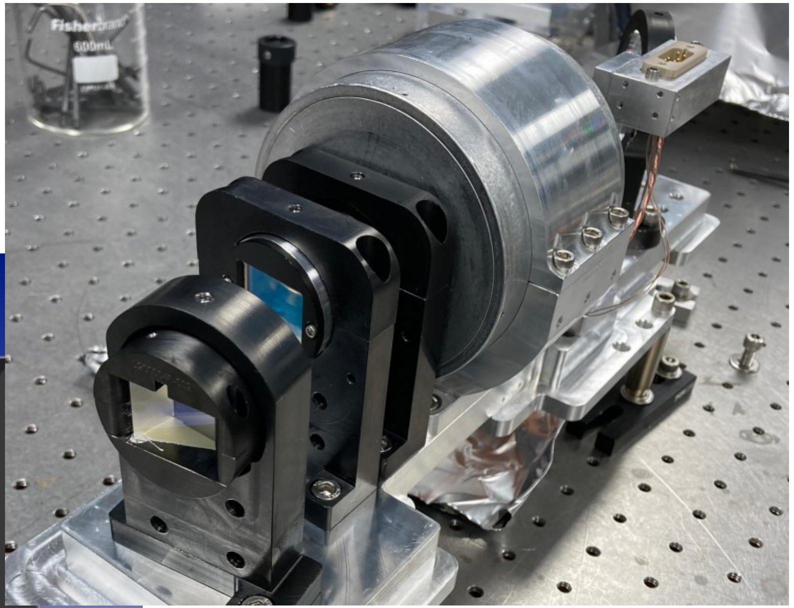
A+ OFI ghost beams and baffles apertures LIGO-T2000598-v5

