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Advanced Virgo Plus: future perspectives

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on behalf and with the contributions of *The Virgo Collaboration*

Sep 15th, 2022

Advanced Virgo Plus future perspectives

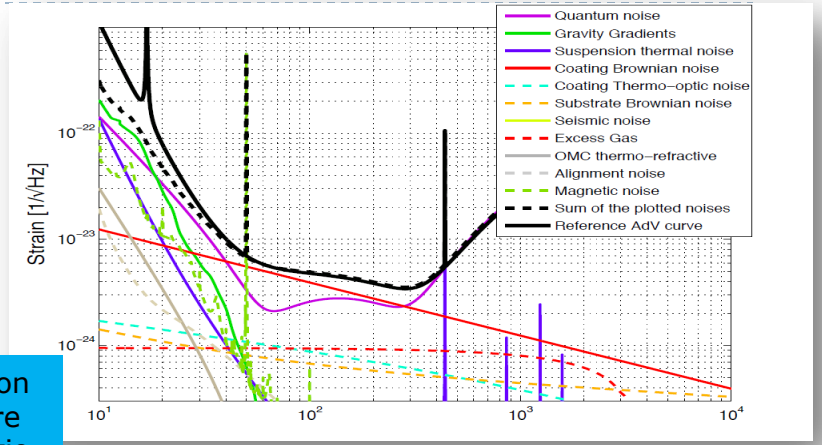
EGO - VIRGO

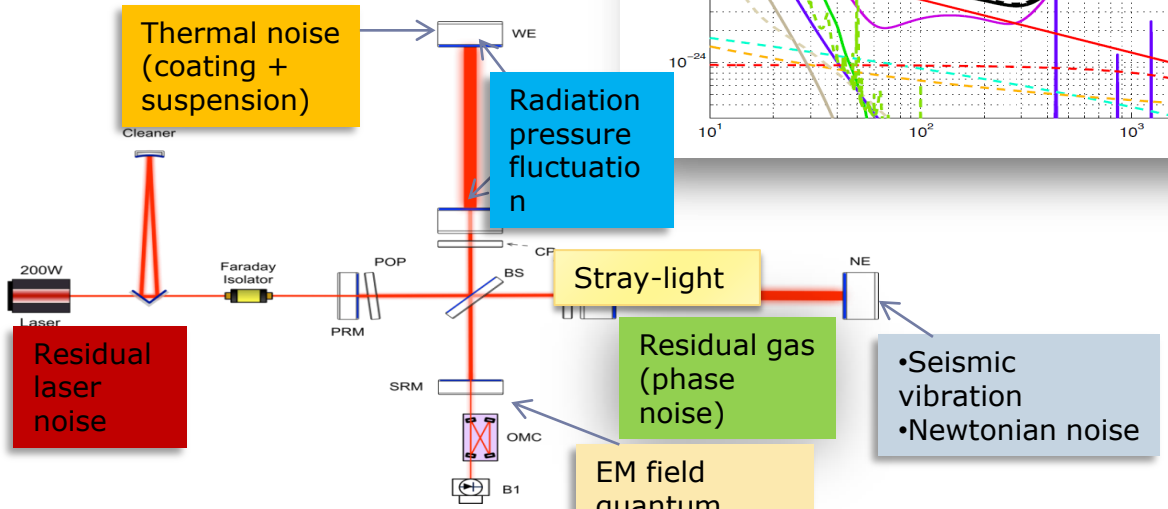
- The Virgo collaboration is completing the commissioning to prepare the interferometer for the next joint Observation Run **(O4)** (see M. Mantovani, M. De Laurentis talks)
- But it is also finalizing the design of the next upgrades to the detector to be employed in the following Observation Run **(O5)**
- The major upgrade will concern *decreasing the thermal noise limit*, which will imply using very large test masses and increased laser beam size.
- But this will not be the only upgrade to be implemented in the break between the O4 and O5 observation runs to increase the Virgo detector strain sensitivity.
- Challenges linked to this upgrade will be shown

GW Detectors – A myriad of noise sources

EGO - VIRGO

To increase the reach of the GW interferometric antenna:
-Increase sensitivity
-Reduce noise

