Advanced Virgo: Stray-Light Control

A.Chiummo - EGO
on behalf of the AdV SLC team

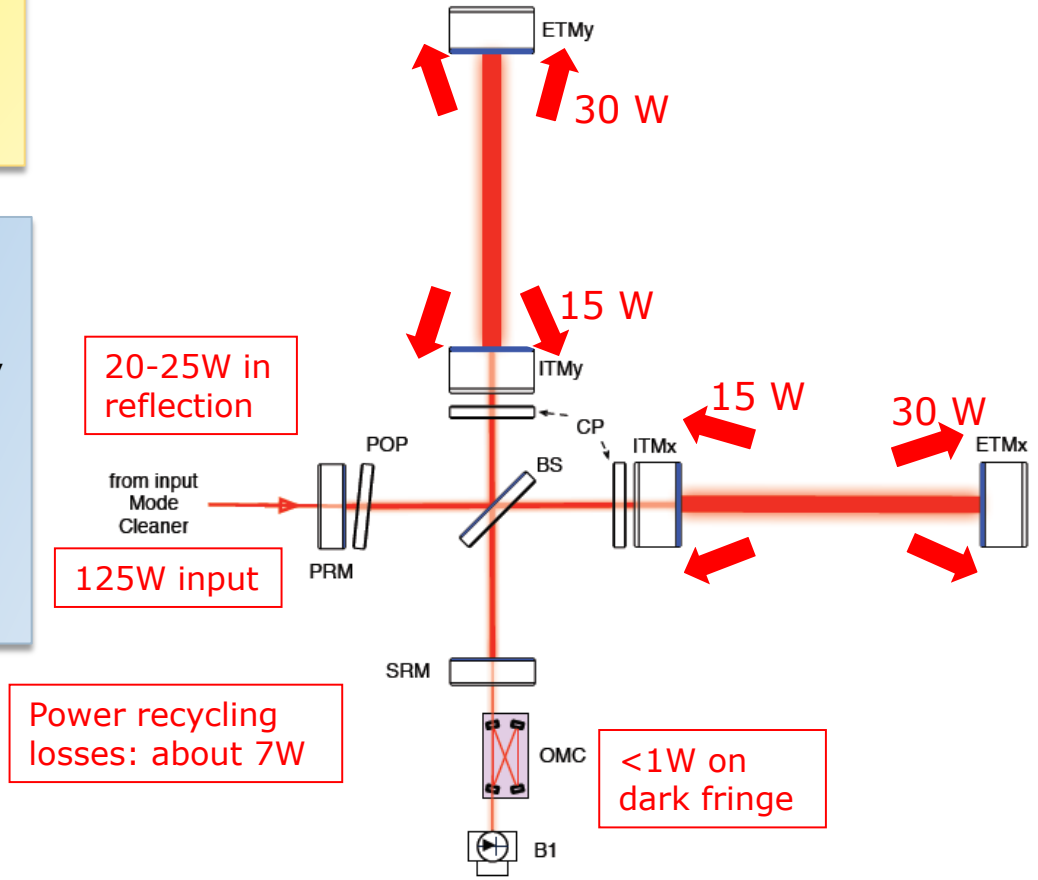
Outline

- AdV SLC subsystem
- Simulations and requirements
- Design and Materials
- Construction highlights

An Old Enemy

In AdV, more than 70% of injected power is intended to be lost in the arms (design).

Need to control these wandering photons so that the spurious info carried by them contribute negligibly to sensitivity limit (10 times less then fundamental noises).



A bit of history

- SLC subsystem estabilished only in late 2011
- J. Marque (EGO) as SSM until 2013 (then AC took over)
- Chronical lack of manpower, very few people (~2) had this as main assignment
- Scope of the subsystem was to identify and control potential issues inside the ITF
- Benches were out of scope - supposed to be taken care of by the related subsystems (INJ, DET, TCS)
- Main goal was to hide from possible scattered light rough mechanical structures: use of suitable baffles
- No SLC commissioning group: part instead of general ENV after construction phase

Requirements

How to design new baffles /accept existing ones?

- Main requirements:
  - Damage threshold (according to expected intensity)
  - External and internal diameter of baffles (solid angle)
  - Roughness and reflectivity of baffles
  - Edges geometry (sharp angles)
  - Maximum allowed displacement amplitude (mechanical structure)
  - Cost and feasibility (for new baffles)

Requirements

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❑ How to design new baffles /accept existing ones?

1) Need to evaluate baffle displacement noise and project it to the strain sensitivity.

Recipe for noise projection:

Parameter	Meaning	Estimation method
|c|^2	recombination efficiency	FFT (FOG -SIS) /Semi-analytical
Xbaf	(effective) displacement noise of scatterer	Measurement /simulations
Tbaf	Transfer function from Xbaf to dark fringe PD (B1)	Optickle /Finesse /MIST
Tdarm	Transfer function from DARM dof to dark fringe PD	Optickle /Finesse /MIST

$$hbaf = |c|\ Tbaf/Tdarm\ 1/L\ Xbaf$$

Requirements

EGO - VIRGO

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Recipe for noise proje

Roughness, reflectivity, shape, position

Mechanics, linear /non-linear (fringe wrapping)

location

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EGO - VIRGO

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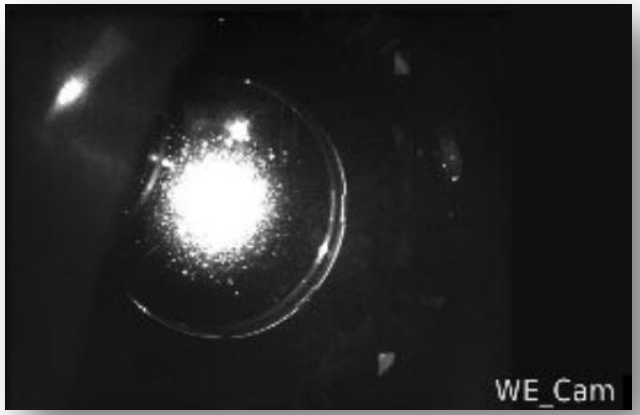
$$hbaf = |c|\ Tbaf/Tdarm\ 1/L\ Xbaf < h/10$$

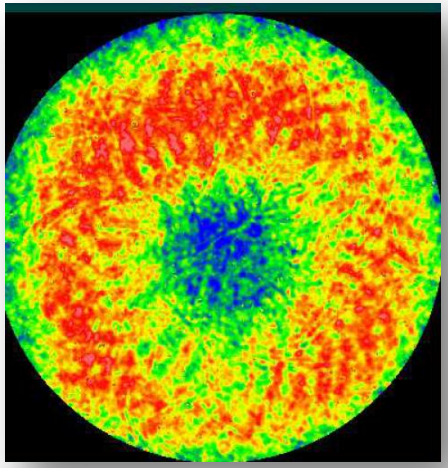
Recombination factor calculations

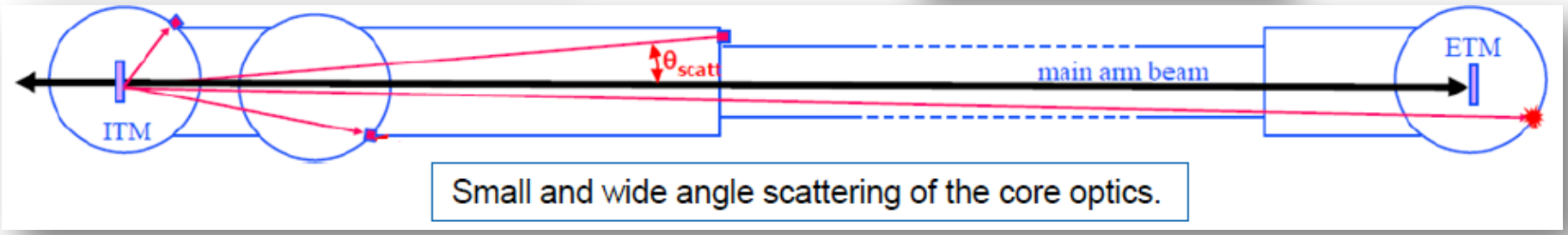
EGO - VIRGO

❑Wide angle scattering from the core mirrors (u-roughness)



❑Low angle scattering from the core mirrors (figure defects)





This path requires at least three scattering events to recombine

Recombination factor calculations

EGO - VIRGO

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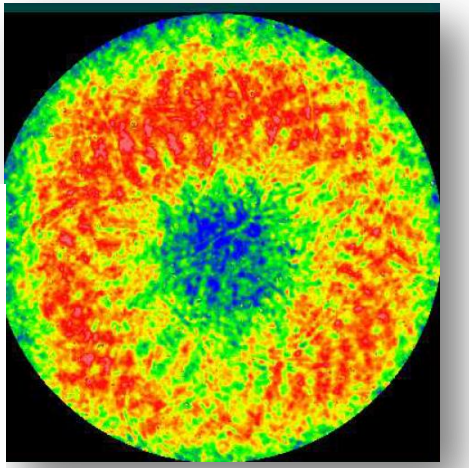
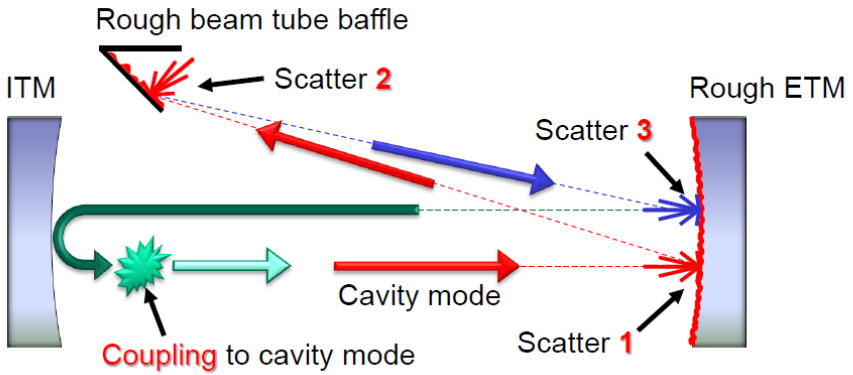




How much scattered light coupled into cavity mode?

