Scattered light noise mitigation in DET

R. Gouaty of behalf of DET sub-system (but also SBE, SLC and many others)

- What has been done during AdV installation and commissioning
- What is planned for AdV+
- What is missing

Mitigating scattered light noise

Two complementary strategies:

- Reduce the amount of scattered light:

  - High quality optical surfaces: low roughness, low scratches and digs, high quality coatings
  - Clean environment: avoid dust on the optics
  - Use of Faraday Isolators to reduce back-reflected light
  - Use diaphragms and beam dumps to absorb ghost beams (residual transmission through HR coatings and reflection on AR coatings) and scattered light → relies partly on optical simulations
  - Avoid shiny metallic surfaces as much as possible on the suspended benches and inside vacuum chambers → use of black optical mounts, tower baffling

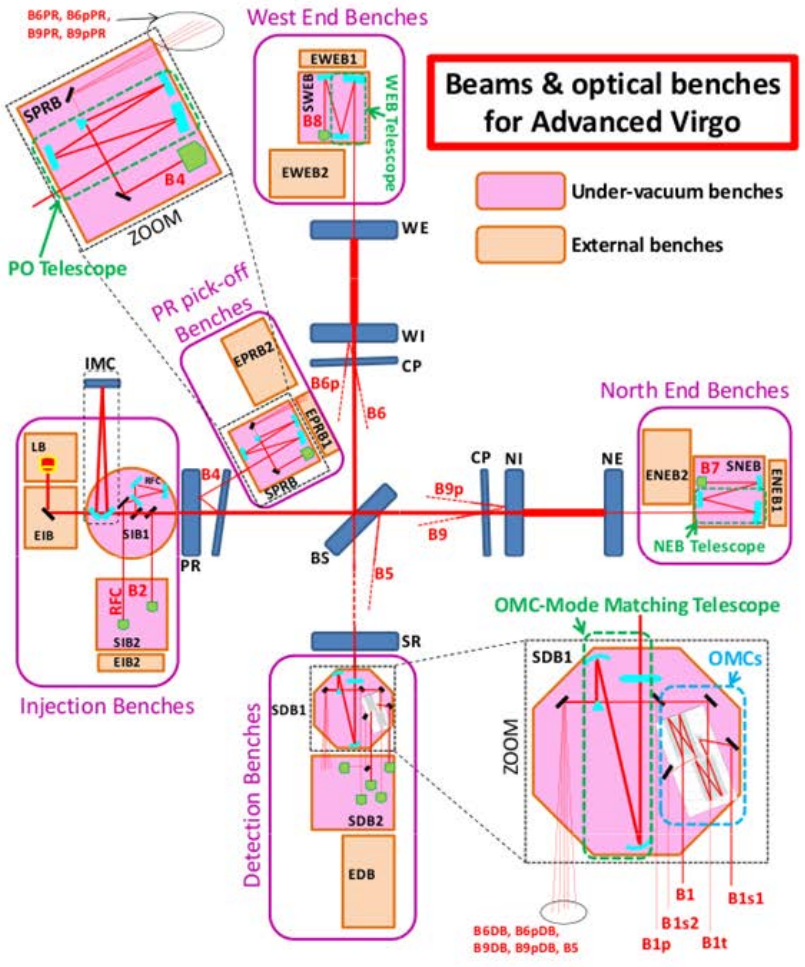
- Reduce optical elements vibrations:

  - Seismic and acoustic isolation > avoid excitation of opto-mechanical components resonances in the ITF bandwidth
  - Control of the relative position between the benches and the interferometer mirrors > reduce low frequency motion of the scattering surfaces (avoid noise upconversion)
  - Robustness of optical mounts

What has been done during Advanced Virgo installation and commissioning

Seismic and acoustic isolation of optical benches (AdV design)

- Optical benches hosting the main photodiodes (B1, B2, B4, B5, B7, B8) all suspended and placed in vacuum.



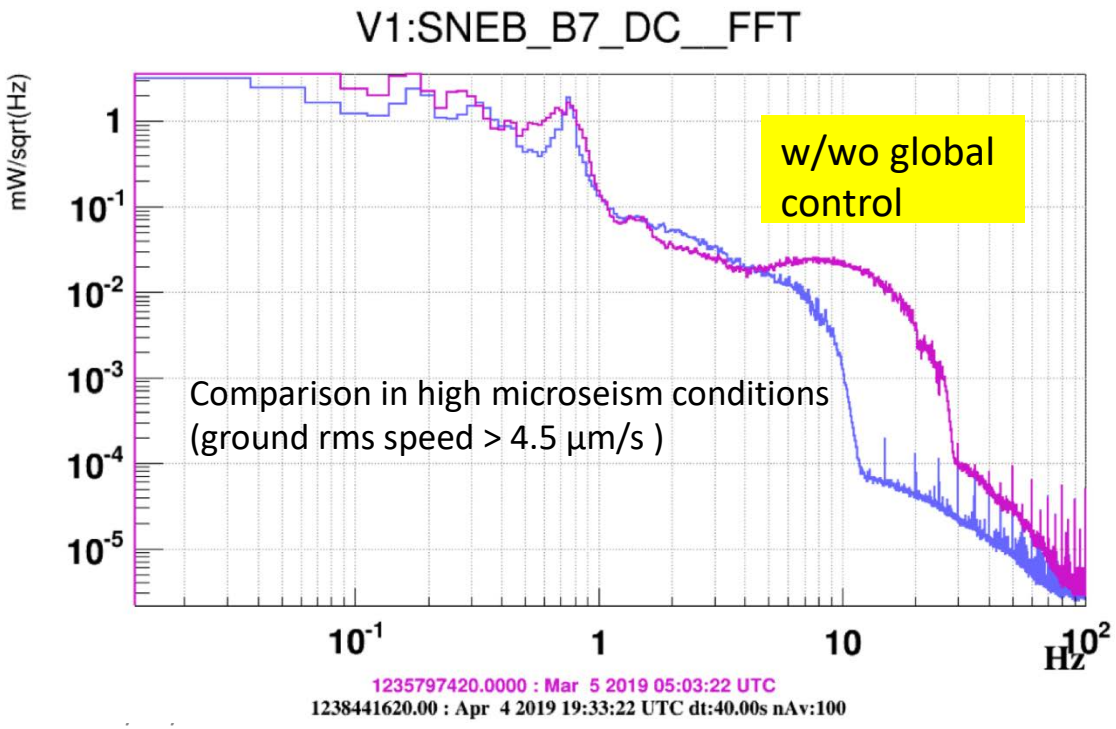
This added several constraints:

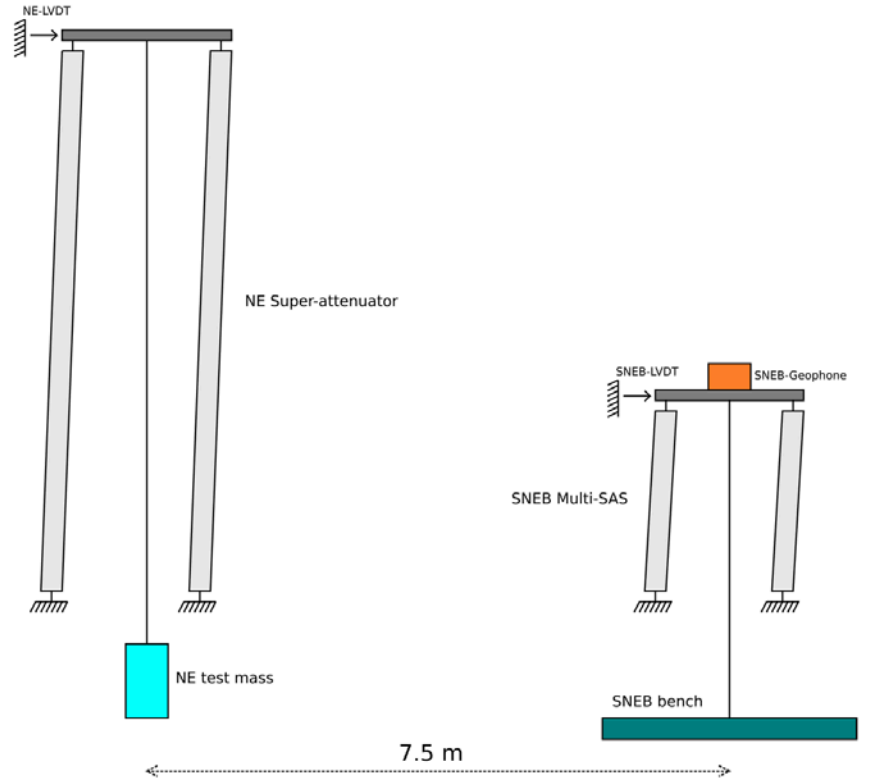
- Photodiodes and preamplifier inside air-tight boxes
- Bench with integrated electronics to avoid too many cables going through the suspension and mechanical short-circuit

Reducing bench motion at low frequency (O2-O3 commissioning)

- SDB2 tracking loop (used during O2 and O3):
  - SDB2 is tracking in Z direction (beam axis) the position of SDB1 around the micro-seismic peak
  - The error signal is the difference between SDB1_LC and SDB2_LC horizontal LVDTs