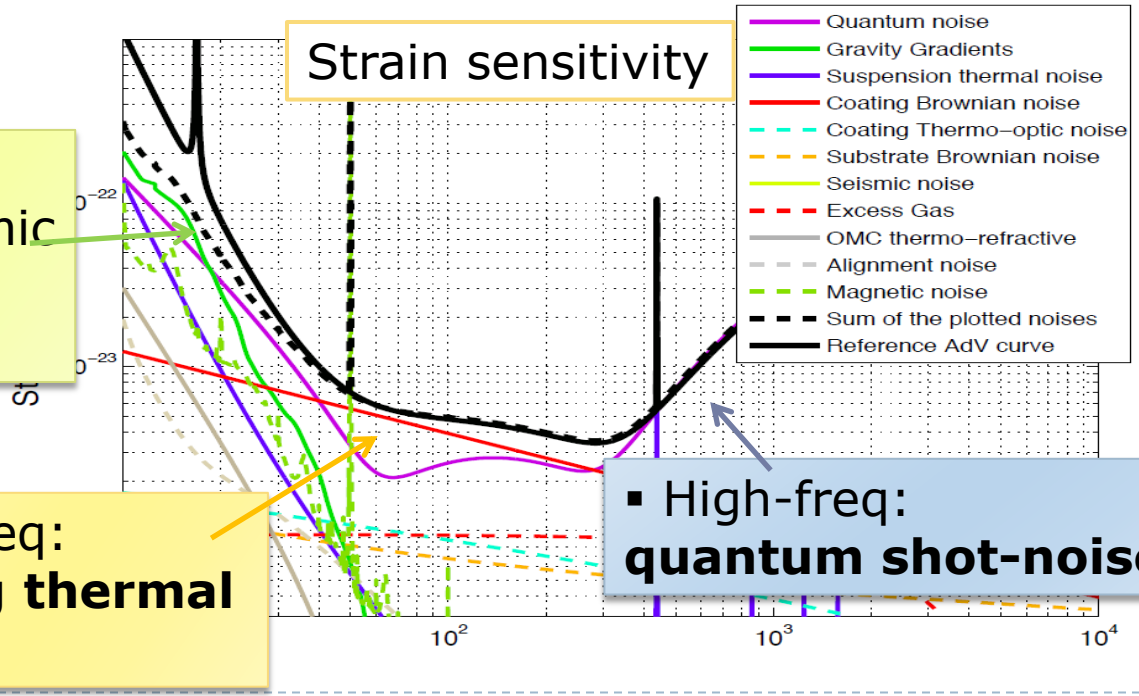




GW Detectors - Noise

EGO - VIRGO

Limiting noises at different frequency ranges:



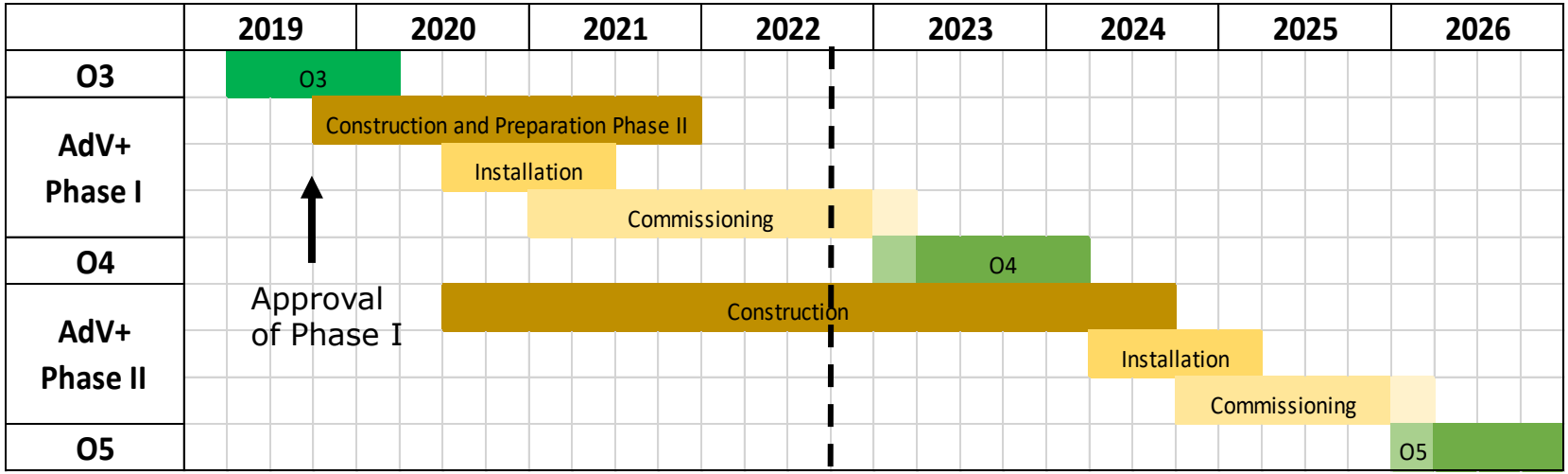
- Low-freq: **newtonian noise**, seismic noise, residual technical noises