Scatter 1 → Ok : Use FFT & mirror maps

Scatter 2 → Tricky : Use BRDF to estimate

Scatter 3 → Ok?: Use FFT & mirror map (but what field?)

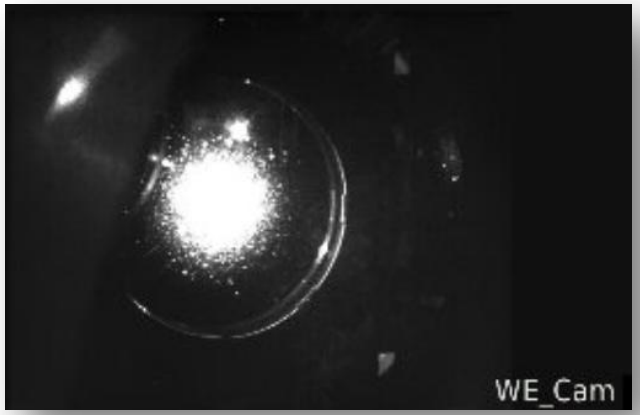
Coupling → ?: How exactly does it couple?

From R.Day, G1300532

Recombination factor calculations

EGO - VIRGO

❑Wide angle scattering from the core mirrors (u-roughness)



Use measured BRDF of the wide angle scattering off the core mirrors to compute light intensity reaching the external structure

Use “reciprocity theorem” to compute fraction of such light backscattered to main ITF mode

$$\frac{\delta I_{mb}}{I_{mb}} = \frac{\lambda^2}{r^2}\left(\frac{dP}{d\Omega_{ms}}\right)^2 \frac{dP}{d\Omega_{bs}}\delta\Omega_{ms}$$

“Recyprocity theorem”, Flanagan, Thorpe - T940063

Effective displacement noise of scatterer

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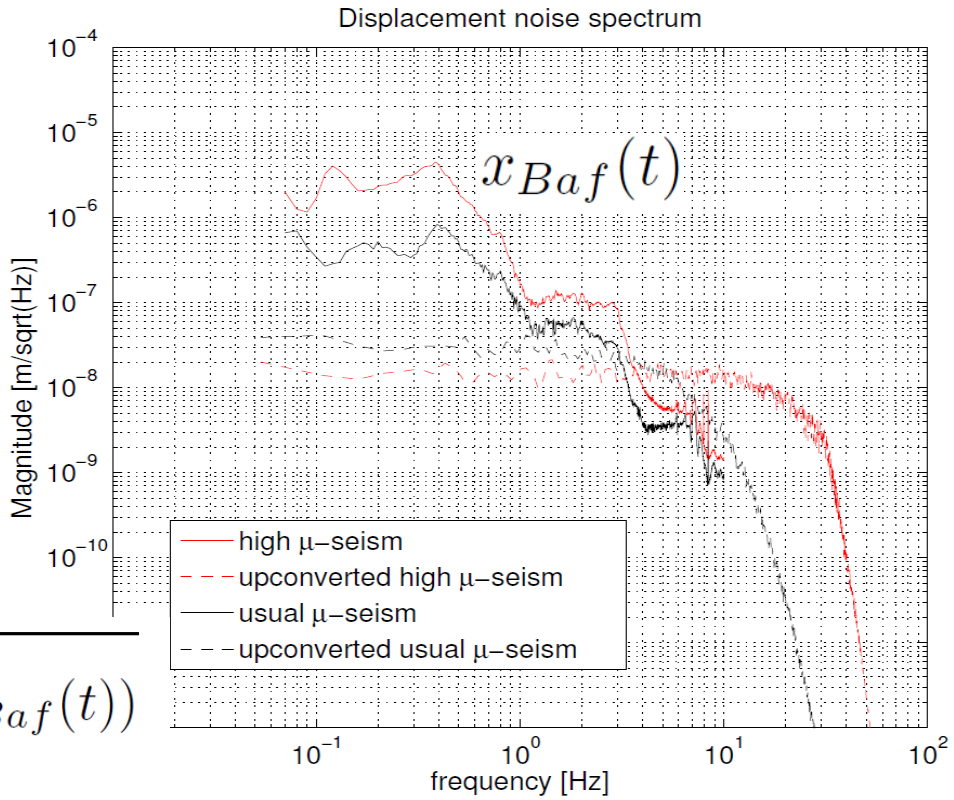
- Non-linear coupling (fringe-wrapping)

Regardless of the amplitude of motion of the scatterer, scattered light phase modulation cannot exceed 2pi. For large amplitude we must use an effective displacement:



$$\tilde{x}_{Baf}(\omega) = \frac{\lambda}{4\pi}\sqrt{PSD(\sin(\frac{4\pi}{\lambda}x_{Baf}(t))}$$

Either add the cosine or scan microscopic static position to compute the TF using Optickle (see M. Was talk)

Requirements: small angle scattering

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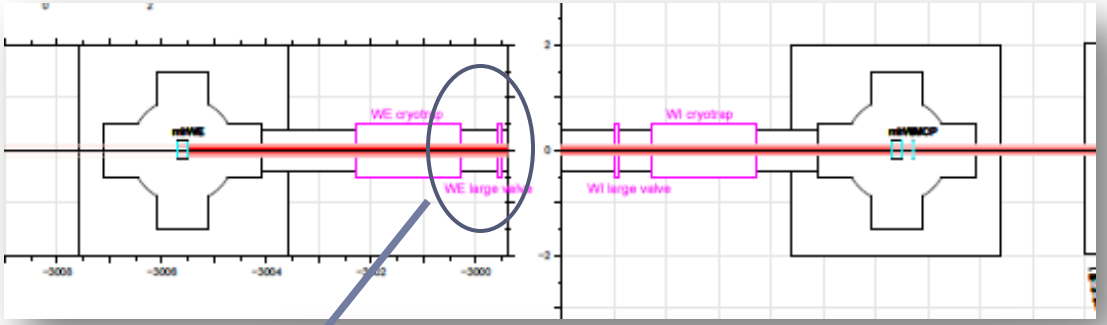
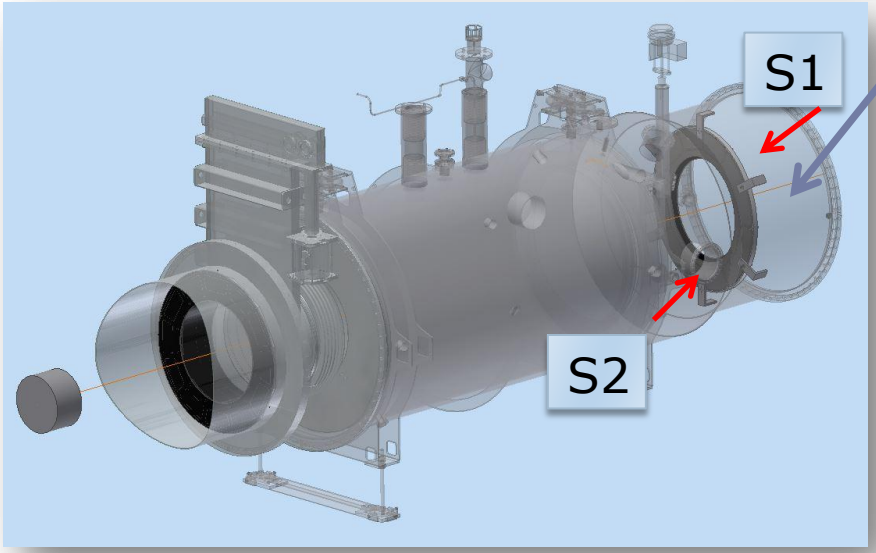
- Example: baffles for arm cryogenic traps

Needed to obscure inner walls of the cryotrap from:

- Farthest test mass (baffle S1)
- Closest test mass (baffle S2)





Noise projection for Cryo-baffle (design)

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❑ Design study for baffles in arm cryogenic traps [VIR-0417B-13]:

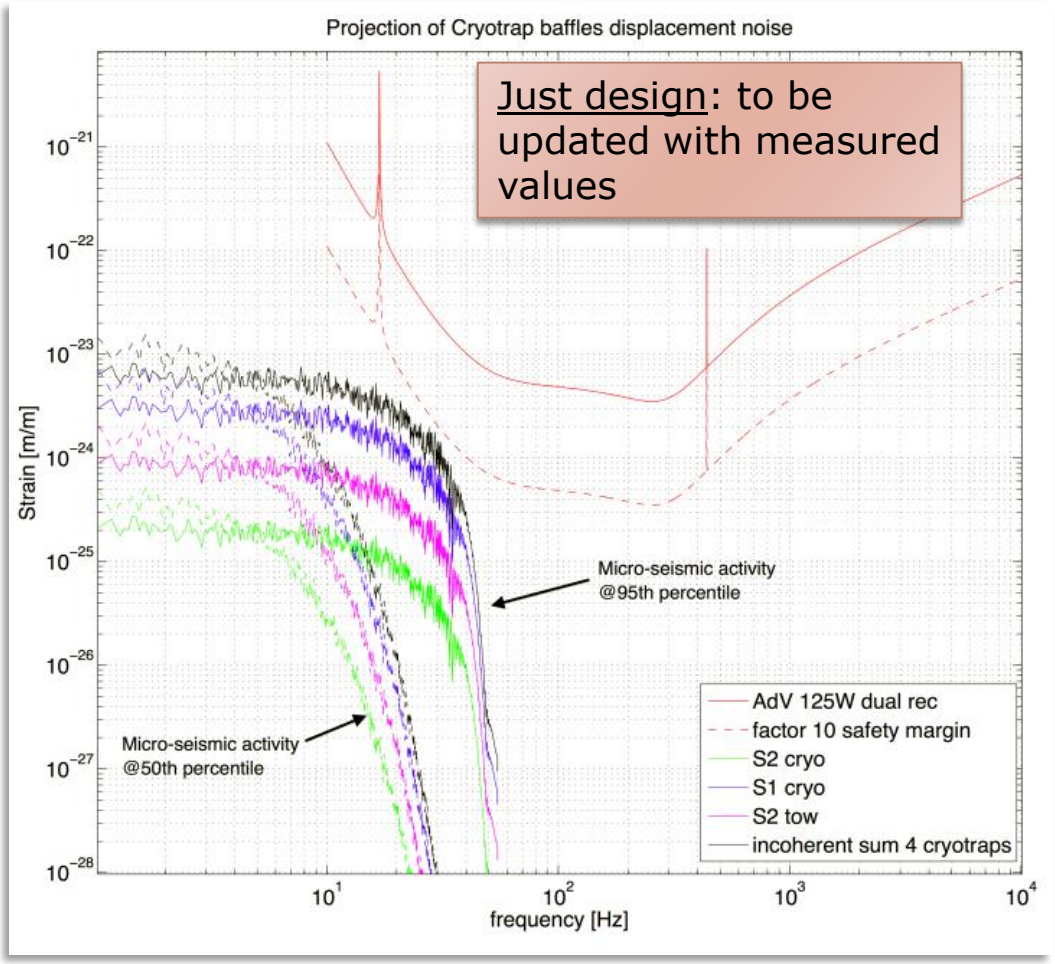
❑ Simulations with:
- FFT / BRDF for the coupling,
- Optickle for TFs
- Baffle displacement *caused by micro-seism*