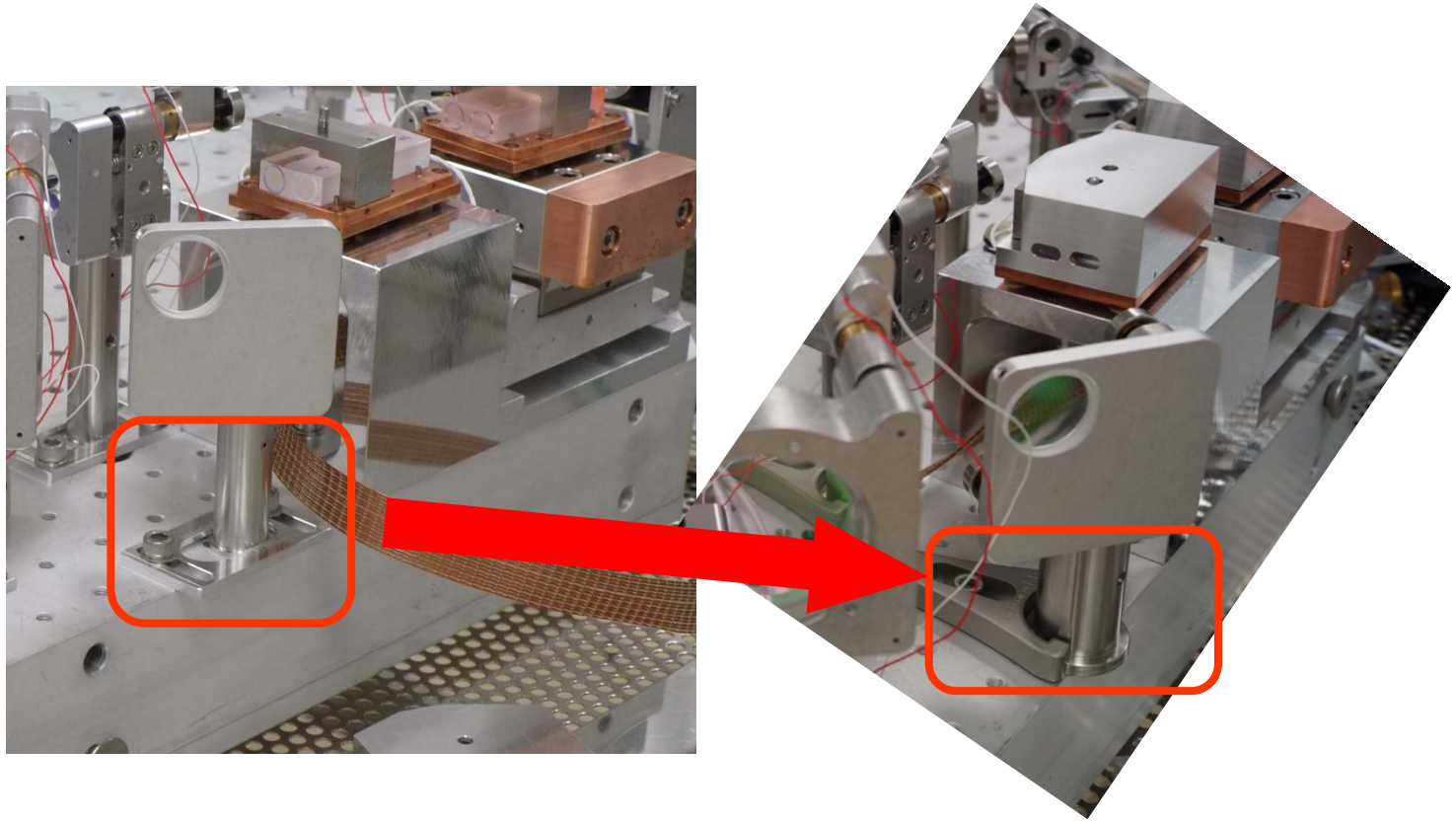
- SNEB/SWEB global control (implemented by SBE during O3):
  - Make SNEB and SWEB tracking the nearby SAT.





From VIR-0936A-19, A. Bertolini

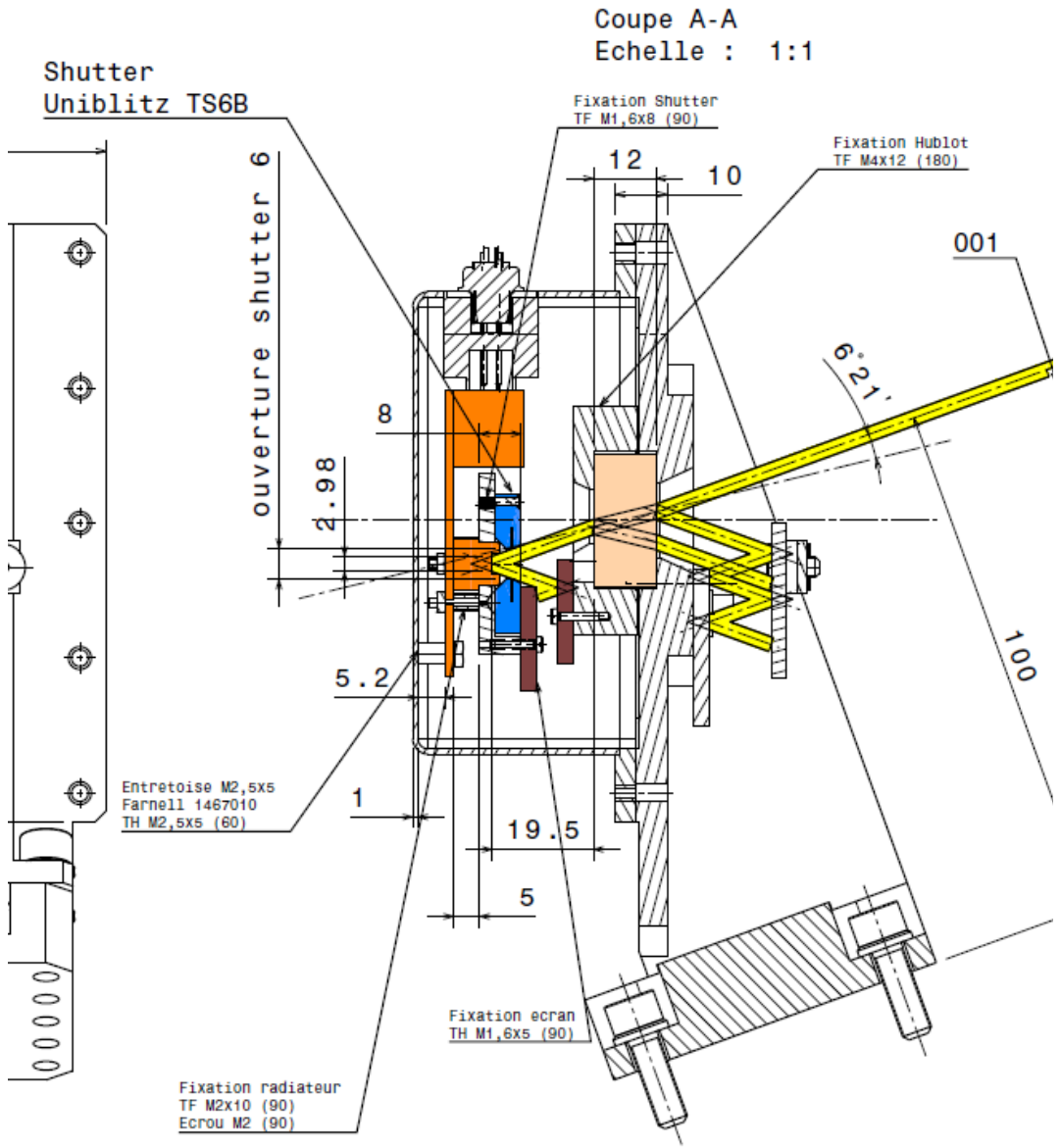
Optical mounts selection (AdV installation)



Resonance frequency measurement by **I. Fiori et al.** (**logbook 31750**):
→ Better performance of the Newport commercial post than first implemented solution: resonance frequency increased from ~200 Hz to ~275 Hz
→ All beam splitters & folding mirrors of the suspended benches were equiped with these more robust posts

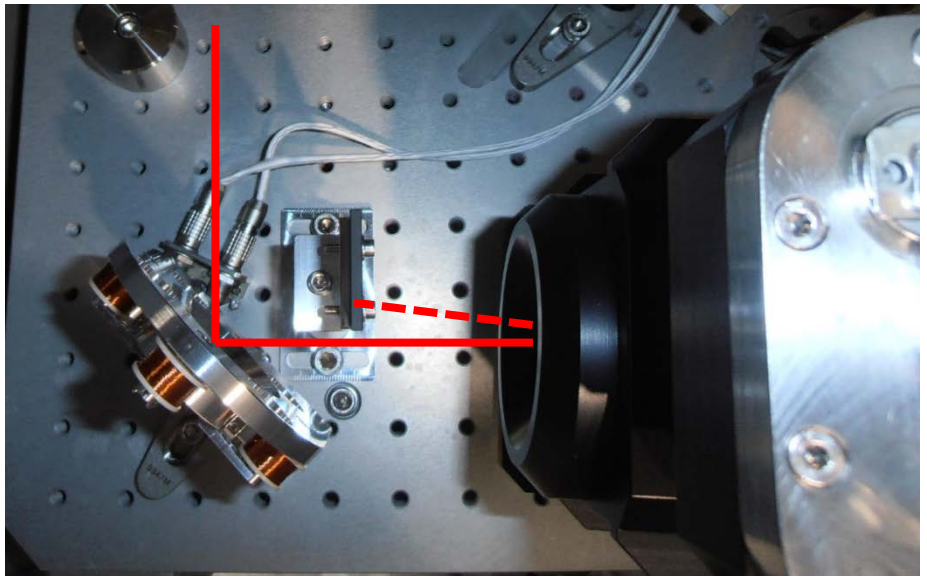
Dealing with the reflections of the photodiode air box (AdV design)

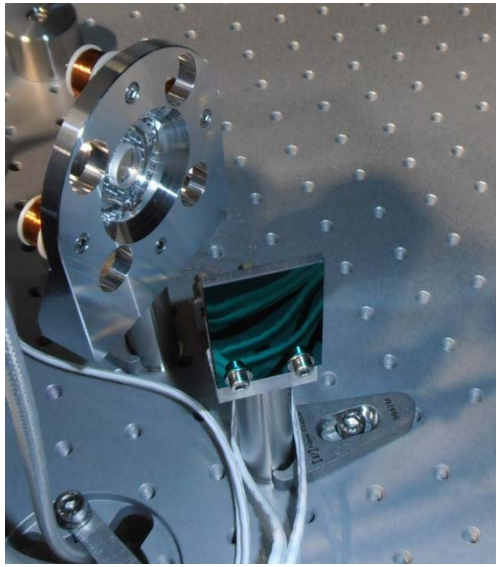
- Glass (or mirror polished steel) beam dumps integrated in the air box design:
  - Dump reflections on the viewport
  - Dump reflections on the photodiode



Dealing with the reflections of quadrant AR surface (O2 commissioning)

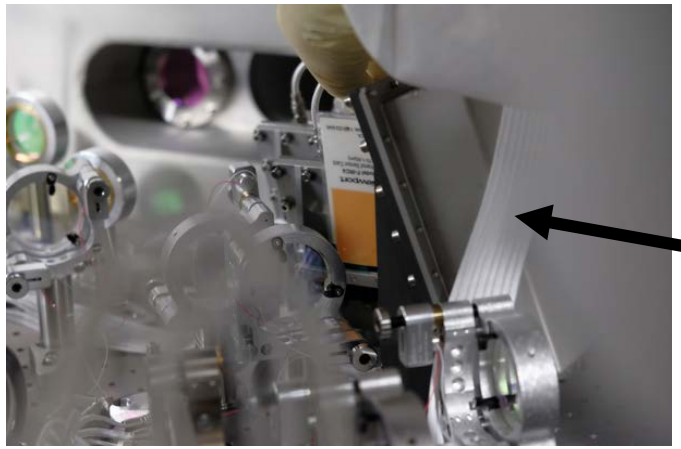
- Scattered light observed around the reflection of the B8 quadrants in February - April 2017 (logbook 36637, 37215)
- Solved by placing absorbing glass beam dumps in reflection of the quadrants (B8, B2, B1p, and more recently on B7)