- Mid-freq: **coating thermal noise**

- High-freq: **quantum shot-noise**

Advanced Virgo+ Two-stage project

EGO - VIRGO



Phase I:

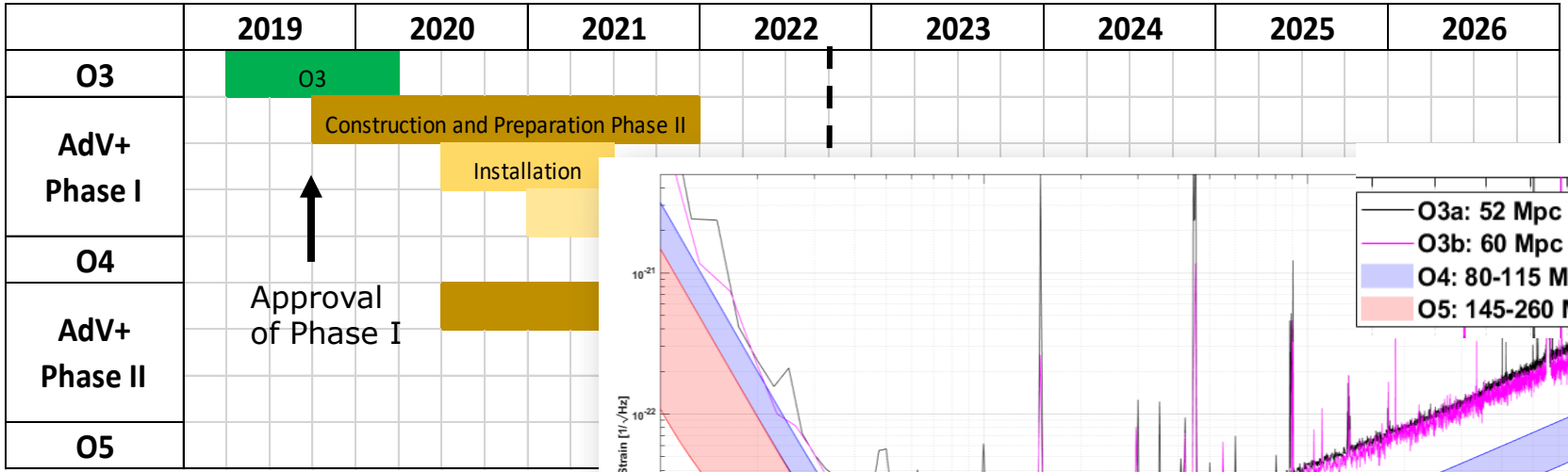
reduce quantum noise, hit against thermal noise.
BNS range: 100 Mpc's

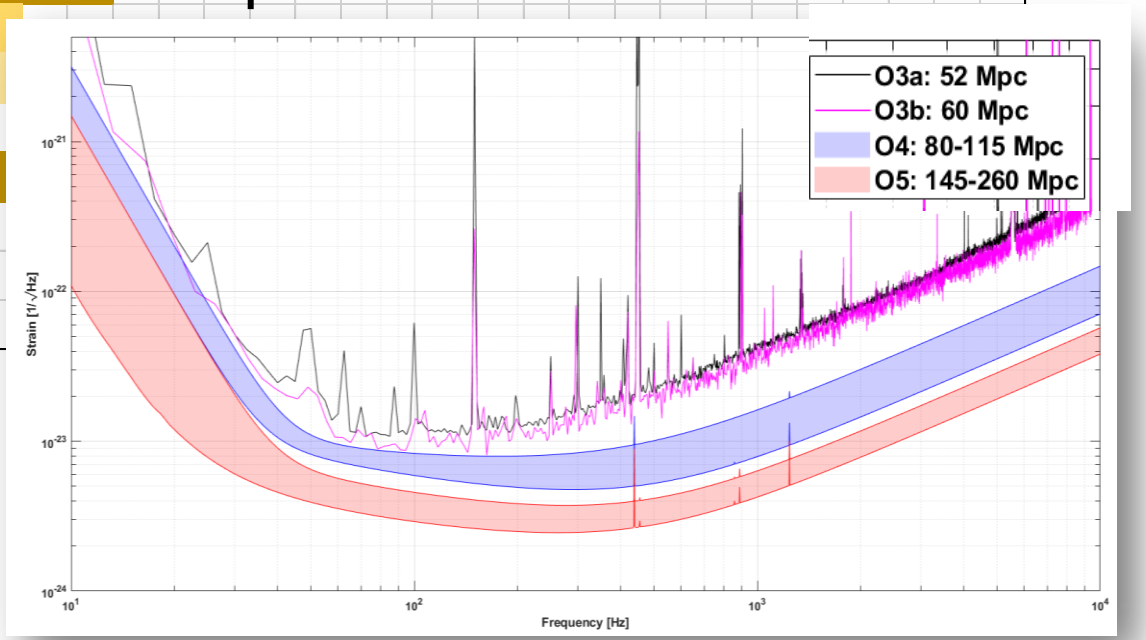
Phase II:

lower the thermal noise wall.
BNS range: 200 Mpc's or more

Advanced Virgo+ Two-stage project

EGO - VIRGO





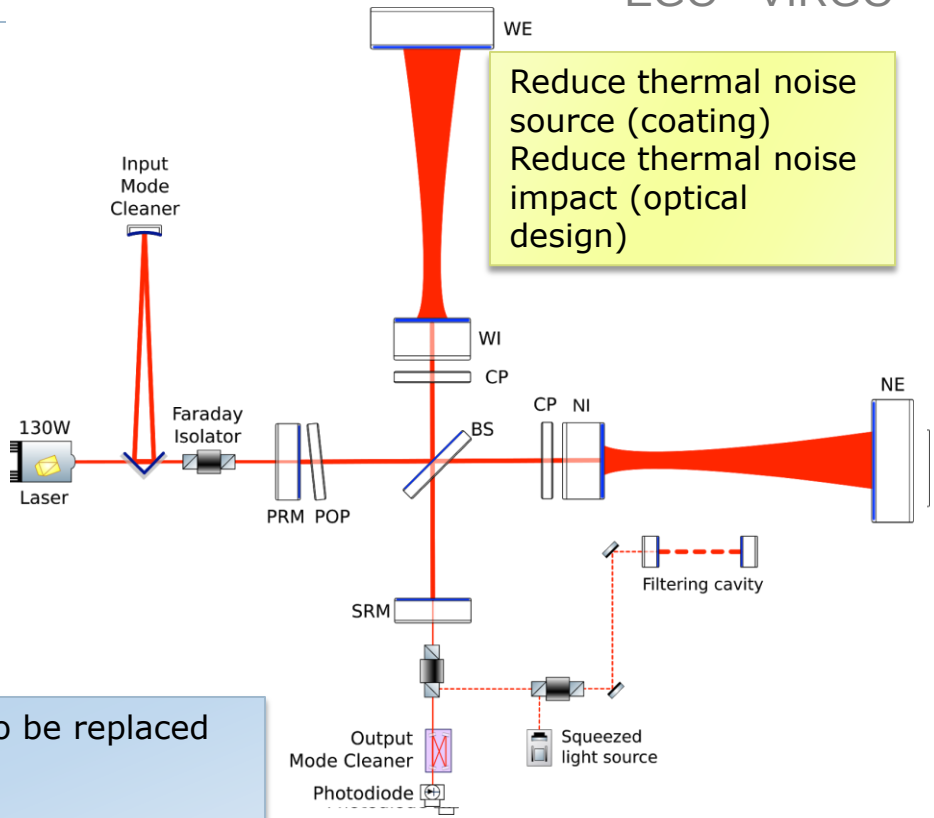
Phase I:

reduce quantum noise, hit against thermal noise.
BNS range: 100 Mpc's

Advanced Virgo+ Phase II

EGO - VIRGO

- Main changes
  - Larger beams on end test masses
    - 6 cm radius ⇒ 10 cm radius
  - Larger end mirrors
    - 35 cm diameter ⇒ 55 cm diameter
    - 40 kg ⇒ 100 kg
  - Better mirror coatings
    - Lower mechanical losses, less point defects,
      better uniformity
  - New suspensions/seismic isolators for large mirrors
  - Further increase of laser power
    - 40W ⇒ 60W ⇒ 80 W