❑ Overall expected noise *ok* even for <u>severe</u> seismic conditions

Table 1: BRDFs of baffles for cryotrap

Baffle surface	BRDF [sr^{-1}]	Coupl [W/W]
S2 Baf_Cryo	3×10^{-2}	$1.5\ 10^{-27}$
S1 Baf_Cryo	3×10^{-3}	$3\ 10^{-25}$
S_{Cyl}	$\sim 10^{-2}$	$\sim 10^{-26}$
S2 Baf_Tow	3×10^{-3}	$2.6\ 10^{-26}$

Parameters used for the simulations (actual ones *turned out to be better*)



Requirements: small angle scattering

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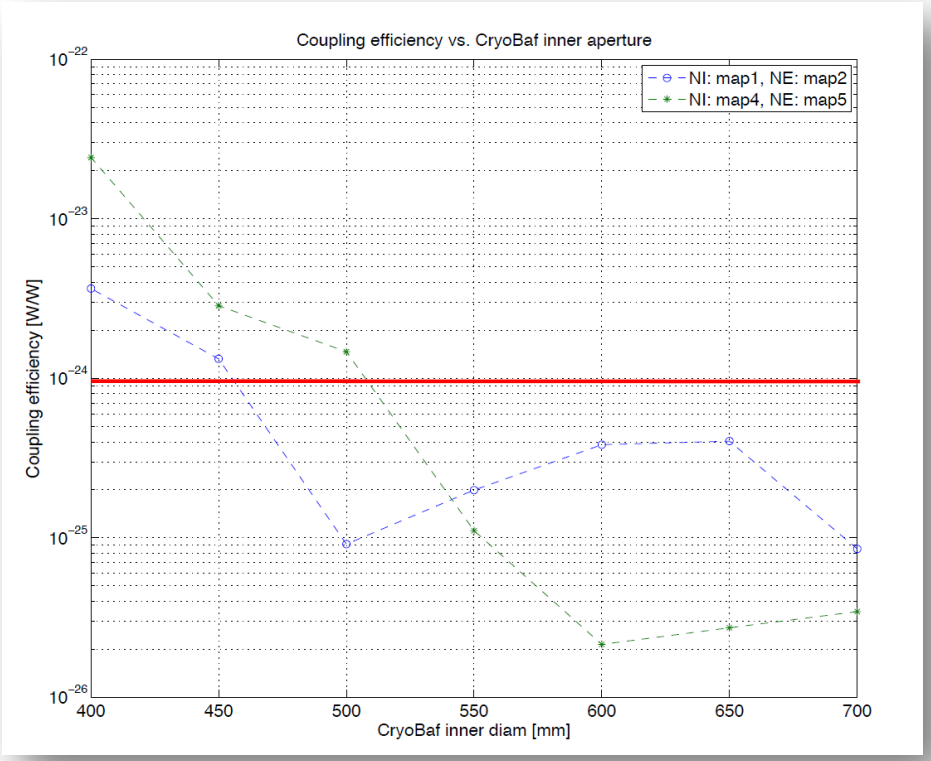
- Border between inner diam of cryo baffle and outer diam of payload baffles



VIR-0417B-13

Figure 4: Coupling efficiency of light scattered off the Baf_Cryo versus its inner diameter. The red line marks the value $10^{-24} W/W$ that corresponds to the safety margin of 10. All of the results are obtained with $BRDF = 3\ 10^{-3}\ sr^{-1}$.

Requirements: LIDT

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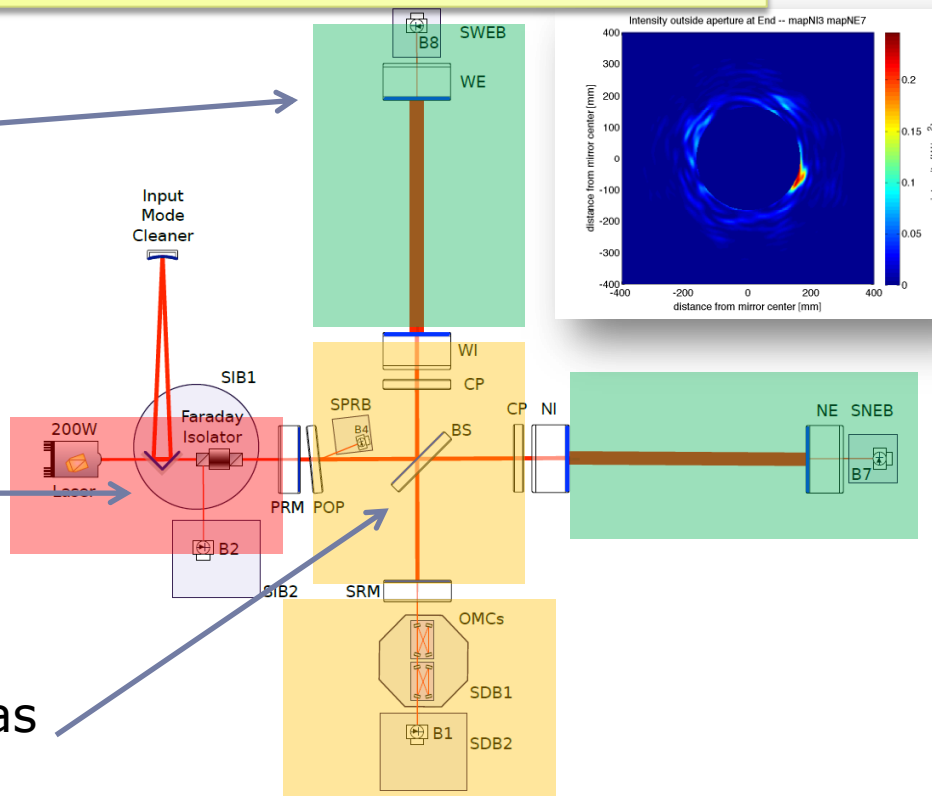
How to design new baffles /accept existing ones?

2) Material also according to maximum expected intensity

- Arm cavity safest place (!), (build-up only occurs when main beam does not hit baffles)
- INJ side most demanding (I~1kW/cm2 – 0.1kW/cm2)
  - CITF has beam parking areas (I~0.1W/cm2)



Design and Materials

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- Some materials were short-listed for validation:

- Choice based on past generation experience

- Main features tested:
  - Absorption
  - in-vacuum LIDT
  - TIS
  - UHV compatibility
  - ...

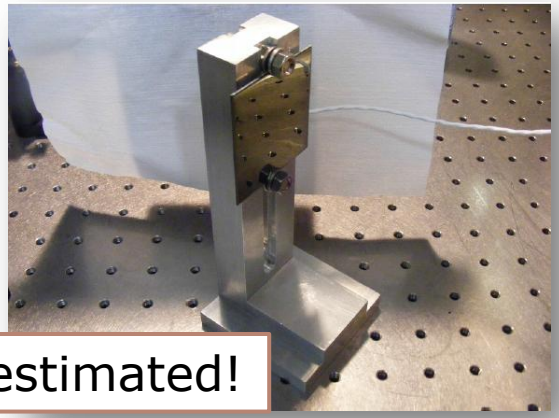
- ***Cost*** was also a key parameter!
- ... And ease of machining/installation too

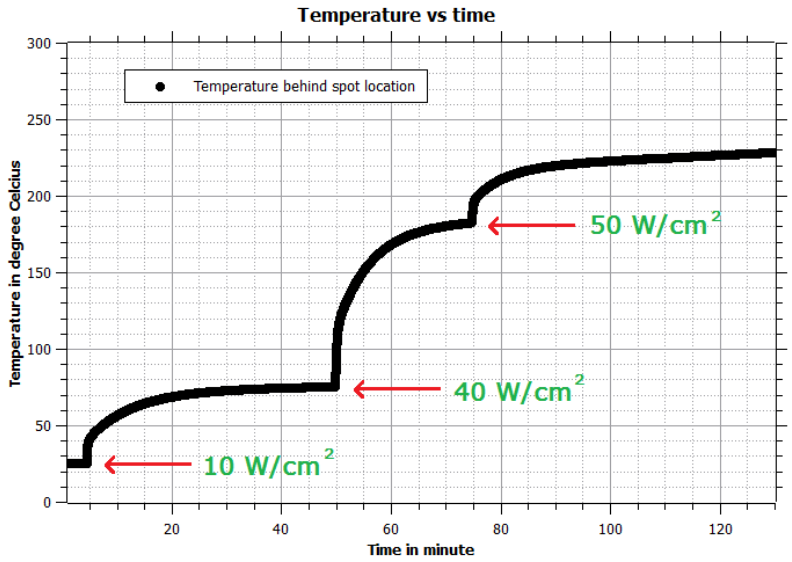
Design and Materials

EGO - VIRGO

- Some materials were short-listed for validation:

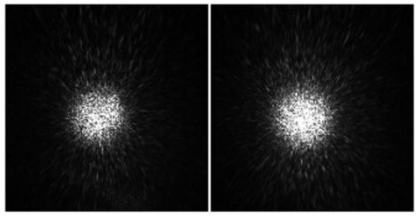
AR-on-steel characterization





!Likely underestimated!