FDR slide on zemax model httLIGO-G2000808
FDR LIGO-L1900454

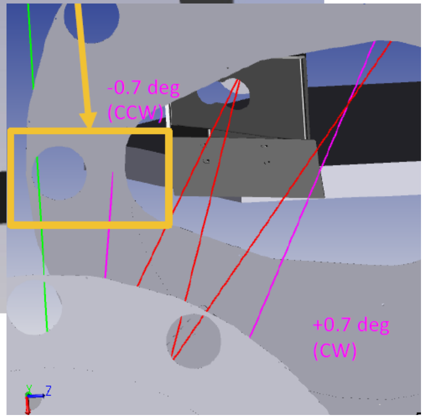
Ghost beams - on HAM5

QR&TGG horiz tilt -0.7 deg





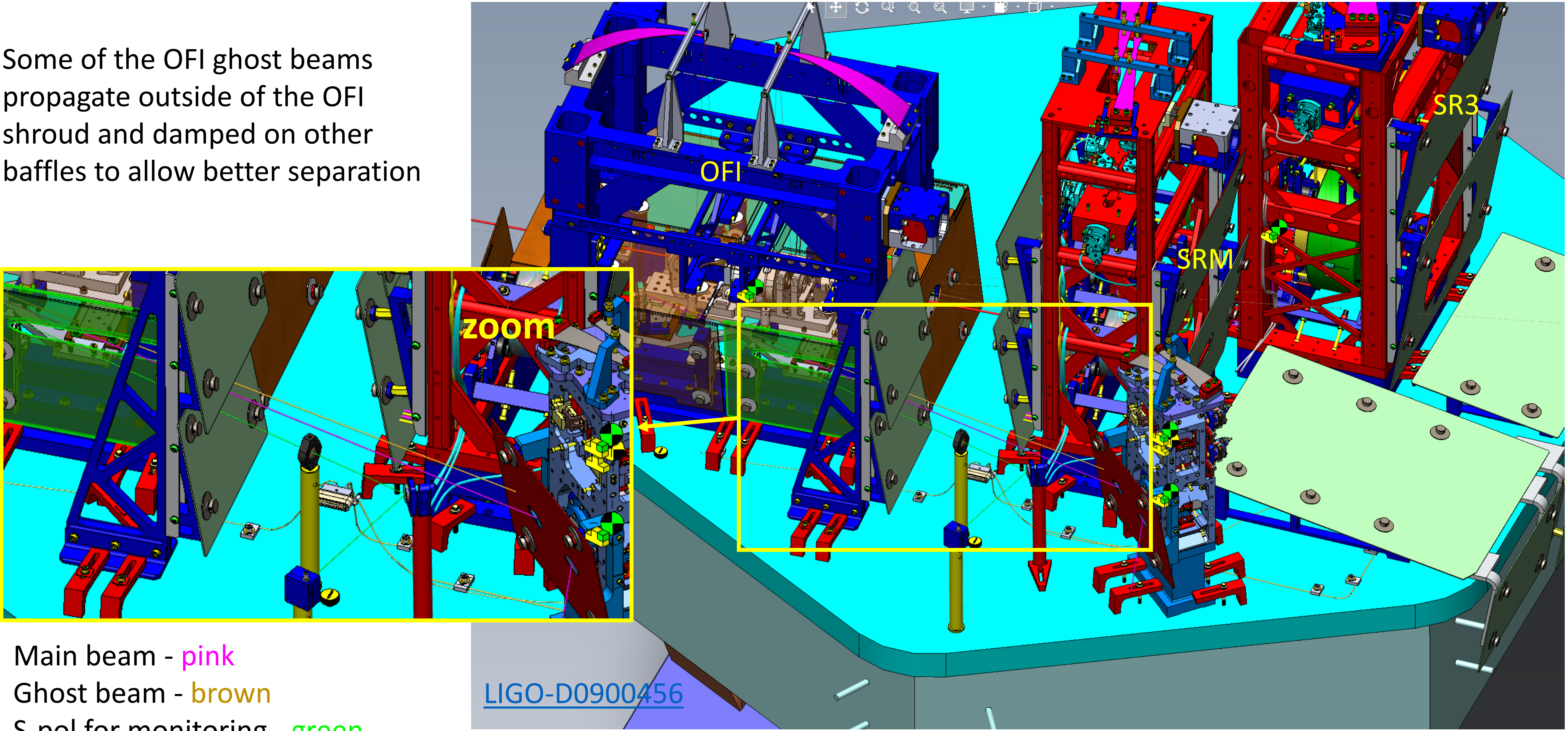
A+ OFI on a test bench at University of Florida



As per the A+ OFI optical layout LIGO-D1900487, rejected S polarization from OMC can clip on the aperture of SRM HR baffle if not dumped on OFI shroud input panels or SRM AR

A+ OFI shroud and surrounding baffles in HAM5

Some of the OFI ghost beams propagate outside of the OFI shroud and damped on other baffles to allow better separation