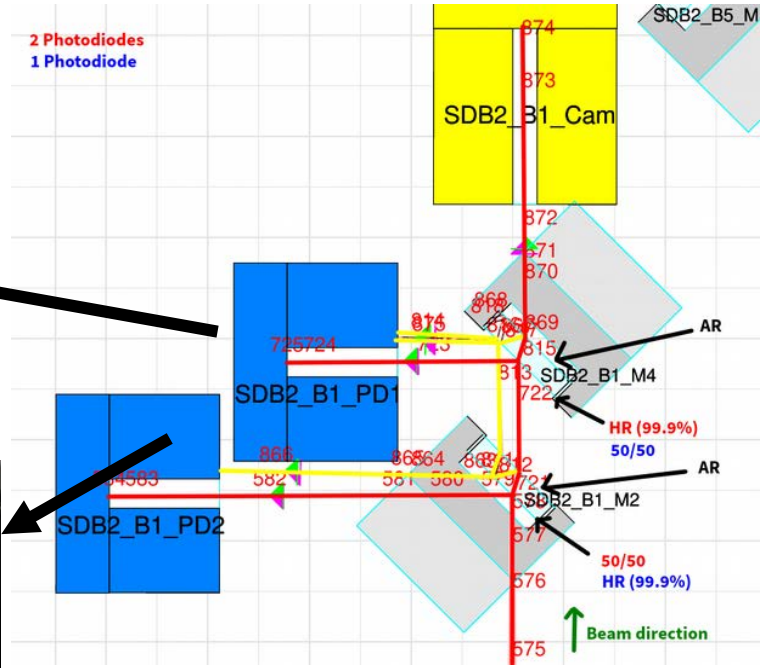


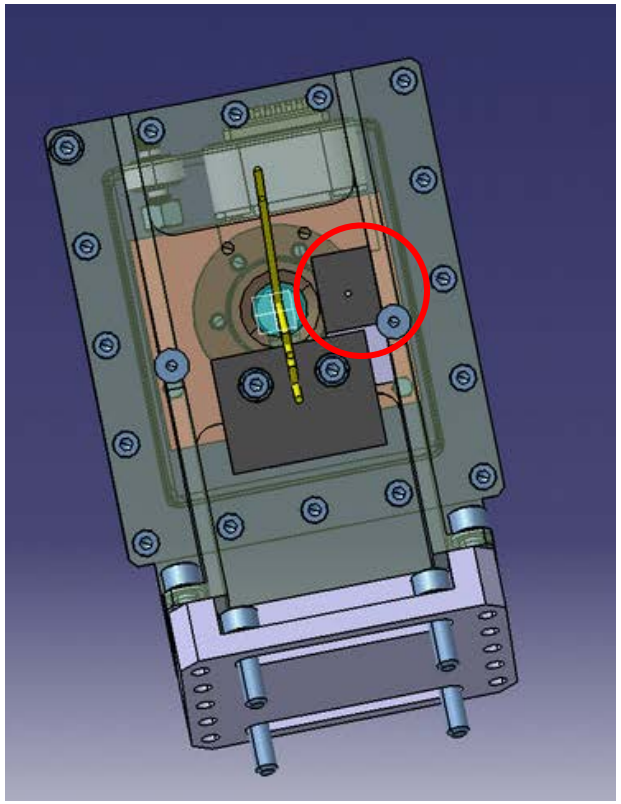


Dealing with the reflections of beam splitters AR surface (O3 commissioning) 1/2

- In Jan-Feb 2019, while investigating possible sources of « flat noise » we found ghost beams hitting the B1 photodiodes
- First we corrected the position of a mirror whose HR and AR surfaces had been swapped, leading to extra ghost beams
- The Optocad simulation allowed us to confirm the origin of the ghost beams coming from the reflexions on AR surfaces
- This was solved (only for B1) by adding an extra glass beam dump on the air box

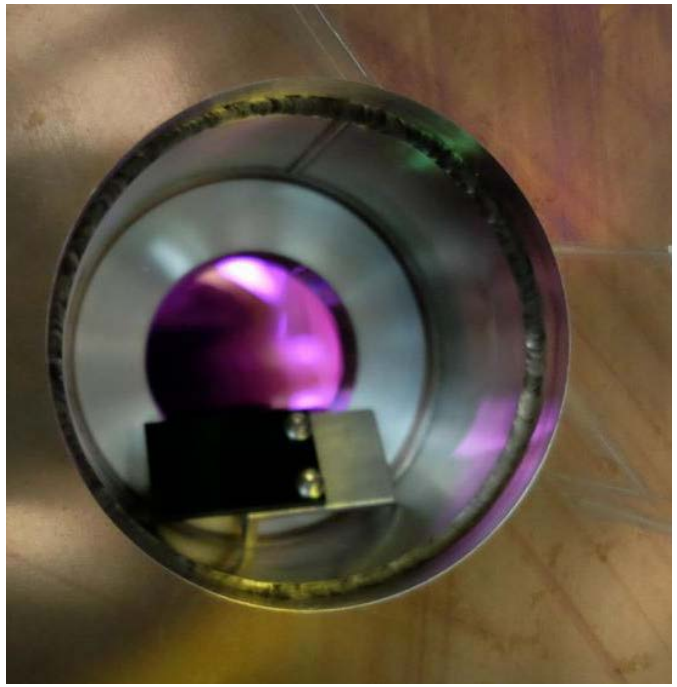




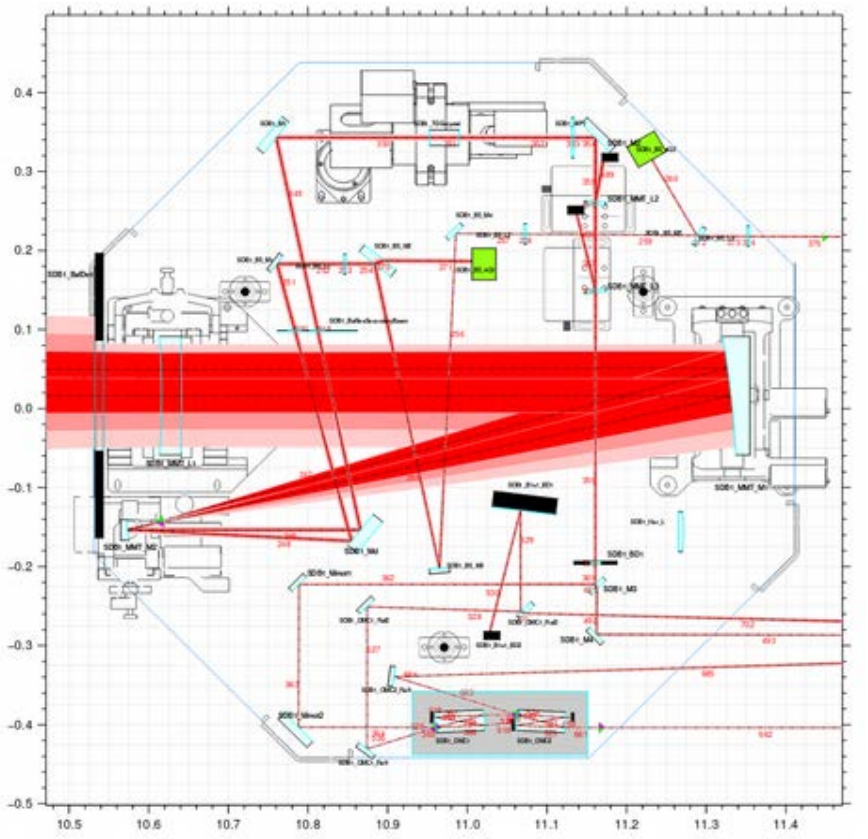


Dealing with the reflections of beam splitters AR surface (O3 commissioning) 2/2

- During SDB1 bench inspection: Found ghost beam hitting metallic ring inside B1p minilink
- Beam is residual reflection on AR surface of B1p pick-off 98.5% reflective mirror (~1uW in dark fringe)
- Absorbing glass beam dump added in front of the minilink

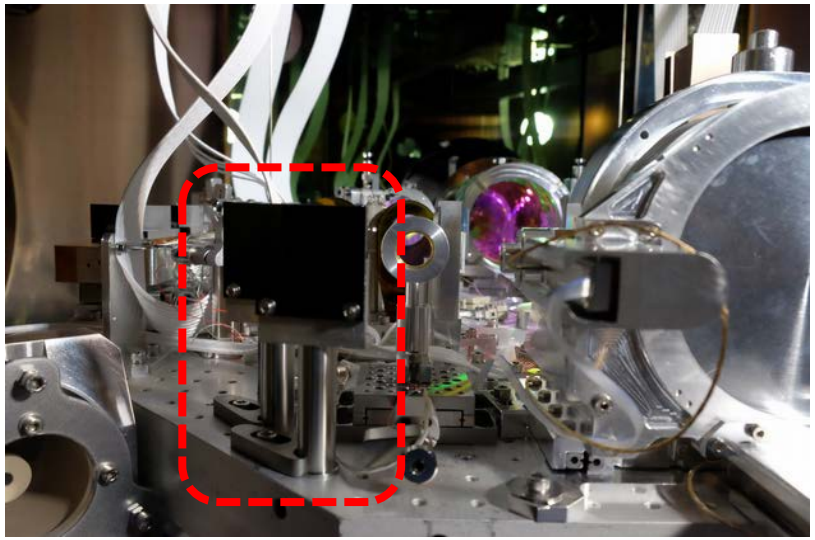


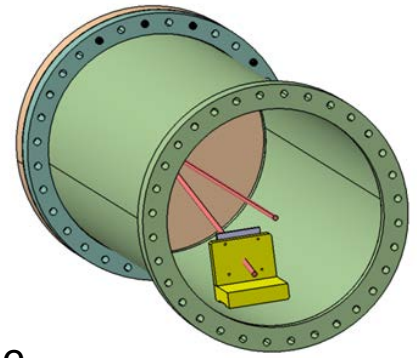
Dealing with the reflections of viewports (AdV design and O3 commissioning)



Suspended Detection Bench (SDB1)

- 5 viewports crossed by beams around SDB1 bench:
  - 4 minilinks between SDB1 and SDB2 vacuum chambers
  - 1 minilink between SDB1 and squeezing bench
- All these viewports are tilted by 5° in order to separate the residual reflections from the incident beams
- Beams dumps installed on SDB1 to dump the viewport reflections
- Beams dumps modified during O3 commissioning to account for a wrong orientation of the tilt of the B1p viewport