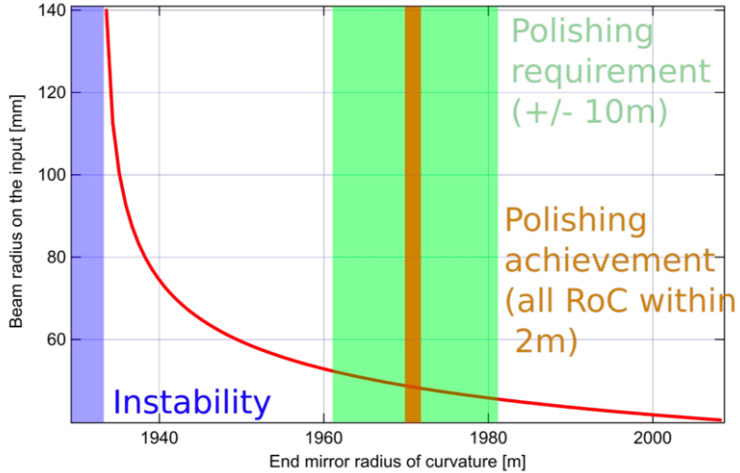
- All the core optics (but the Beam Splitter) will have to be replaced to adapt to new beam geometry
- All the telescopes will be modified

Cavities geometry

EGO - VIRGO

- Larger g-factor
  - Tighter angular control requirements during pre-alignment
    - 0.2 microrad
  - Tight requirements RoC control
    - Delta RoC~0.3 m

	Phase I	Phase II
EM diameter	350mm	550mm
beam radius @ EM	58mm	91mm
beam radius @ IM	49mm	
EM RoC	1683m	1969m
IM RoC	1420m	1067m
g factor	0.87	0.95



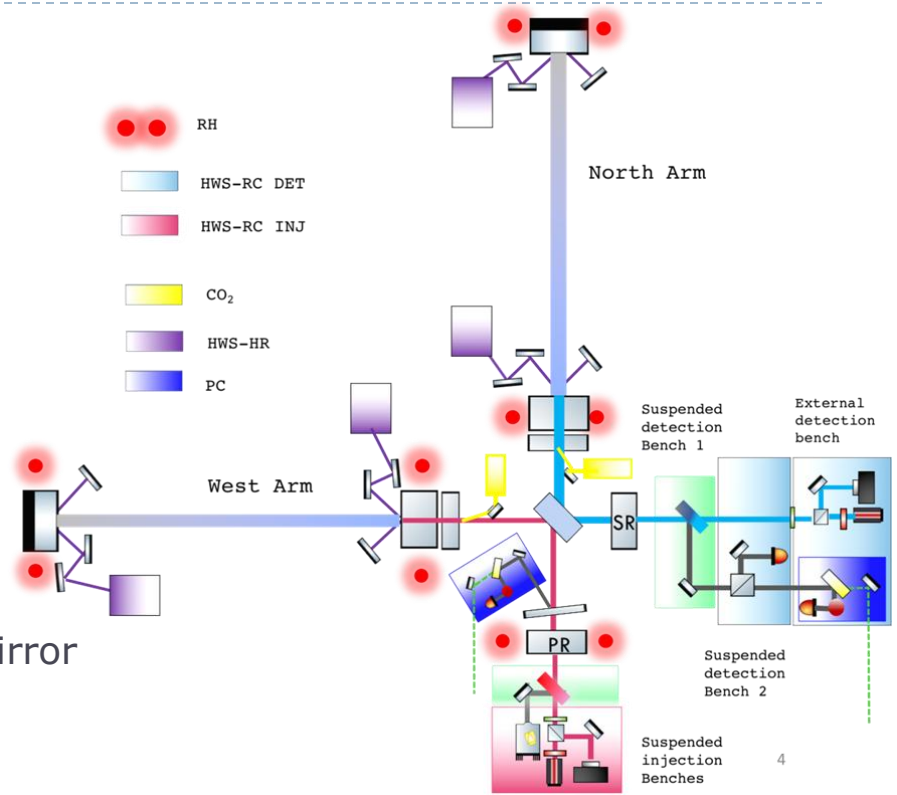
Challenge from optical design:
to enlarge the beam on the test masses, arm cavities closer to instability

- ➢trickier controls
- ➢Polishing requirements more strict
- ➢More sensitive to aberrations