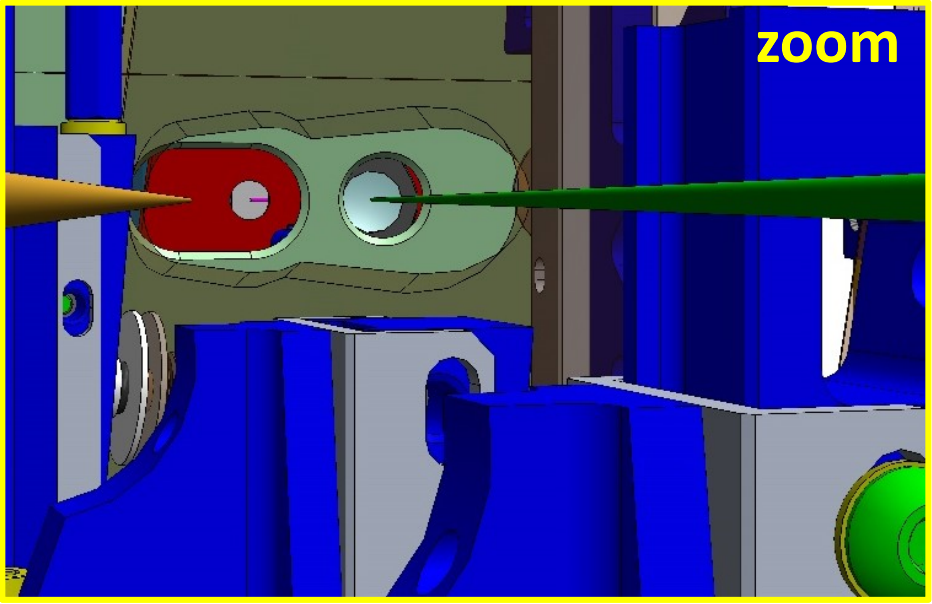


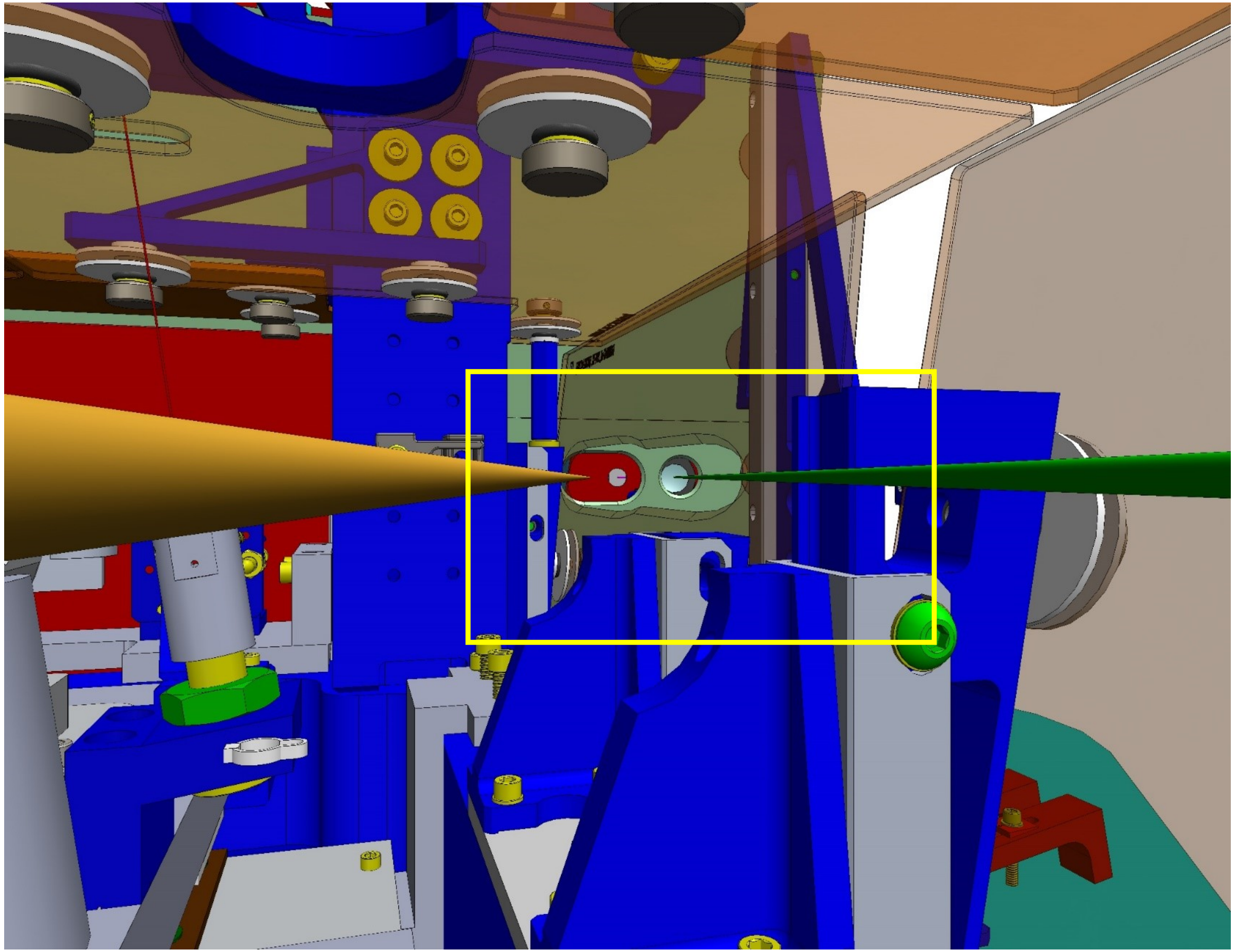
Main beam - pink
Ghost beam - brown
S-pol for monitoring - green