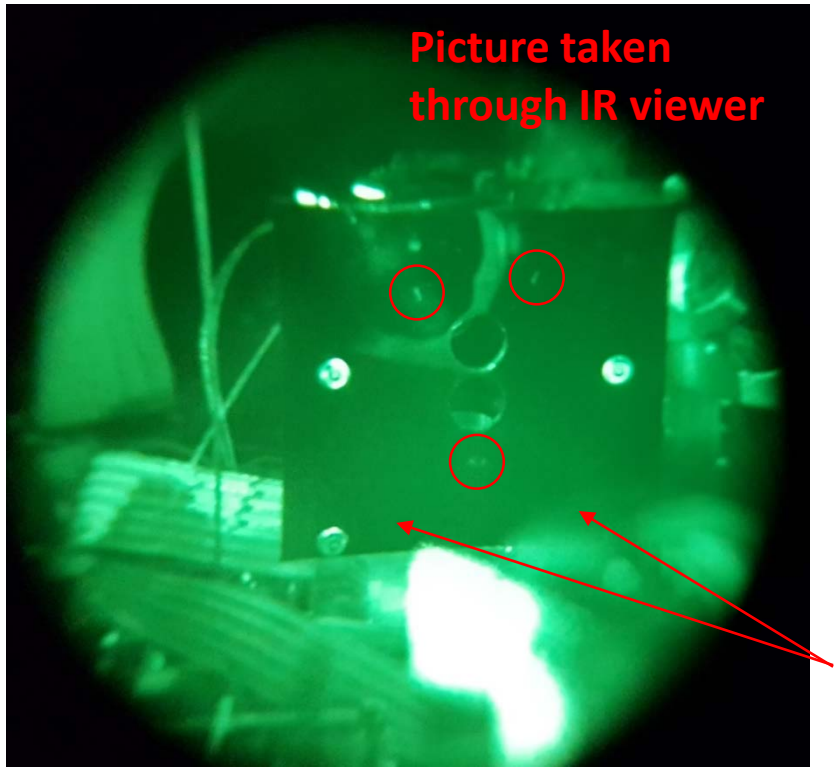


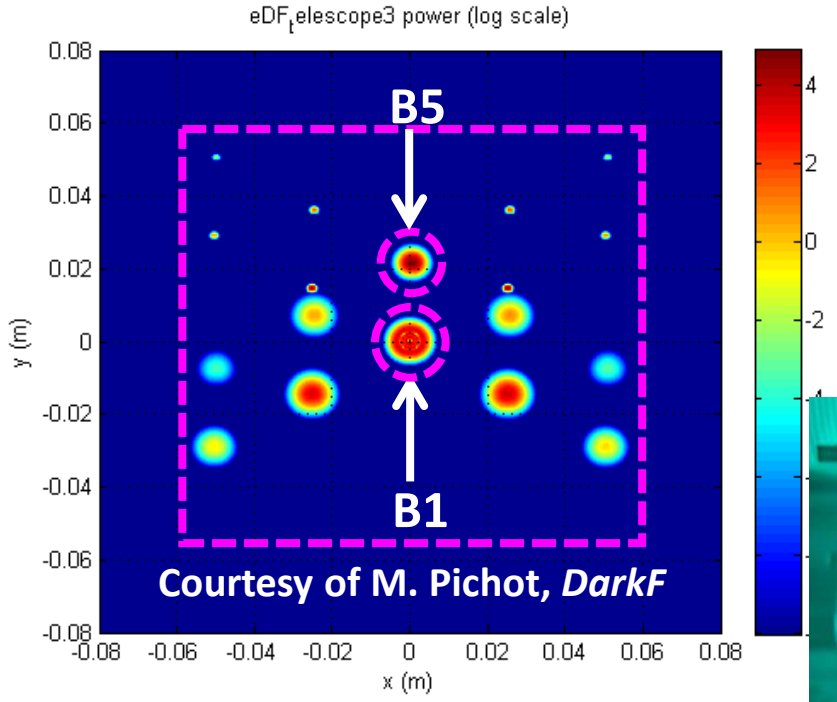


- Reflexion from SDB1-SQZ viewport dumps inside the tube

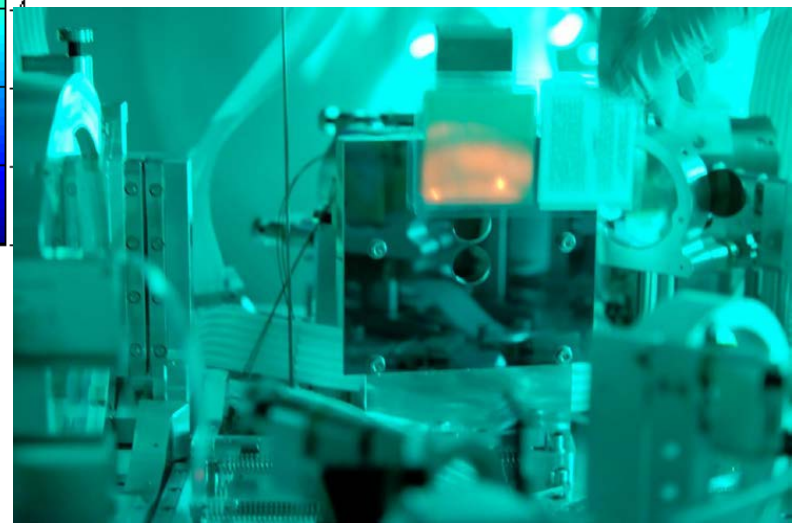
Dealing with ITF secondary beams (AdV installation + commissioning): SDB1

- Optical simulations (DarkF, Zeemax) predicting the position of secondary beams coming from ITF AR surfaces (CP, POP, BS)
- Designed diaphragm on SDB1 to dump these secondary beams
- Secondary beams (CP reflections) found on the diaphragm at expected positions



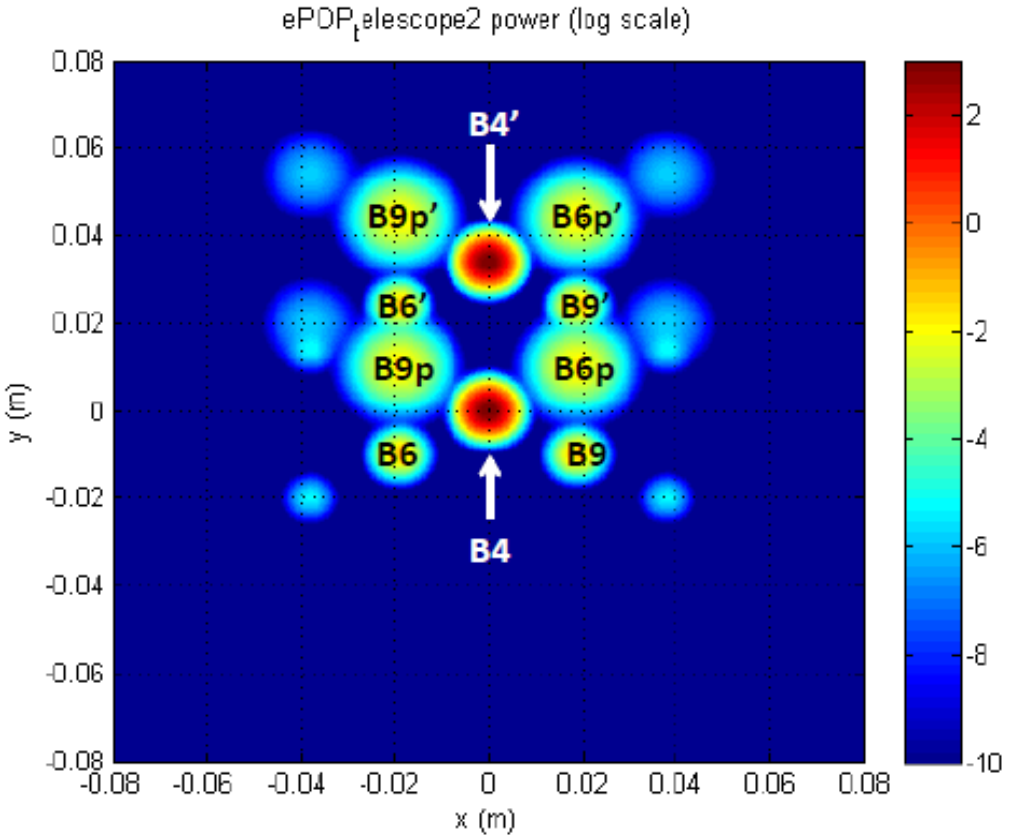


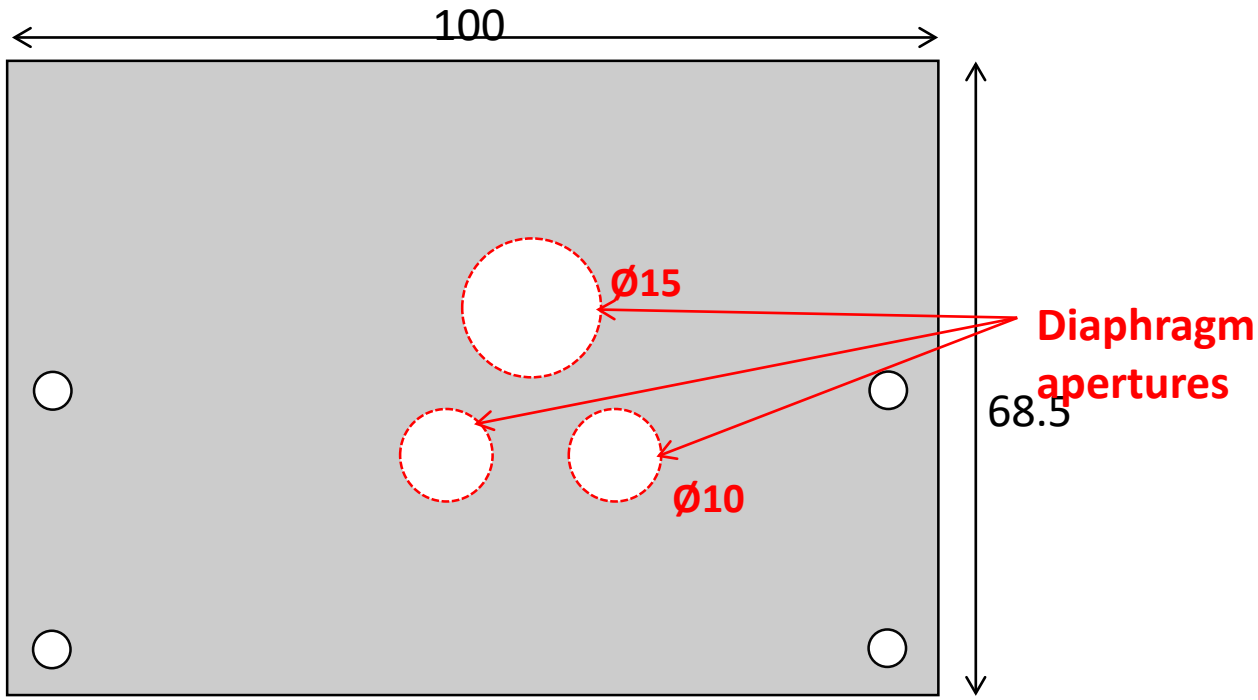
Found weak secondary
reflections from CP as expected