Material	LIDT	TIS
SiC + AR	30kW/cm2	~20-50ppm
DLC + AR	500W/cm2	~500-1000ppm
AR-on-steel	>50W/cm2	~300-500ppm
Absorbing glass	~1W/cm2 (???)	~100ppm



[G. Pillant, V. Bavigadda]

Design and Materials

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SiC + AR	30kW/cm2	~20-50ppm
DLC + AR	500W/cm2	~500-1000ppm
AR-on-steel	>50W/cm2	~300-500ppm
Abs. Glass + AR	~1W/cm2 (???)	~100ppm

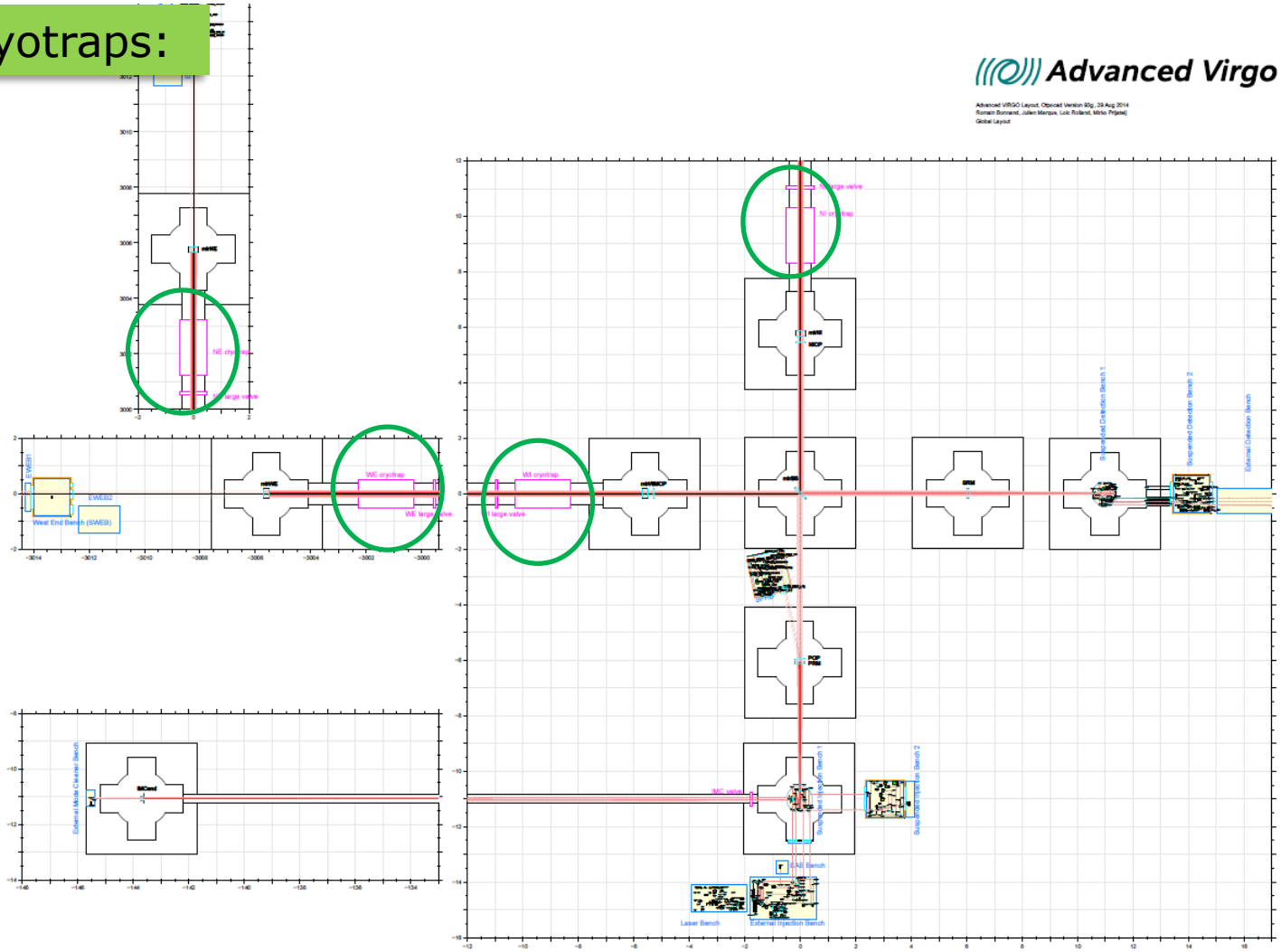
Cost increase

Selection of material driven by:

- location-dependent requirements
- validation of solution
- trade-off with budget needs

Construction Highlights

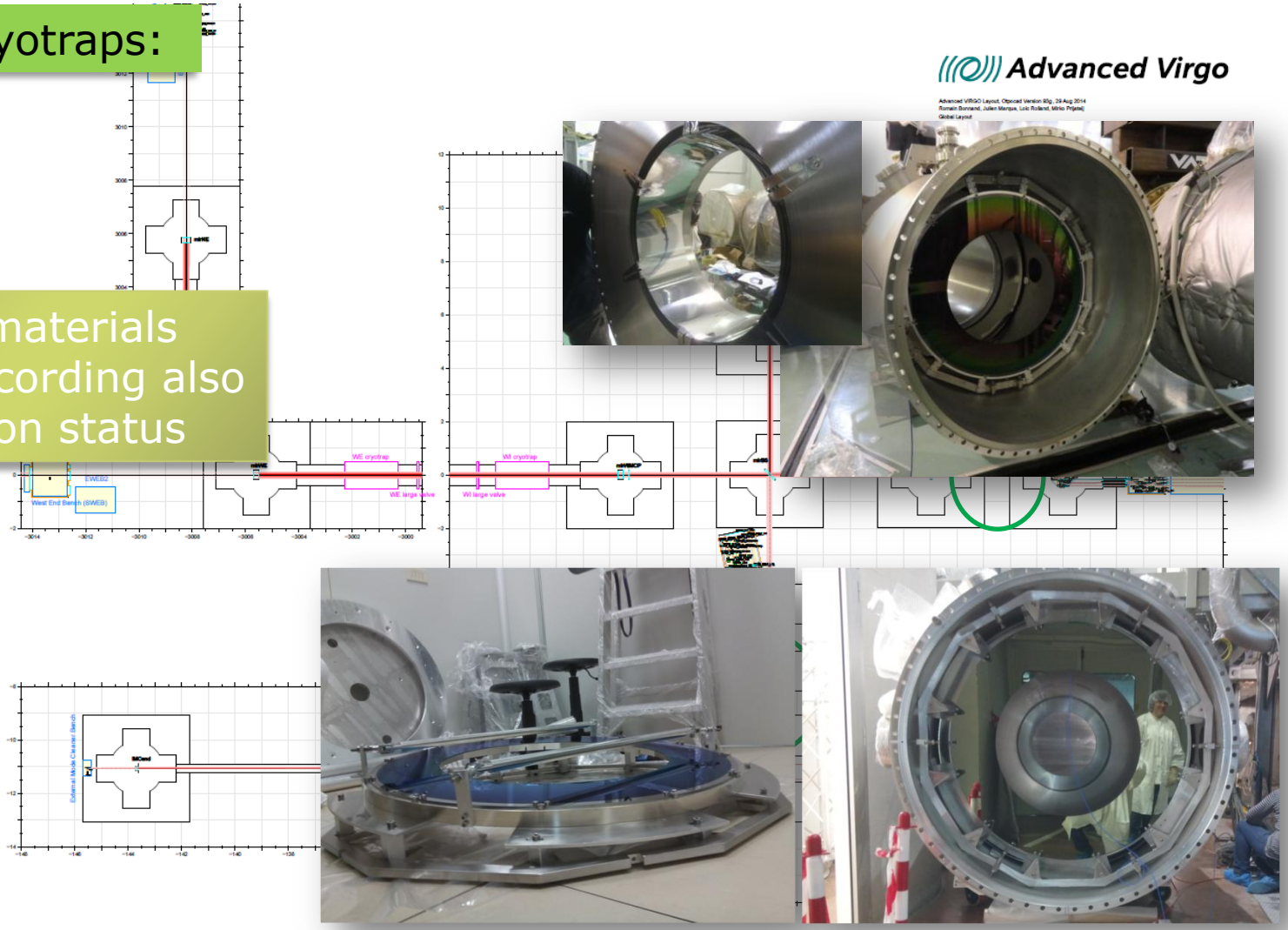
- Arm cryotraps:



Construction Highlights

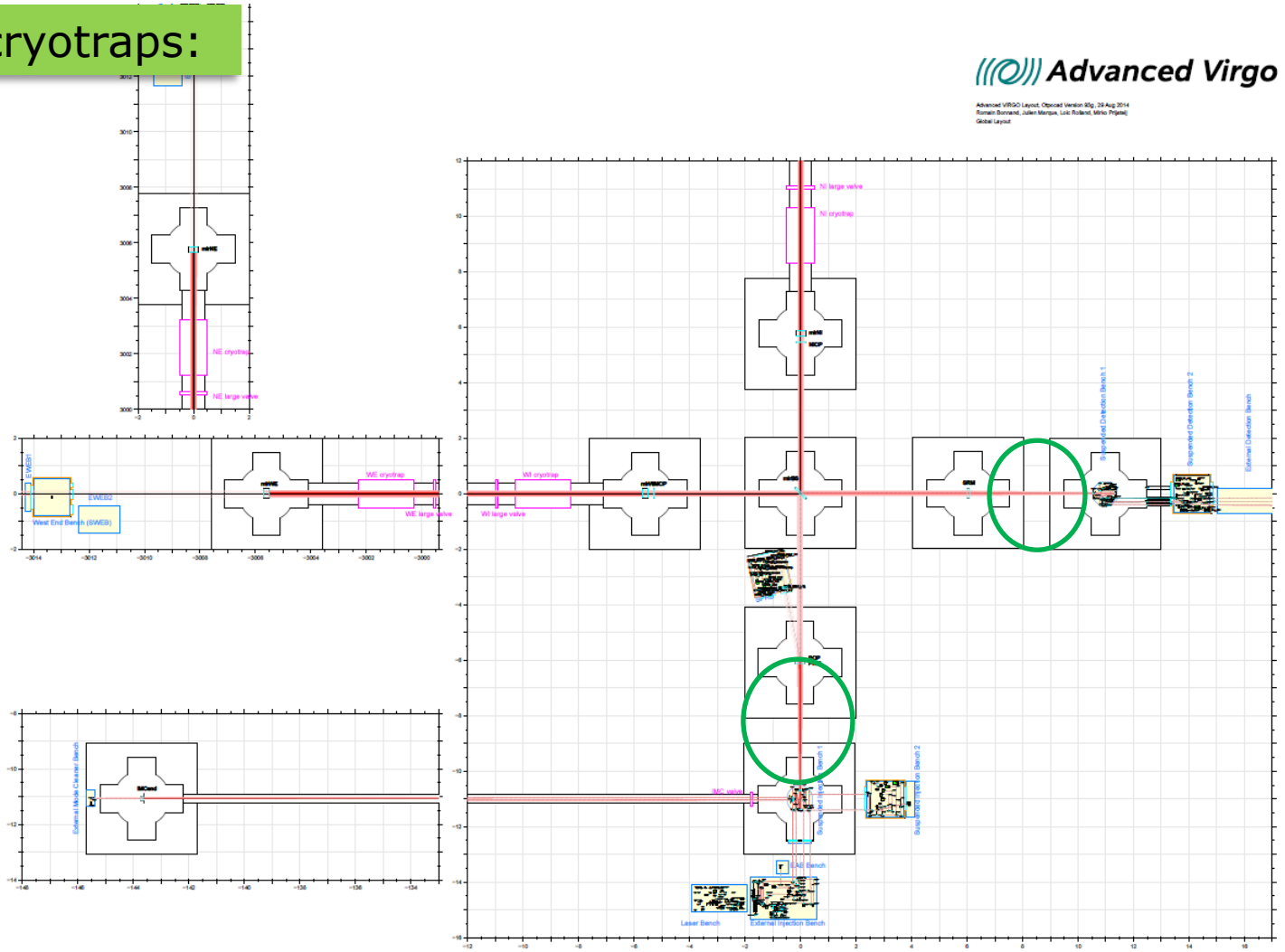
- Arm cryotraps:

Different materials chosen according also to validation status



Construction Highlights

- Small cryotraps:

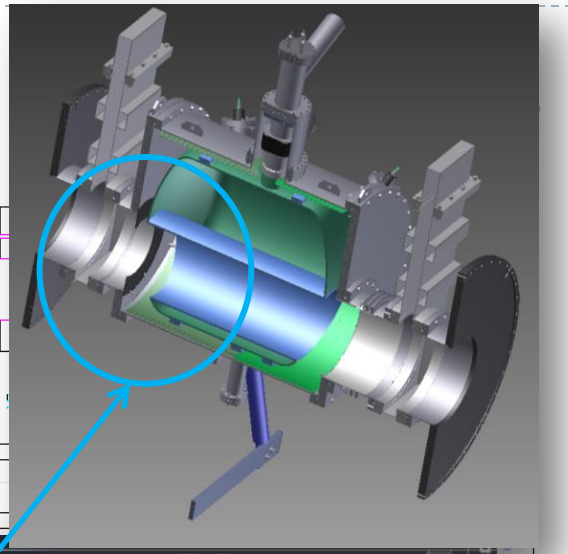


Construction Highlights

- Small cryotraps:

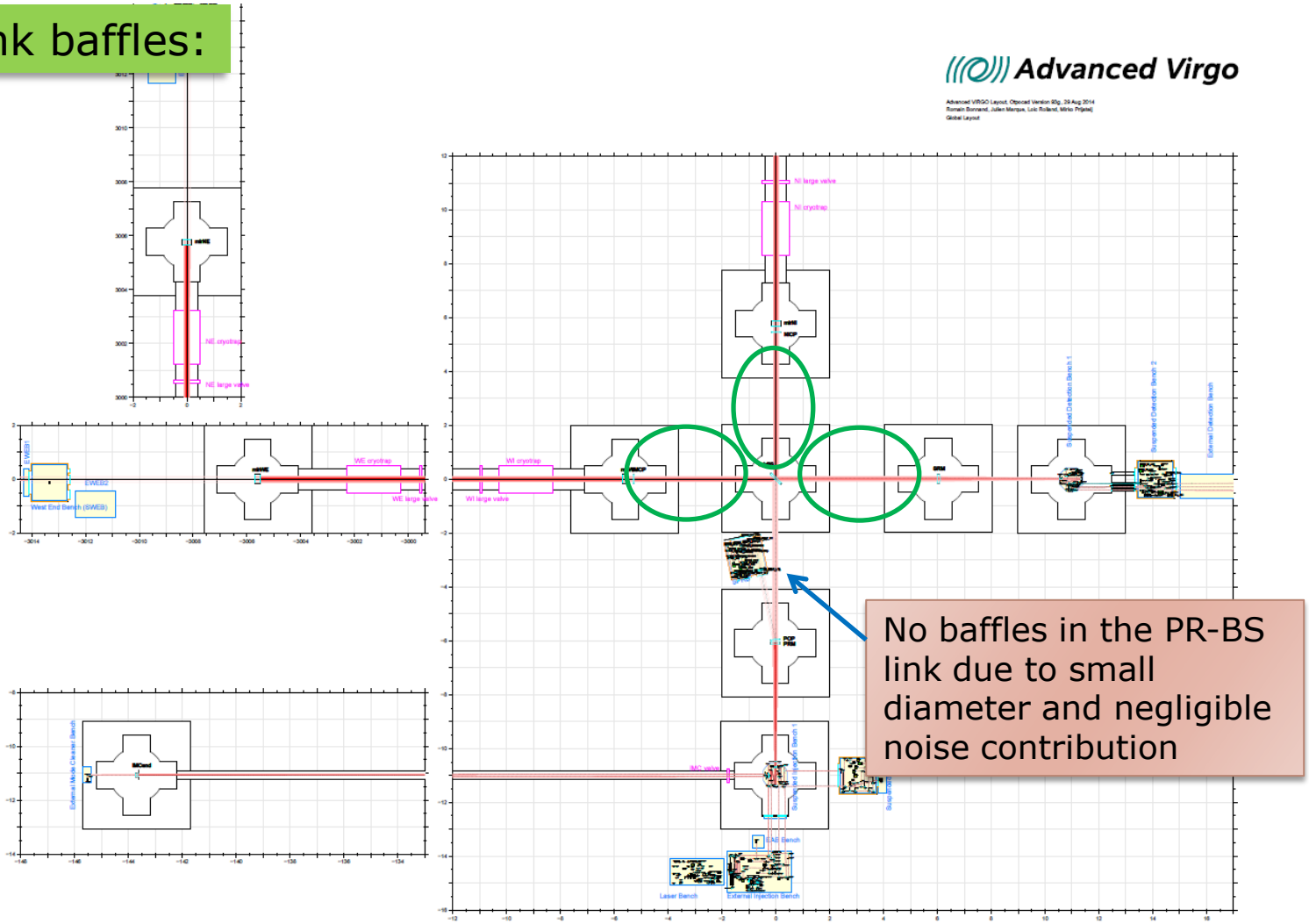
- DET baffle to handle lower intensity: *AR-on-steel* coating

- INJ baffle needs *DLC+AR* because of larger intensities



Construction Highlights

- CITF link baffles:



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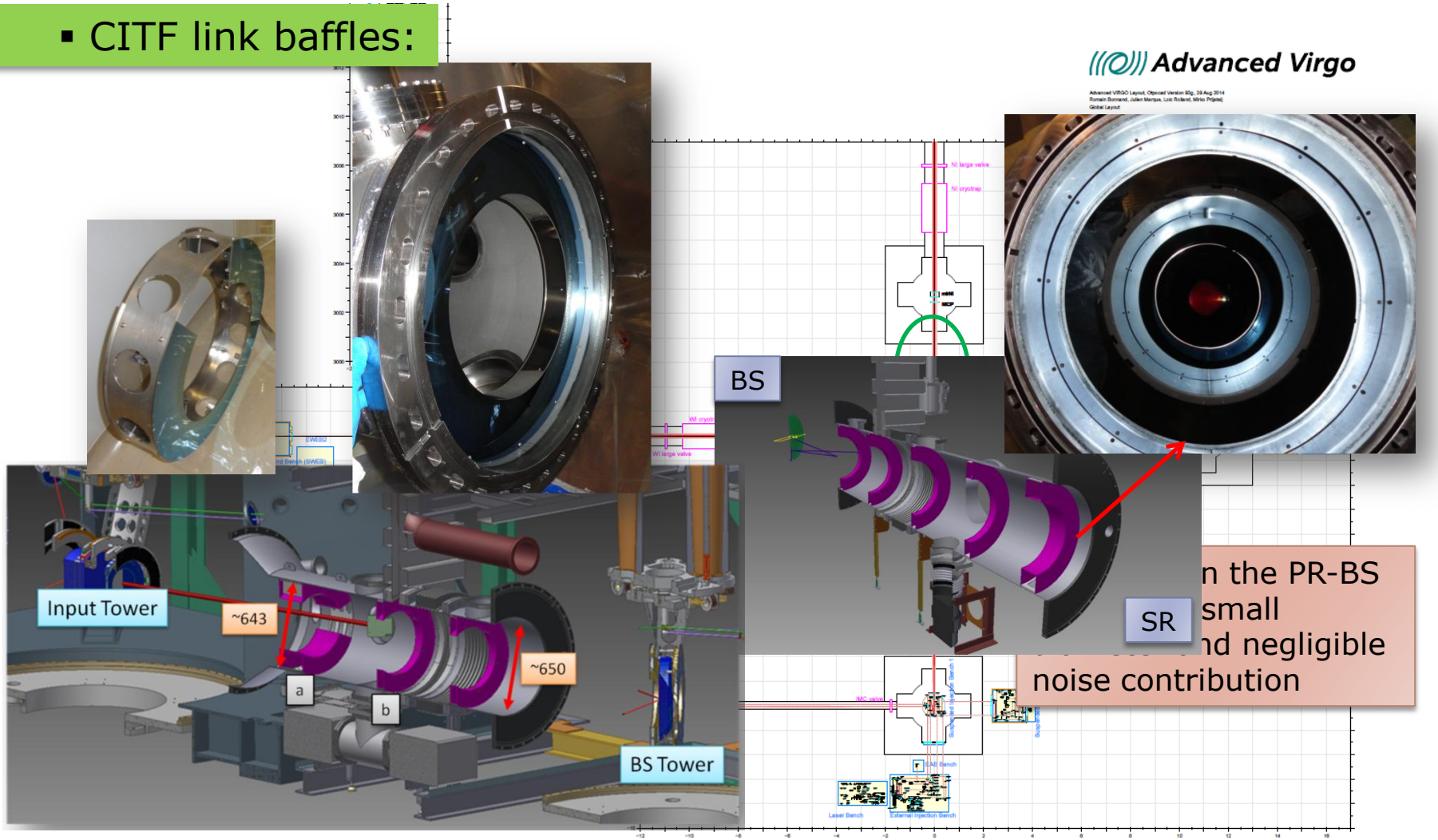
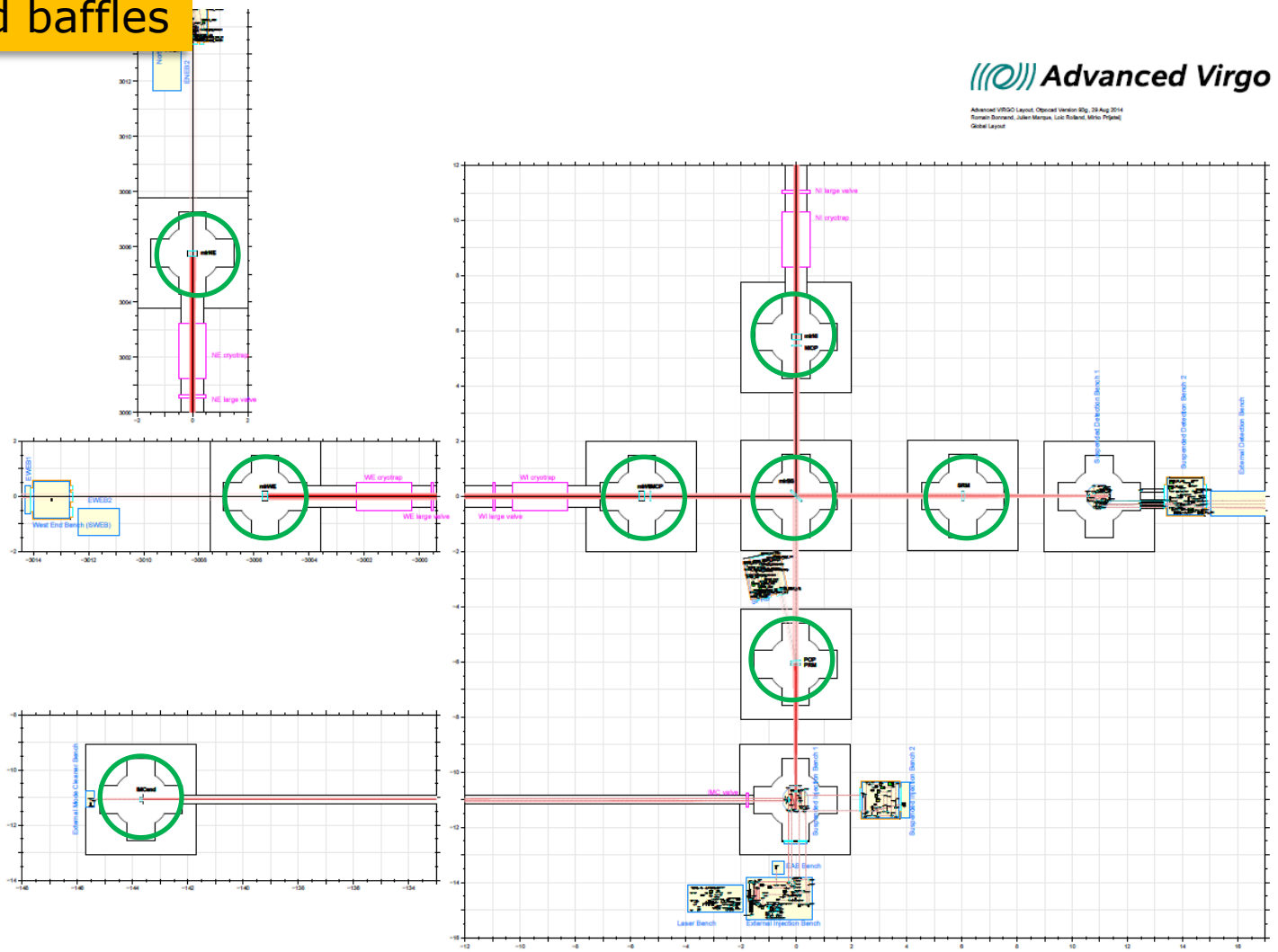


Construction Highlights

- Payload baffles



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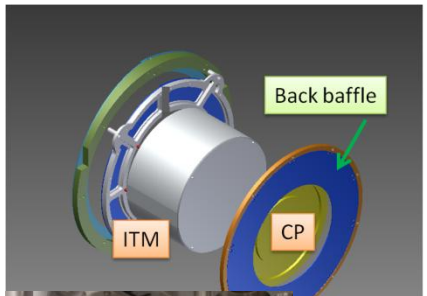
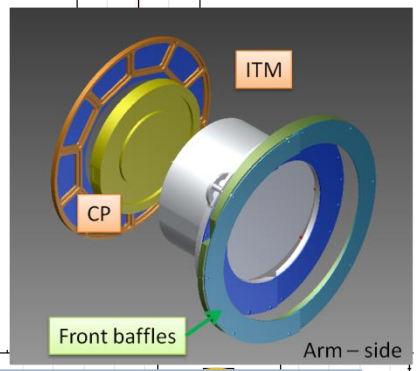
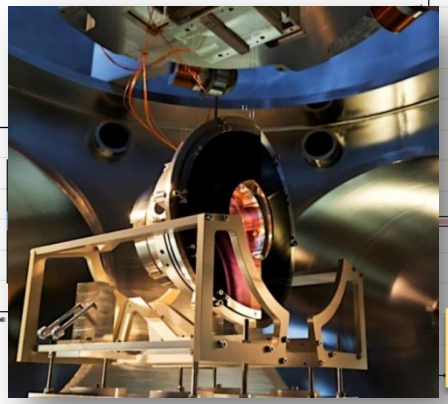




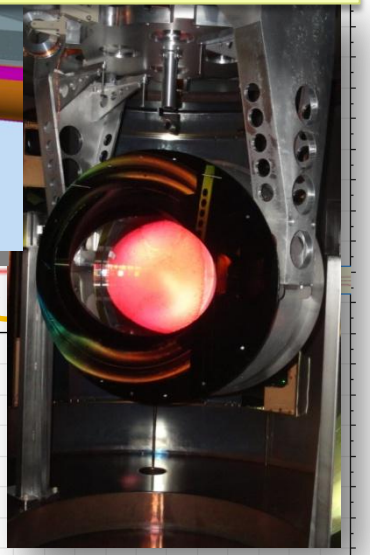
TM Payload baffles



IMC Payload baffles

Advanced Virgo

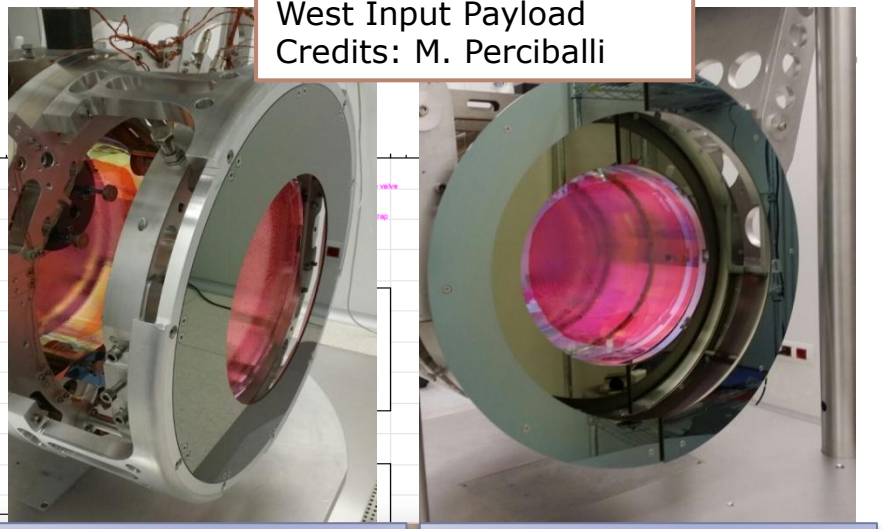
BS Payload baffles



Construction Highlights

- Payload baffles

• Integration with several subsystems (PAY, TCS, Local Controls,...)