CAD camera view from OFI to ZM6 (we are inside the shroud)

The CAD camera view helps to verify all apertures are round to the beam

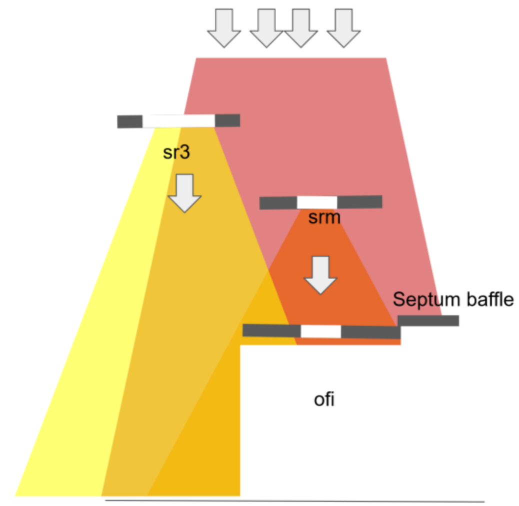
Ghost beam - brown
S-pol for monitoring - green

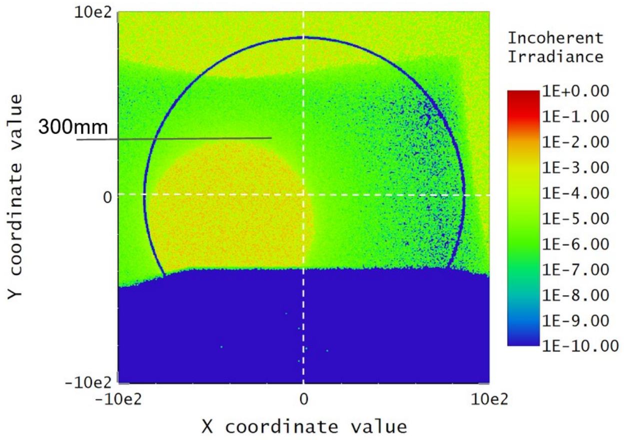




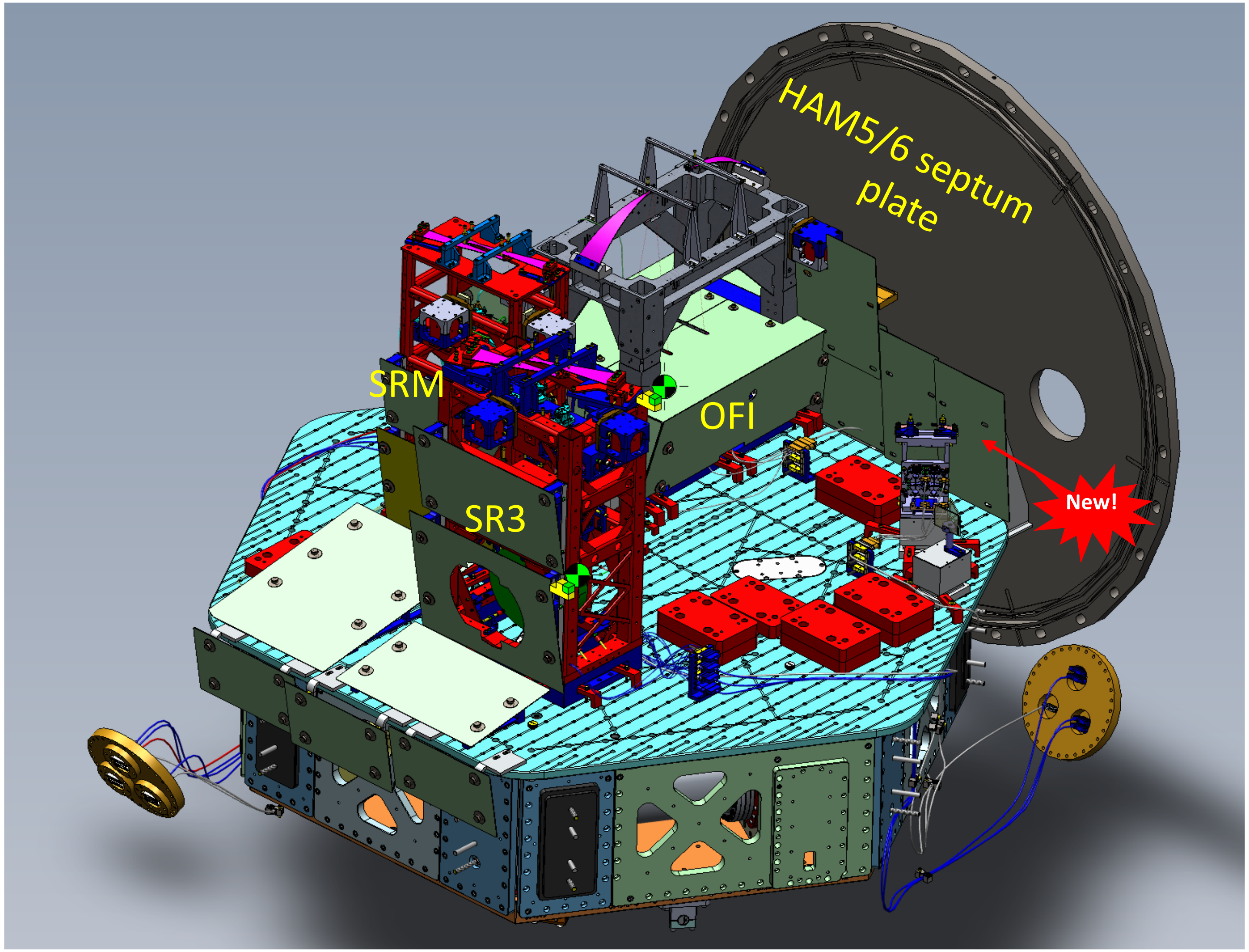
A “wall baffle” in HAM5 and HAM6 to cover the septum plate separating 2 vacuum volumes