Dealing with ITF secondary beams (AdV installation): SPRB

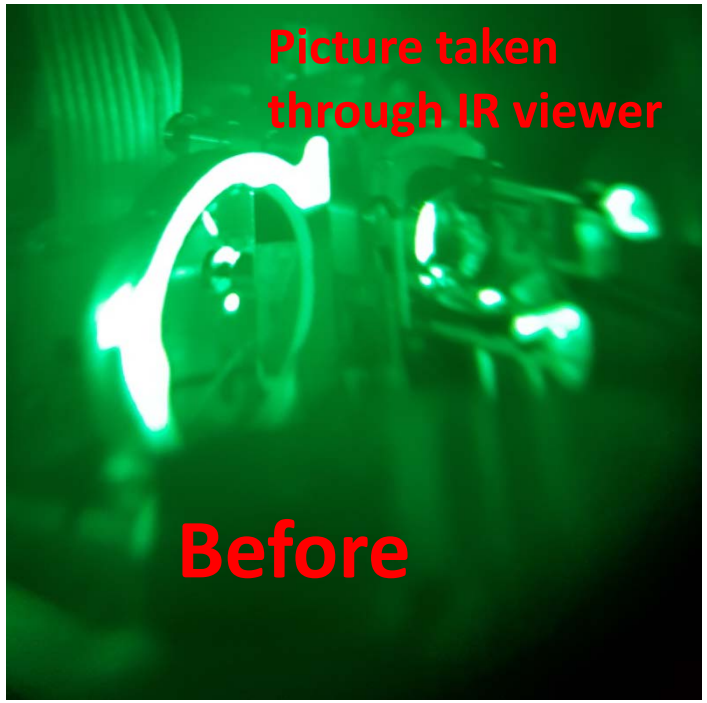
- Designed diaphragm on SPRB to dump secondary beams coming from CP and second POP surface reflections

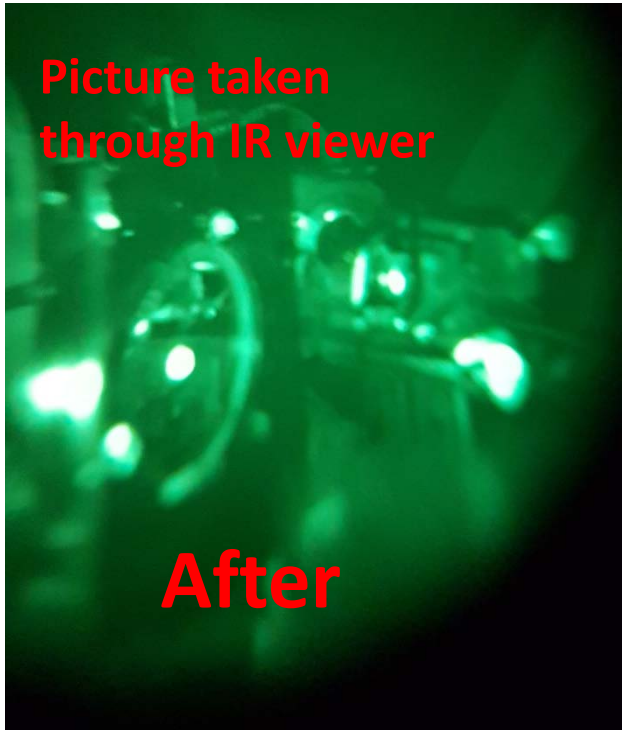


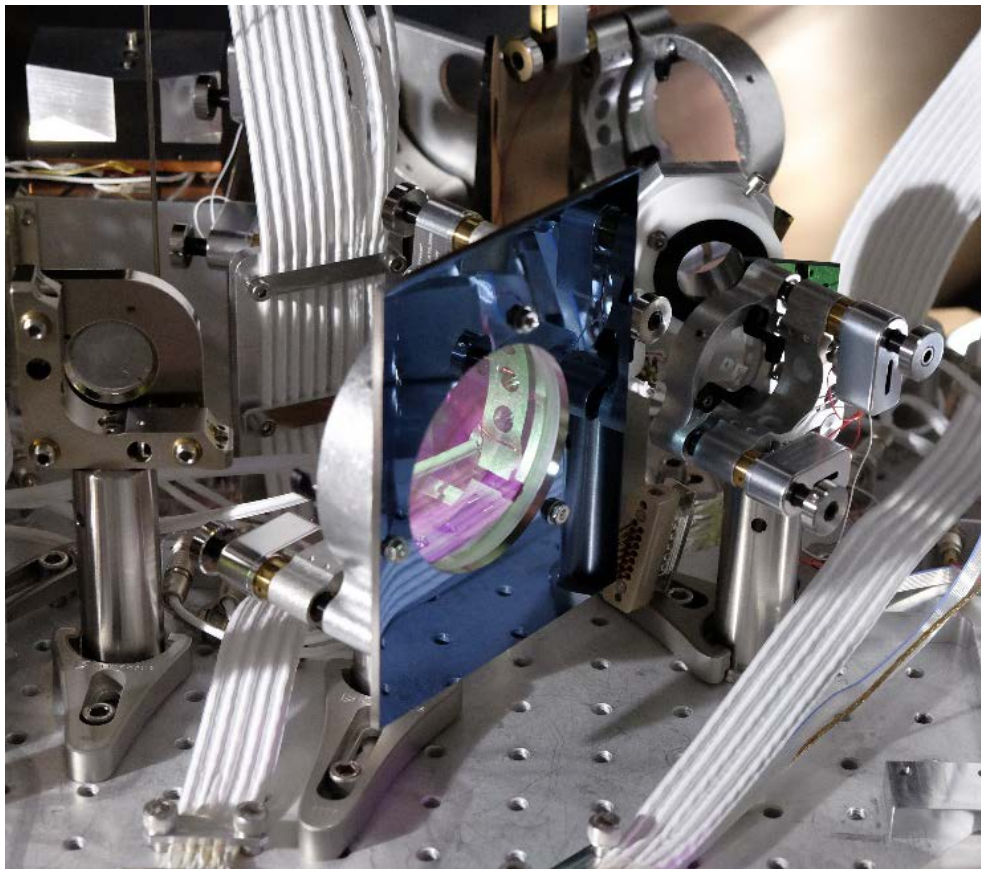


Absorbing uncontrolled scattered light on SDB1 (O3 commissioning)

- SDB1 inspections showed large areas of scattering on the mount of the 3 in dichroic mirror (placed at the output of the telescope parabolic mirrors)
- Situation improved by installing diaphragm made of mirror polished steel

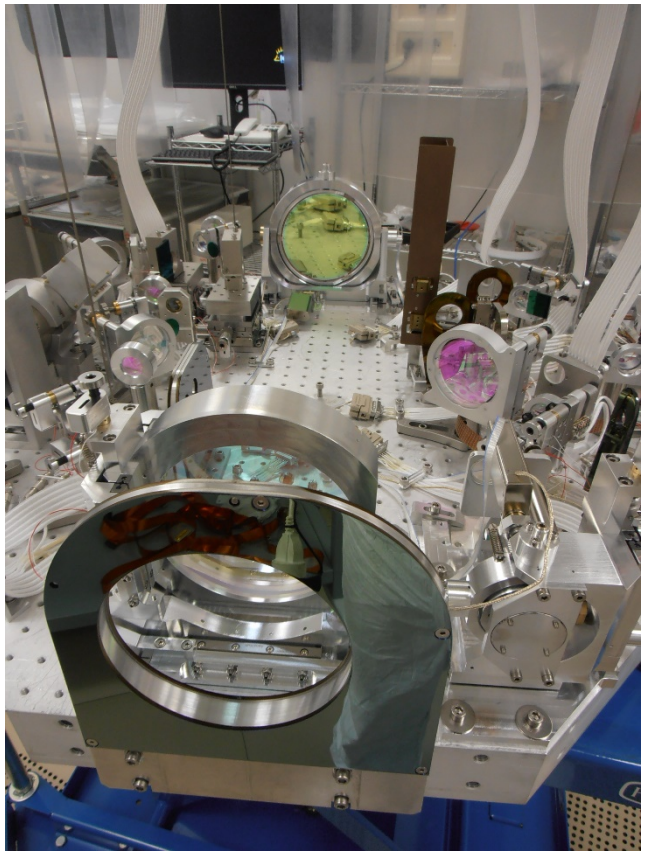


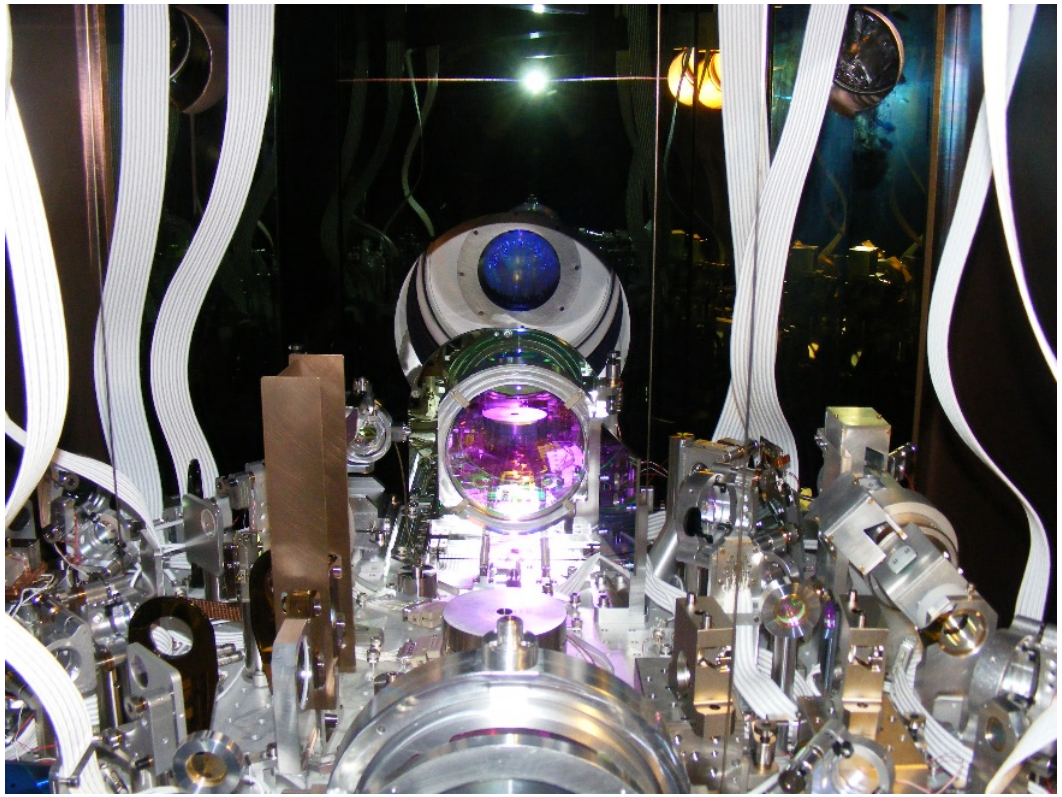




Absorbing uncontrolled scattered light on SDB1 (AdV design)