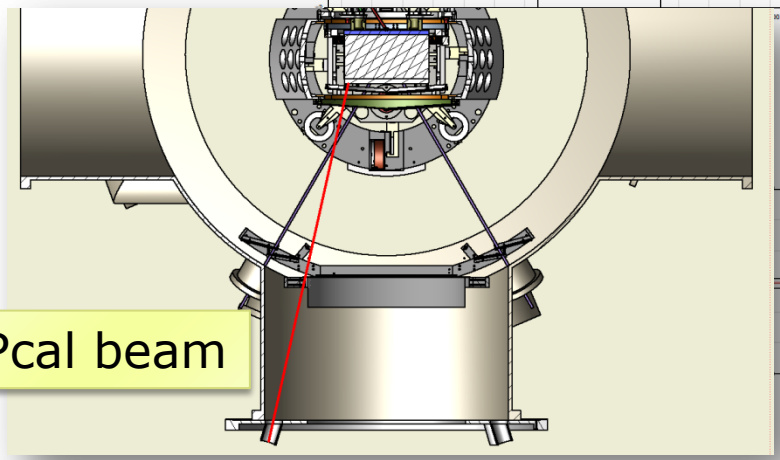


West Input Payload
Credits: M. Perciballi

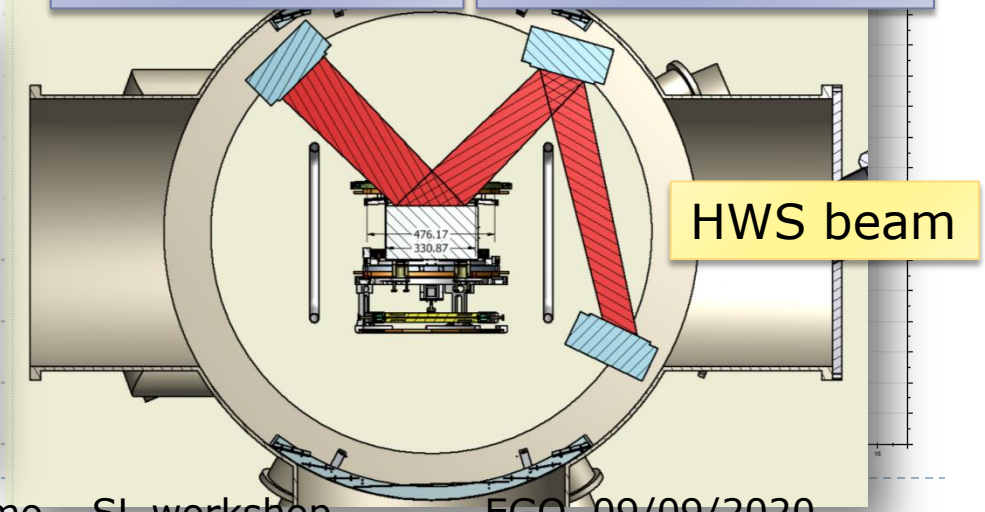
Back baffle (facing BS)

Front baffles (facing arm)

TM Payload baffles



Pcal beam

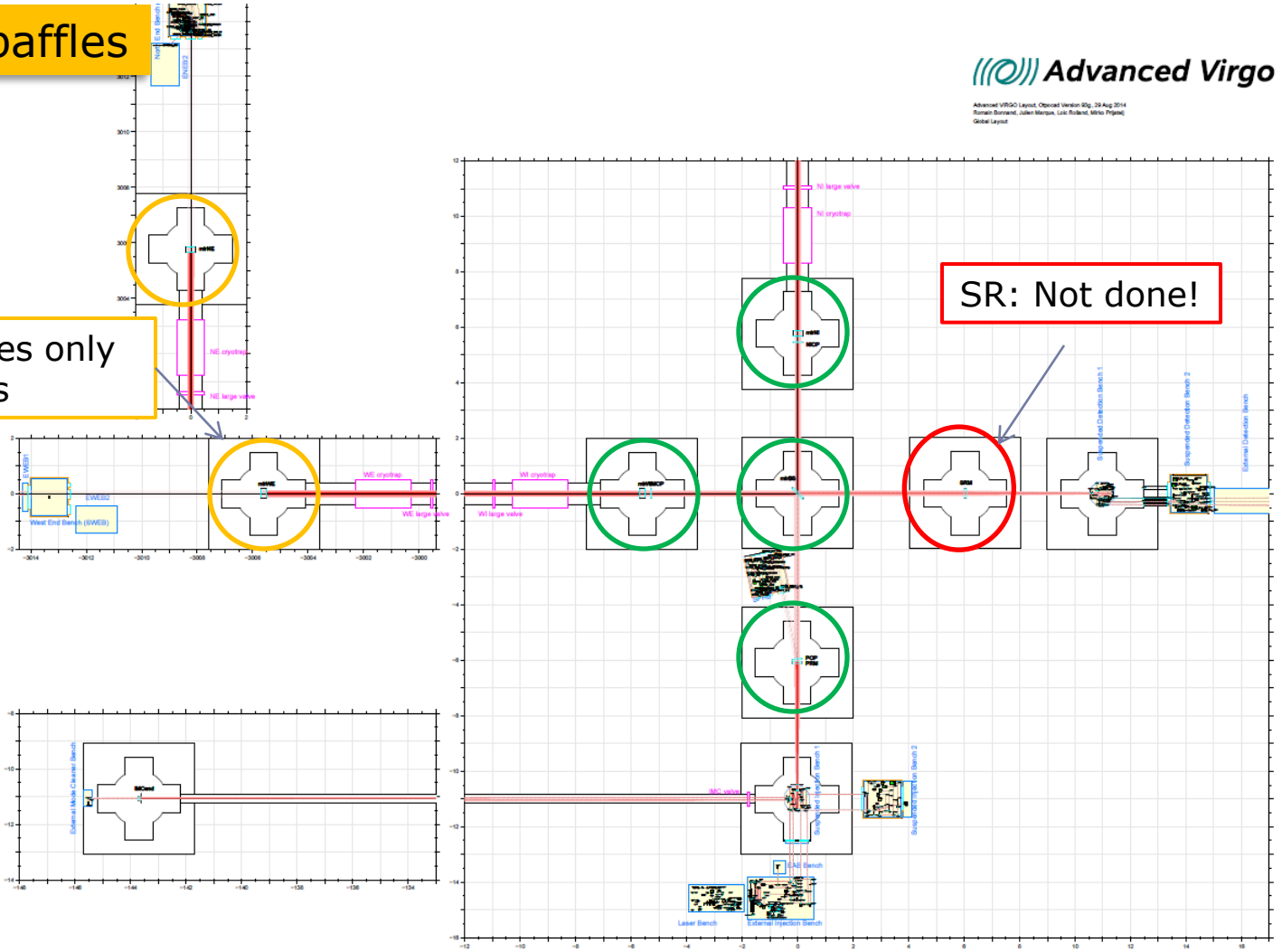


HWS beam

Construction Highlights

- Tower baffles

ETM: Tower baffles only towards the arms

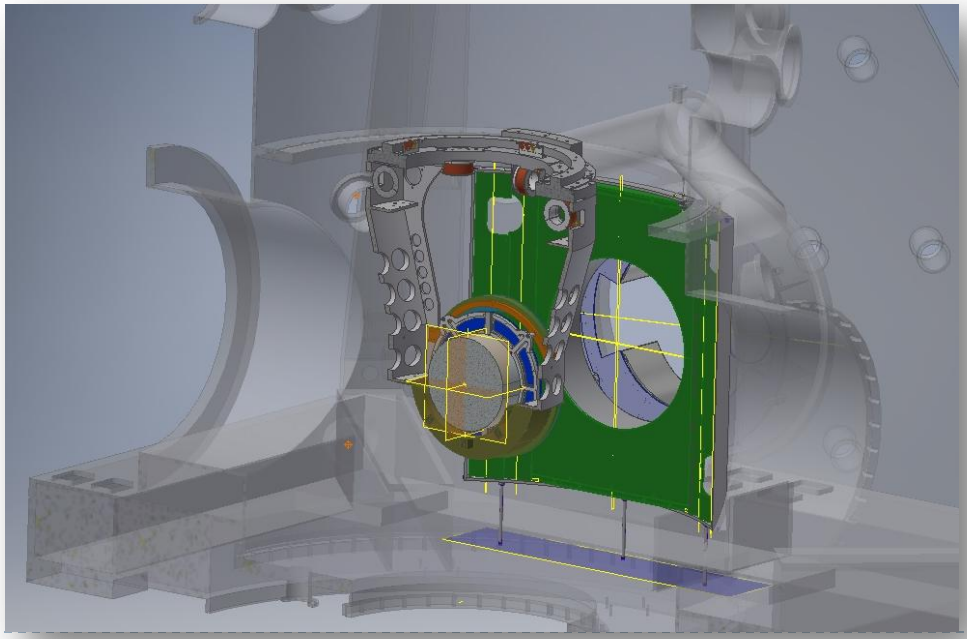


Construction Highlights

EGO - VIRGO

- Tower baffles in a nutshell:

- Needed to hide tower walls from core optics view
- Were in Virgo+ as well, but shape needed to fit new beam geometry
- Previous baffles made of AR-coated athermal glass: *this material meets AdV requirements for new tower baffles,* but *difficult to re-machine*
- AR-on-steel solution *meets AdV requirements as well -> preferred for robustness, availability*



Technical design by A.Moggi (INFN-Pisa),
R.Ceresto, F.Bragazzi (INFN-Genova)