HAM5/6 septum is a known source of noise coupling





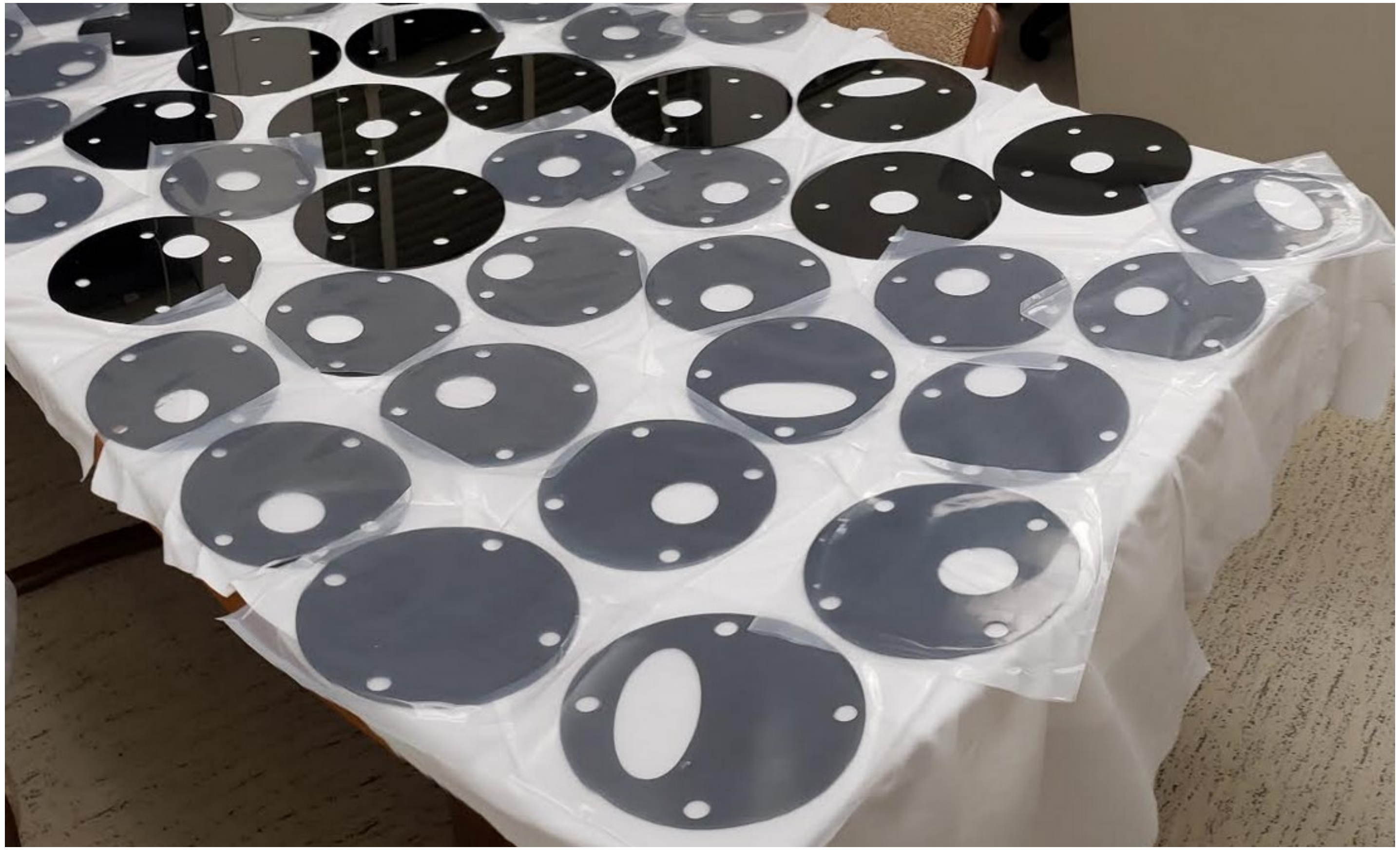
Detector image: SRM scatter on the septum. Blue area is the shadow from the ISI table, Green is the SRM AR baffle shadow (100mm diameter aperture per the ECR). Only the bottom AR baffle is considered in the model.