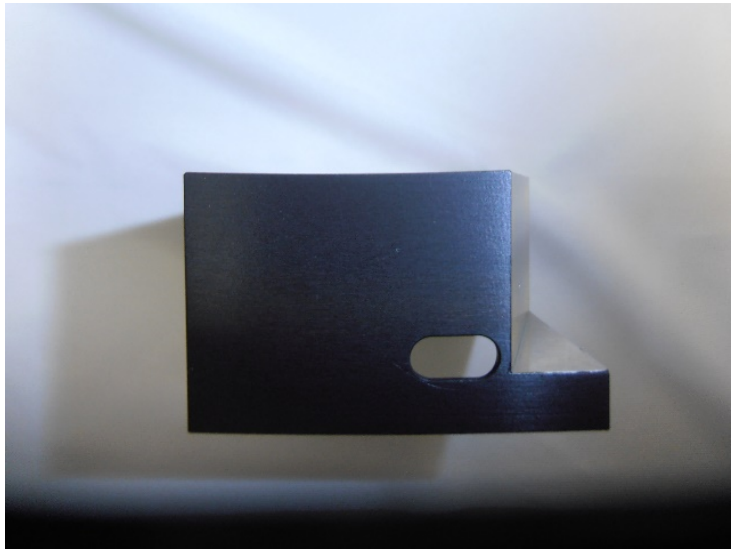
- Mirror polished steel diaphragm designed and installed at the SDB1 input (in front of the MMT meniscus lens)
- Glass baffles installed at the west flange of SDB1 tower (SLC)

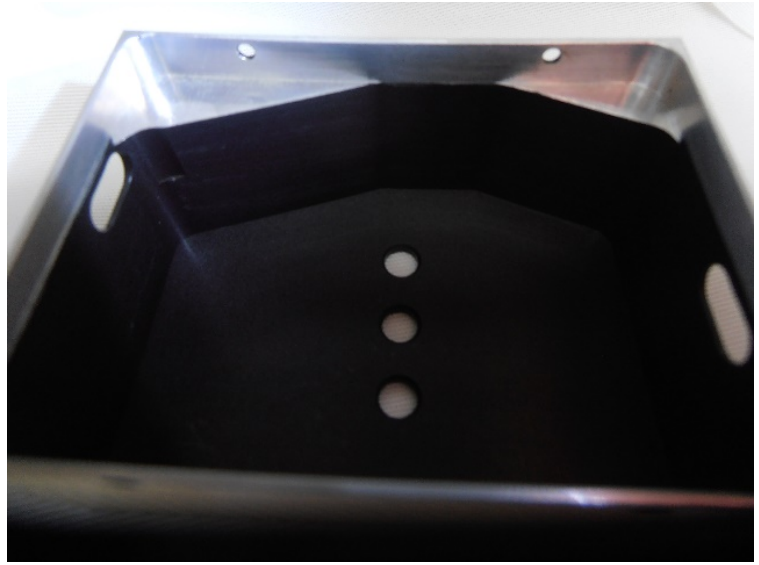




Absorbing OMC scattered light (O3 commissioning)

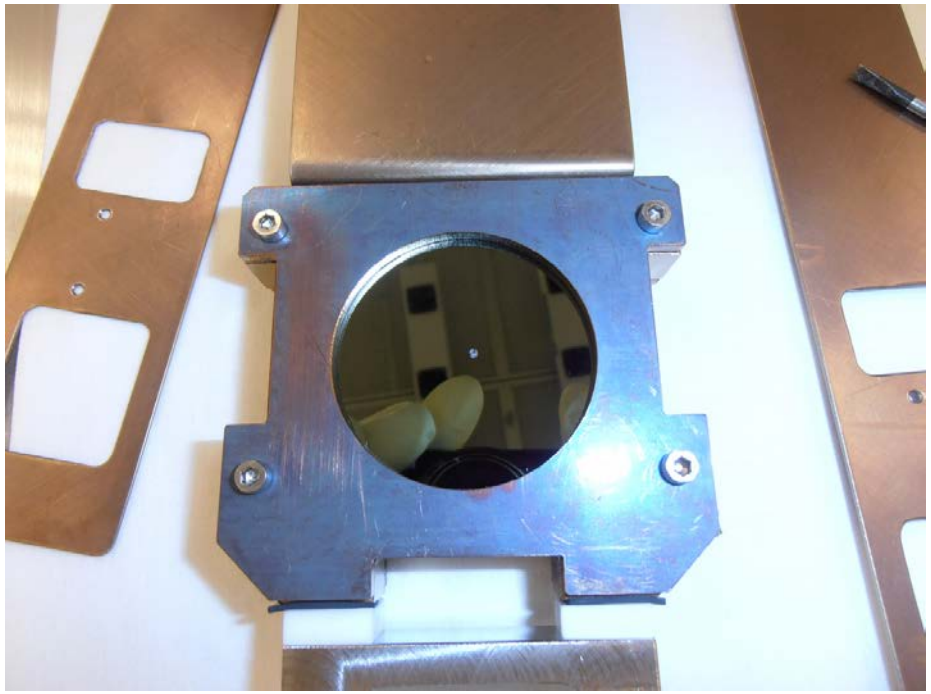
- AdV OMC surfaces roughness ~0.3 nm RMS and F = 120 > 1% of scattering losses per cavity
- OMC aluminium protective covers treated with Anoblack-EC (electrolytic blackening using inorganic metallic salts)
- Installed during O3 commissioning:
  - Absorb part of the light scattered by the OMC
  - Prevent the scattered light coming from other components to couple with the OMC

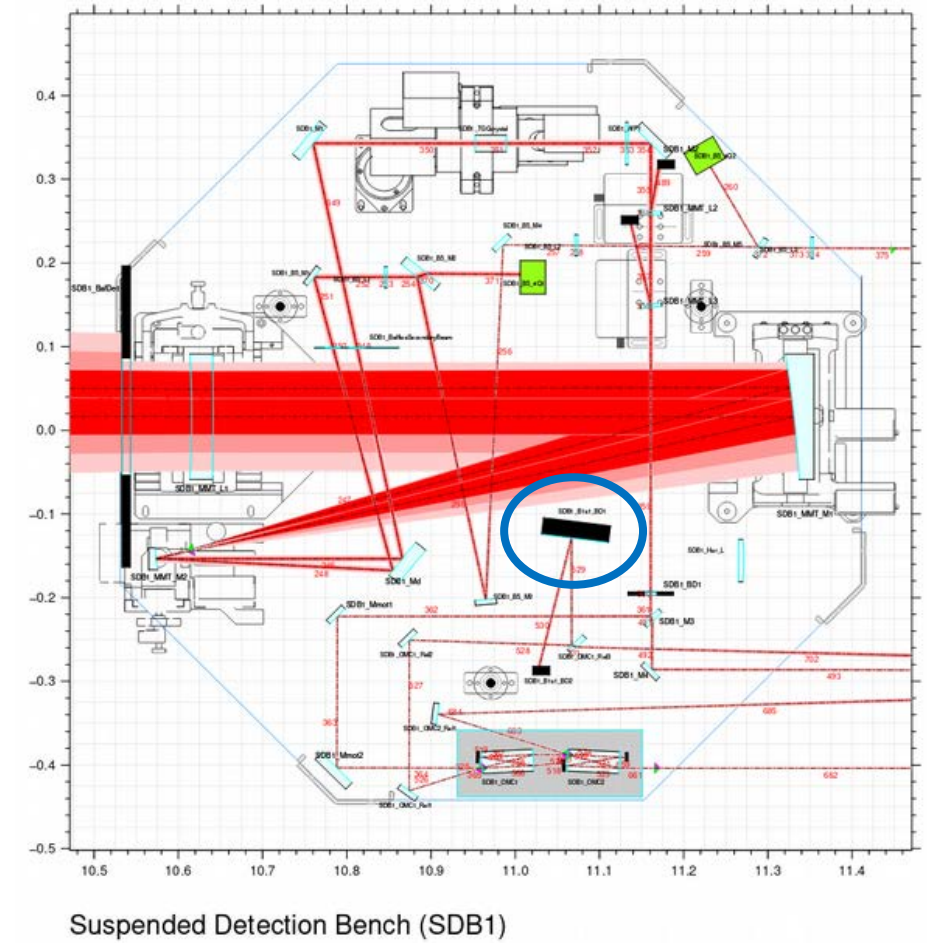




Scattered light from damaged beam dump (O3 commissioning) 1/2

During SDB1 inspection for scattered light:
- First shiny source of scattered light we found was the B1s1 beam dump used to dump 90 % of B1s1 beam (reflection of first OMC).
- Beam dump was damaged. It was projecting light all over the south wall.