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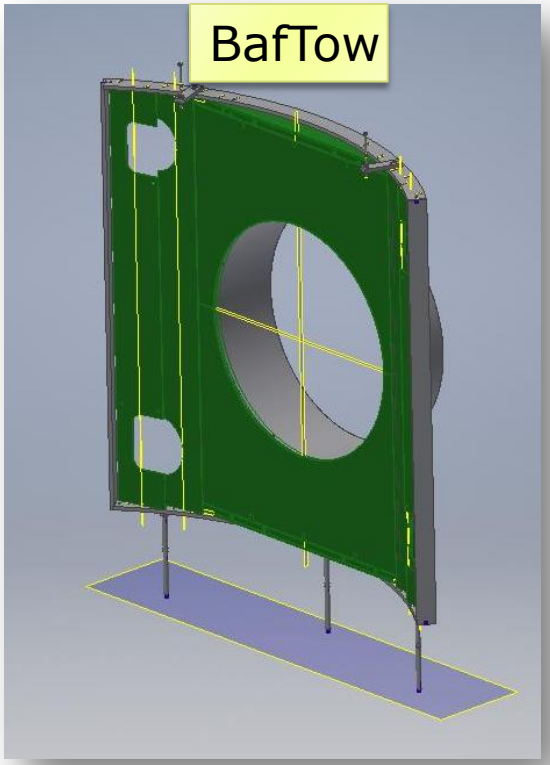

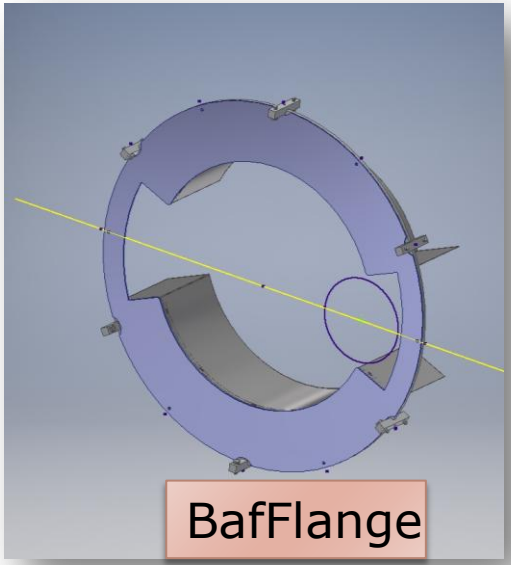

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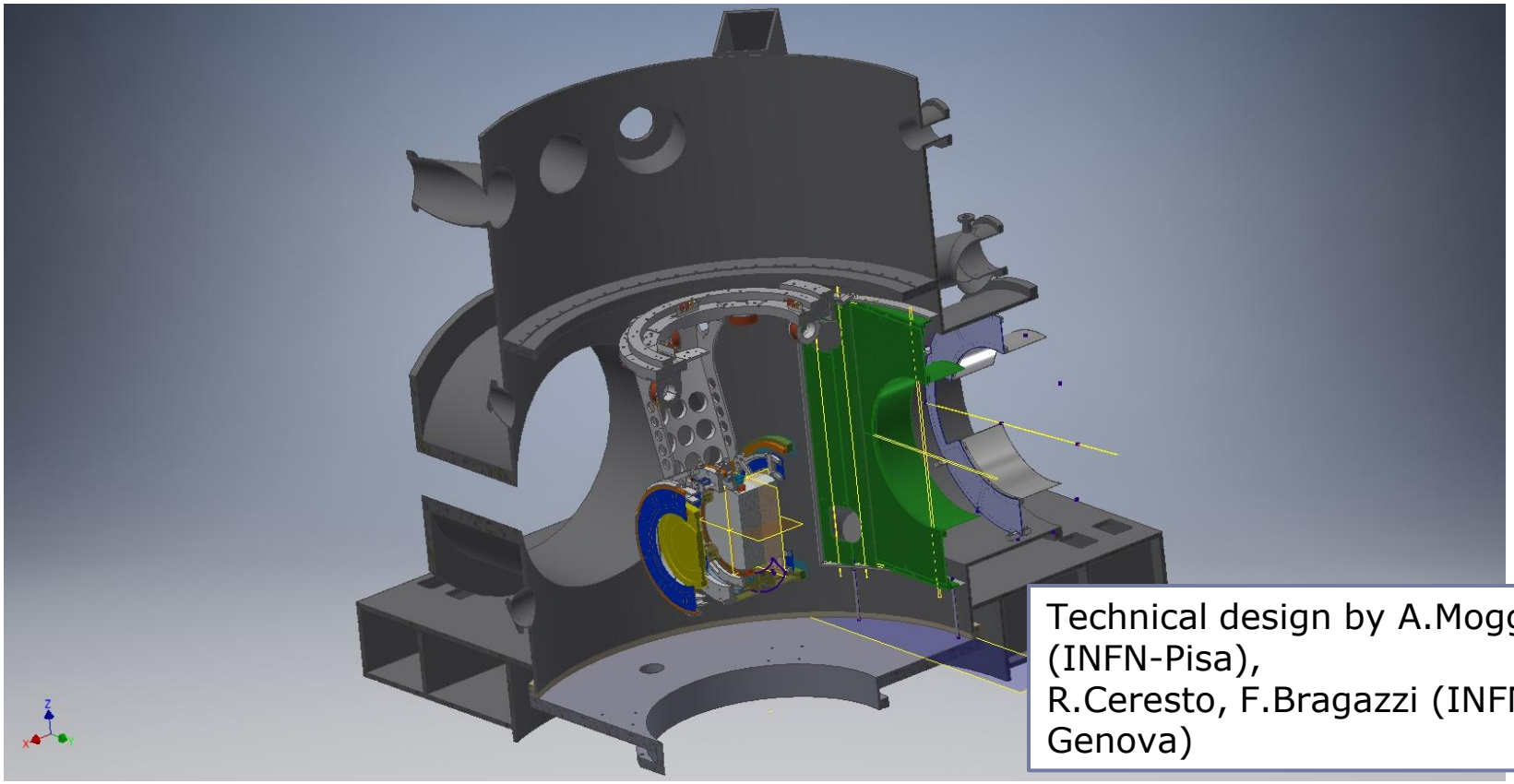


Technical design by A.Moggi (INFN-Pisa), R.Ceresto, F.Bragazzi (INFN-Genova)

Baffle internal modes measurement

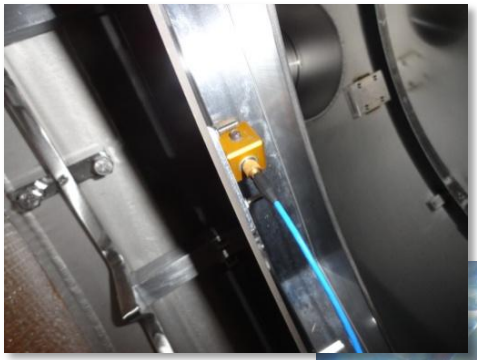
EGO - VIRGO

❑ Inner vibration modes have been measured for sample baffles both to diagnose the mechanical clamping of the assembly and to build a database of the resonance frequencies (to speed up the noise hunting phase).

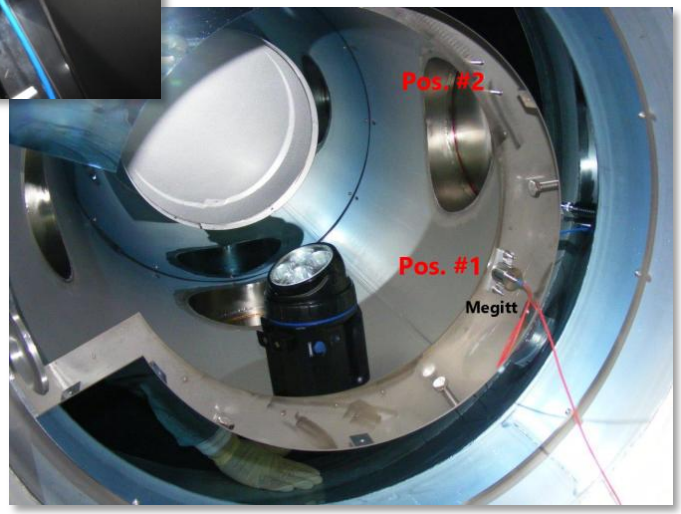
[M. Mantovani, I. Fiori]

Procedure:
The baffle resonant modes are measured:

1. by attaching a very high sensitive accelerometer (1pm/sqrt(Hz) @ 100 Hz) on the rear face of the baffle and measuring the displacement spectrum
2. by exciting the baffle with an impulsive excitation and measuring the ring down.



Measuring ring-down for CITF link baffle



Outcome in VIR-0147A-16

Summary

EGO - VIRGO

- SLC for AdV started late wrt other important subsystems, had to adapt to existing design
- Chronical shortage of manpower, especially because very few people committed to this SS as main task

- Developed full simulations for small-angle scattering
- Developed AR-on-steel coating to realize cost-effective baffles
- Baffles were designed, built and installed for:
  - Arm cryotraps
  - Core mirror payloads
  - NI-BS, WI-BS, SR-BS central links
  - BS, NI, WI, towers (all ITF ports)
  - NE, WE, PR, DET, IB towers (ports towards ITF)
  - IB-PR, DET-SR small cryotraps
    - *Not done for SR tower, terminal ports of terminal towers*

➢As-built documentation still poorly accessible, will be shared soon

Some references

EGO - VIRGO

- Requirements and calculations:
https://tds.virgo-gw.eu/ql/?c=9002
https://tds.virgo-gw.eu/ql/?c=9771

https://tds.virgo-gw.eu/ql/?c=9809

https://tds.virgo-gw.eu/ql/?c=9398

- Characterization of materials and noise projections:
https://tds.virgo-gw.eu/ql/?c=9283
https://tds.virgo-gw.eu/ql/?c=9472
https://tds.virgo-gw.eu/ql/?c=10539
https://tds.virgo-gw.eu/ql/?c=11308

https://tds.virgo-gw.eu/ql/?c=11455
https://tds.virgo-gw.eu/ql/?c=12202

- As-built documentation:
Existing, but very poorly accessible. An effort to collect and share the 3D step files regarding the baffles will be made soon. For the time being, I can simply point to logbook query "SLC" and to my slides on TDS for virgo weeks