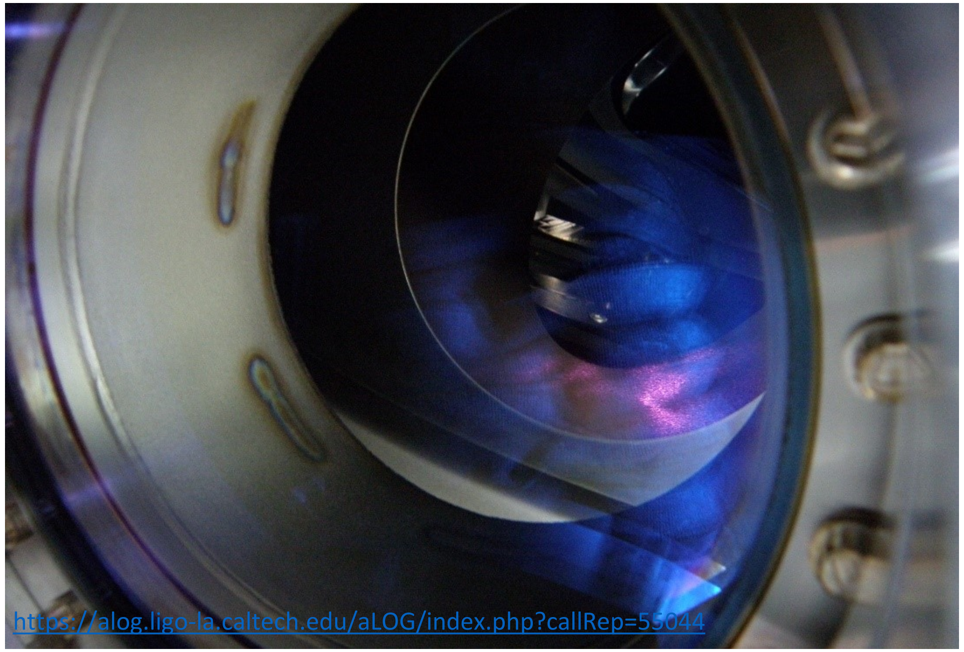


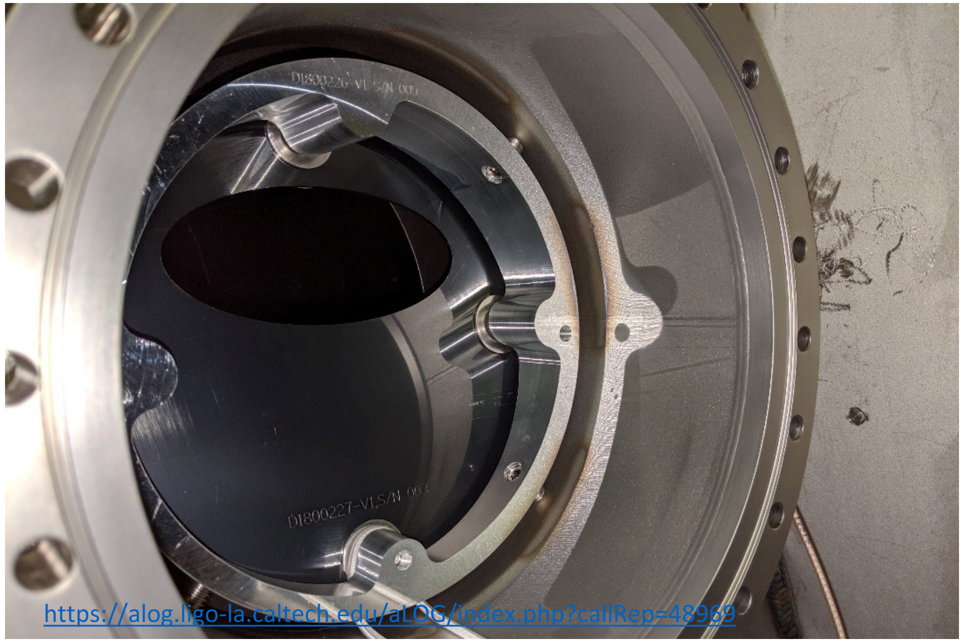
CDR https://dcc.ligo.org/LIGO-G2100167

Nozzle baffles kit for view-ports LIGO-D1800228

The kit consists of DLC coated super-polished SSTL plates with different apertures to be used with various view-ports (unused, camera or oplev view-ports)







Nozzle baffles kit: left – incoming inspection of the coated plates, top right – scatter observed on the surface of a view-port nozzle (seen as pink light), lower right – a nozzle baffle being installed at LLO.