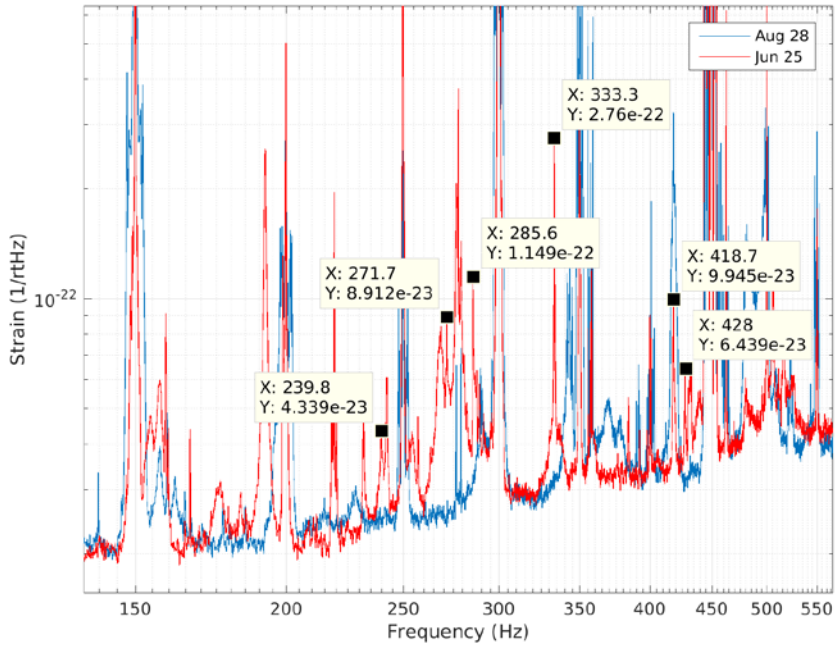


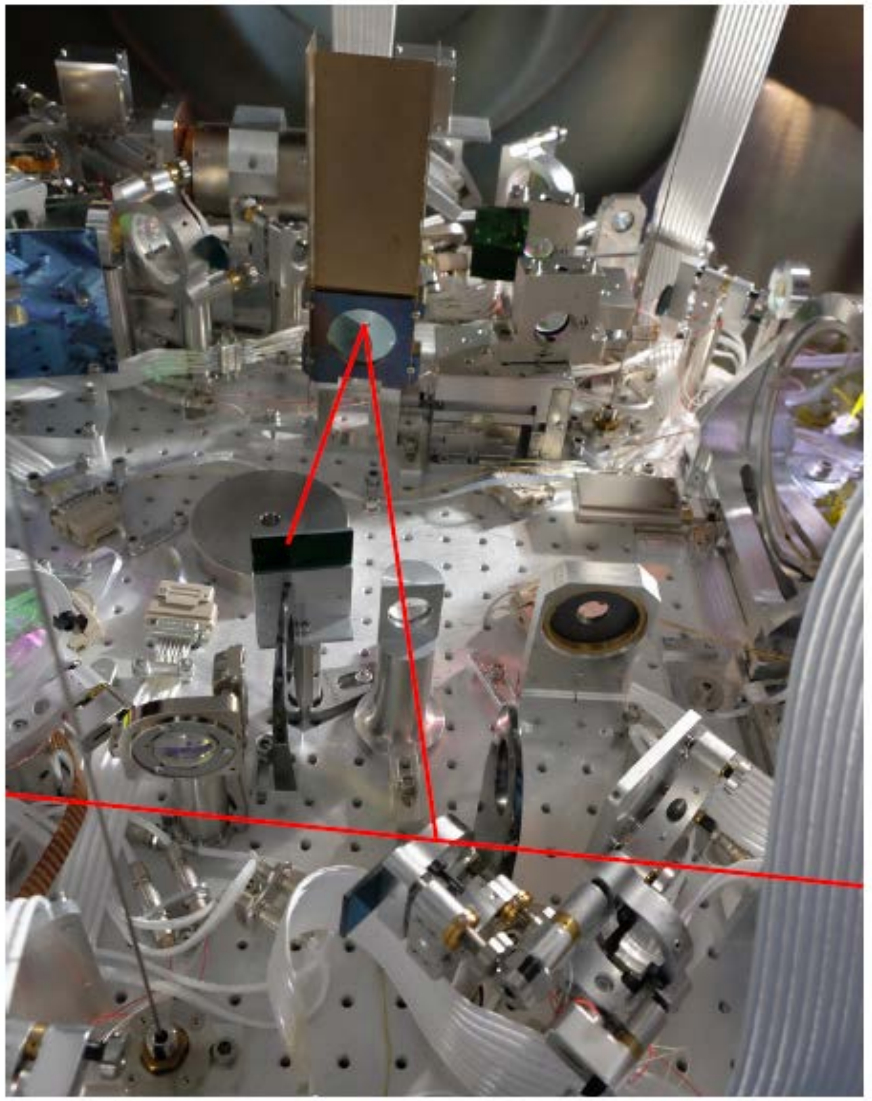


Suspended Detection Bench (SDB1)

Scattered light from damaged beam dump (O3 commissioning) 2/2

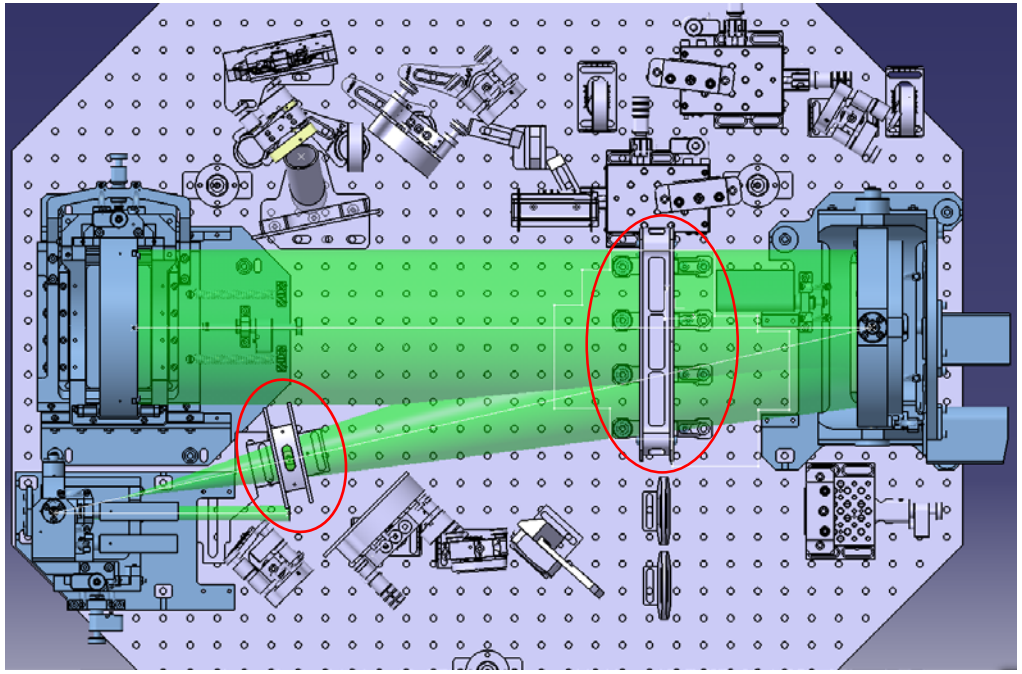
- Si beam dump flipped on the other side which as not damaged
- Beam dump displaced on the other side of the bench and beam size increased by a factor 3 with a diverging lens > to avoid other laser damages
- A black glass beam-dump has been added to catch the reflection from B1s1 beam dump
- This action had a clear effect on the sensitivity : suppression of several peaks (see M. Was and I. Fiori's presentation)

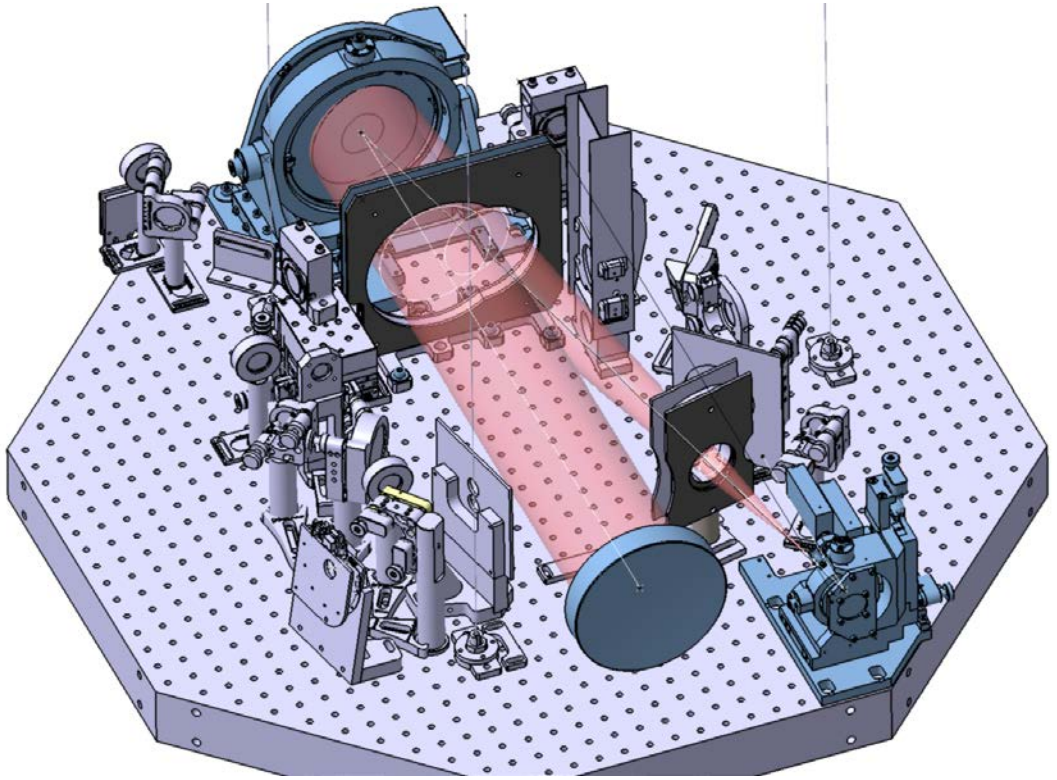




What is planned for AdV+

Adding diaphragms in front of dark fringe mode matching parabolic mirrors (1/3)

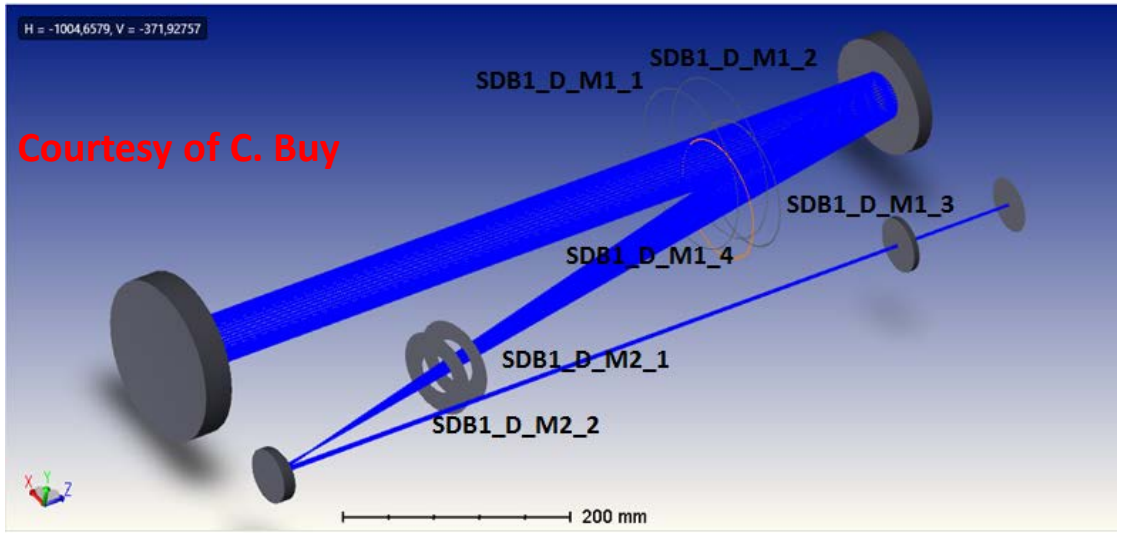




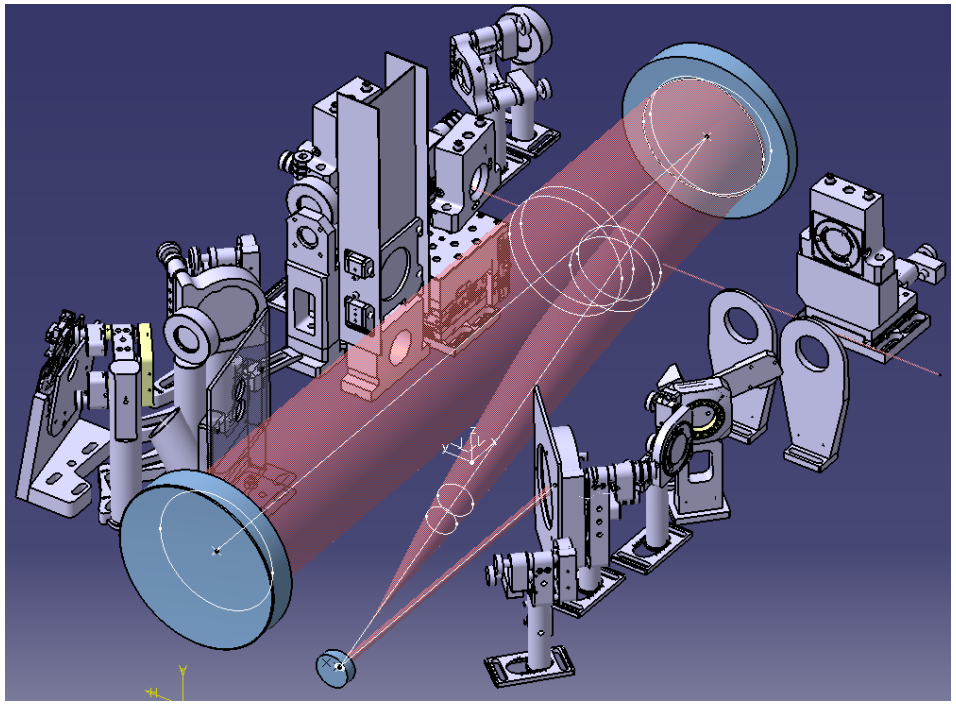
- Goal: block light scattered outside telescope aperture.

Adding diaphragms in front of dark fringe mode matching parabolic mirrors (2/3)

- Use Zeemax optical simulation to check beam size and position at the diaphragm location
- Results of optical simulation integrated inside CAD drawing

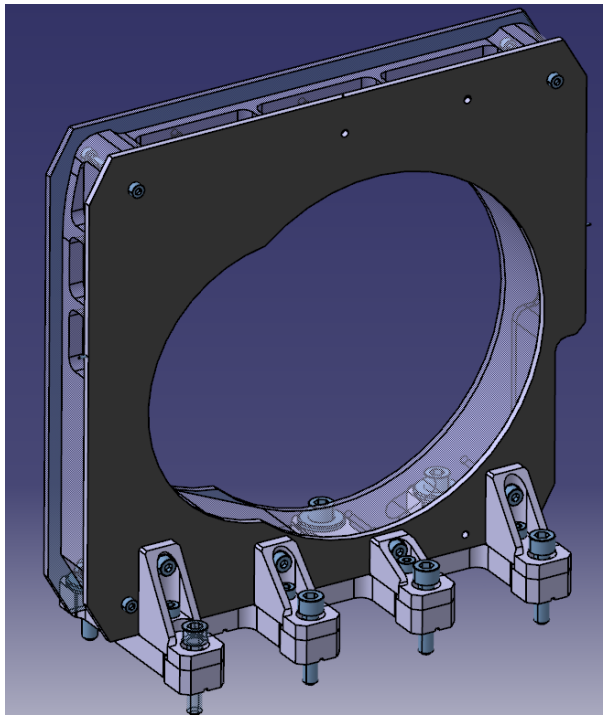


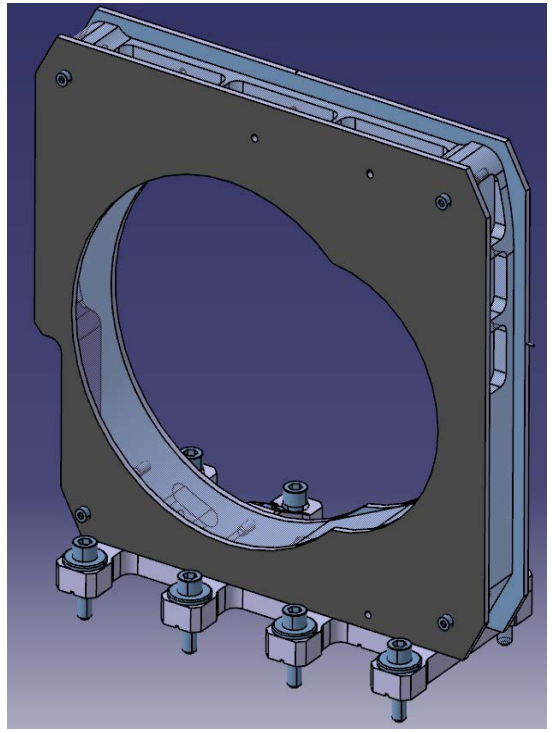
Courtesy of W. Bertoli

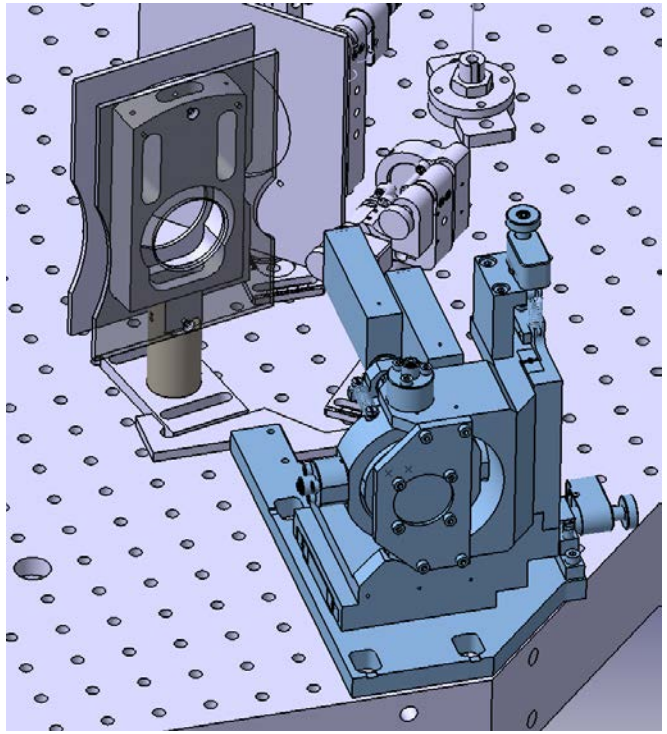


Adding diaphragms in front of dark fringe mode matching parabolic mirrors (3/3)

- Mechanical design of diaphragms optimized to mitigate vibrations and minimize weight: first resonance above 250 Hz
- Solution foreseen to attach steel mirror plates > stainless steel screws with « superblack » deposit
  > Electrolytic Chemical Colored Stainless Steel







Courtesy of W. Bertoli

Other scattered light mitigation foreseen

- Add absorbing glass beam dumps to block the residual light transmitted through HR mirrors on SDB1
- Replace SDB1 B5 quadrants with AR coated ones
- Equip new control photodiodes air boxes with silicon beam dumps > combine good optical properties with high damage threshold
- New OMC cavity with lower scattering : surface roughness < 0.1 nm RMS
  > required in order to have finesse = 1000 without worsening losses
- Baffling on the inner walls of DET tower (SLC): to be revised and rescheduled due to manpower and budget issues

What is missing ?

How to further mitigate scattered light ?
Absorb it better

- Be more systematic in characterizing and dumping the ghost beams that are produced at the level of all optical surfaces:

  - Need optical simulations to support these studies
    - Need 3D optical simulations when vertical tilts, wedges, periscopes are present
    - Possibility to combine 3D optical and mechanical simulation to help designing and positionning the diaphragms

  - Integrate appropriate diaphragms and beam dumps, if possible from the design phase of the optical benches
    - Mostly done on SDB1.
    - Should be done in priority on the most critical benches for scattered light (SDB2, SNEB, SWEB…)

- Generalize absorbing surfaces:
  - Use optics mounts with absorbing surfaces (Anoblack EC already tested) : foreseen for the SIN sub-system

  - Improve baffling of the vacuum chambers and/or build absorbing fences around the suspended benches:
    - Need solutions which remain compatible with commissioning activities, ie enable access to the optics
    - Within the constraints of the vacuum chambers and the suspension system (weight)

How to further mitigate scattered light ?
Reduce the scattered light sources

- Look for sensors (photodiodes, quadrants, cameras) with lower reflectivities

- Generalize use of super polished optics (roughness < 0.1 nm RMS) on the critical benches and for the optical viewports
  - a few mirrors already planned to be changed on SDB1

- Get rid of optical viewports whenever possible
  - constrained by the different levels of vacuum between the ITF and minitowers
  - useful to preserve « fast » accessibility to the benches during commissioning

- Review the benches optical design:
  - avoid placing optical surfaces close the beam waist (whenever possible)
  - favour curved mirrors rather than lenses
  - …

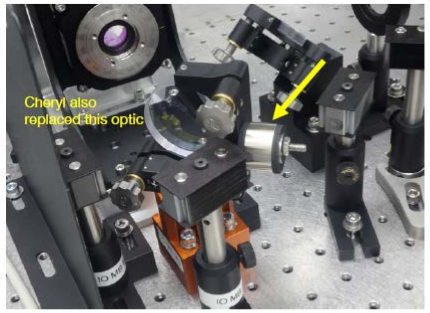
- Improve cleanliness control of the optics (avoid dust deposit during commissioning interventions)

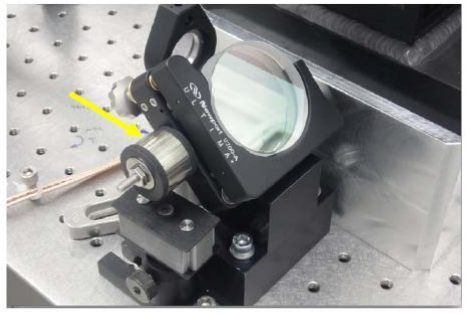
How to further mitigate scattered light ?
Reduce vibrations of scattering surfaces

- Further improve and generalize the relative controls between benches and ITF mirrors

- Improve robustness of the optical mounts and feet
  - Requires mechanical simulation
  - Lower beam axis height whenever possible

- Damp main optical mounts resonance by attaching damping weights (with viton washer) : already done in LIGO
https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=46494





Some final remarks

- A significant amount of work was performed during Advanced Virgo in order to mitigate scattered light
  - a lot of issues were found during commissioning investigations
    - > lack of anticipation during design phase
    - > we missed appropriate simulations
    - > mitigation actions were not obviously correlated with sensitivity improvement
  - a large part of the mitigations actions were focused on the SDB1 bench (the most critical one for scattered light)

- Further mitigation efforts are being made in the context of AdV+
  - still focusing mostly on SDB1

- What is still missing:
  - generalize the mitigation effort to all suspended benches
  - try to anticipate issues as much as possible during design phase
  - use appropriate simulations
  - manpower and money

Useful links

- Advanced Virgo: a 2nd generation interferometric gravitational wave detector
https://arxiv.org/abs/1408.3978
Sections 10. Light detection, and 13. Scattered-light mitigation: photodiode seismic and acoustic isolation

- Optical mounts mechanical measurements:
https://logbook.virgo-gw.eu/virgo/?r=31750

- Mitigation actions during AdV commissioning:
- Presentation (Jan 2019) <https://tds.virgo-gw.eu/ql/?c=13882>
- Presentation (Sep 2018) <https://tds.virgo-gw.eu/ql/?c=13541>
- Presentation (Jul 2018) https://tds.virgo-gw.eu/ql/?c=13427
- Presentation (Jul 2017) https://tds.virgo-gw.eu/ql/?c=12469

- Mitigation actions foreseen for AdV+:
https://docs.google.com/document/d/1fZnL62IgKphd_F6RON8wSnlQCgQ8nkbJyAePRtXvbcc/edit#heading=h.xztqannbyivl, paragraph “Mitigation of scattered light on SDB1 bench”