Thermal compensation system

EGO - VIRGO

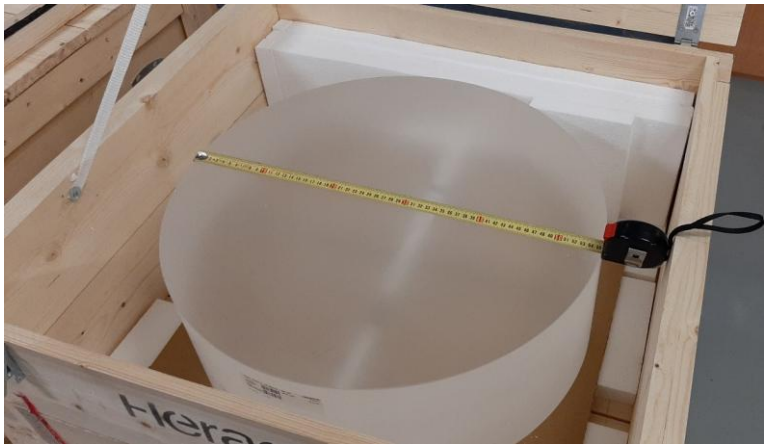
- Actuators:
  - Ring-heaters for fine tuning of RoCs
  - CO2 heaters
- Not only actuators: Sensing
  - Hartman wave-front sensing (HWS)
  - Phase cameras
- Several upgrades foreseen for O5
  - New cameras for HWS
  - Upgraded HWS telescopes for end mirrors
  - Mode-cleaners for CO2 beams
  - DC CO2 laser beam shapers via deformable mirror
  - More remote controls
  - More phase cameras



Large Mirrors: Substrates

EGO - VIRGO

- Status
  - Substrates acquired and received at Laboratoire Materiaux Avancés (LMA) – Lyon
  - Call for tender for the mirrors polishing done
    - Polishing started in December 2021



Large Mirrors: Tools and Metrology

EGO - VIRGO

- Several upgrades at LMA needed to prepare the realization of the large mirrors and the development of new coatings

- For coating realization
  - Large mirror mounts and handling tools
  - Upgrade of cleaning machine
  - Large silica crystallizers for annealing
  - Large coater upgrade

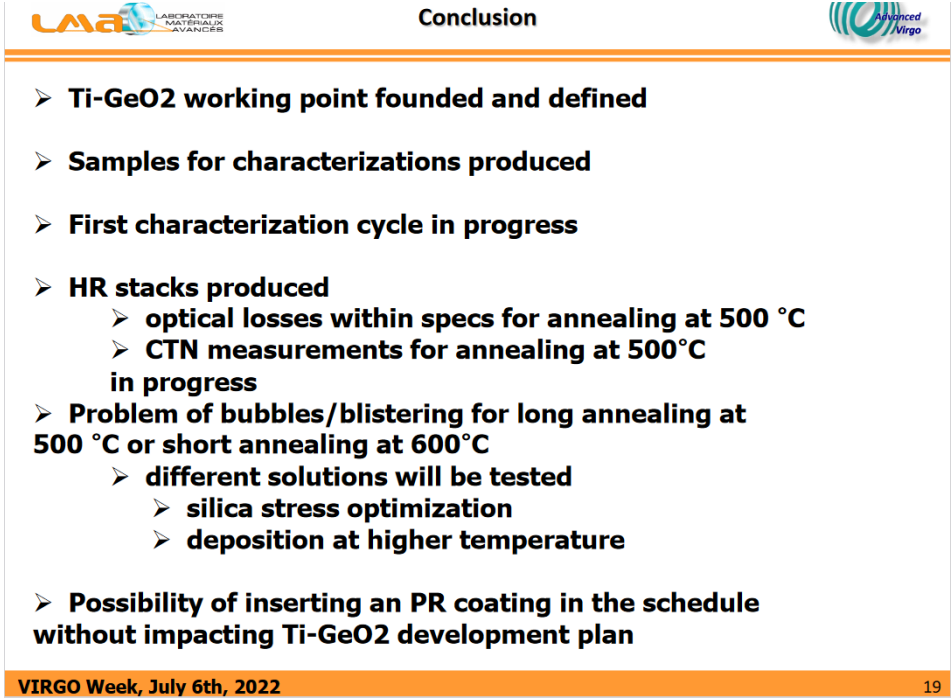
- For the metrology
  - Upgrade of scattering bench
  - Upgrade of absorption bench
  - New reference sphere for flatness/RoC measurement
  - Upgrade of profilometer (done during Phase I)
  - Clean room enlargement (done during Phase I)

Total investment
1.8 M€

Mirrors: Coatings

EGO - VIRGO

- Several coating formula studied in the R&D phase
  - Virgo Coating R&D (G. Cagnoli)
- Outcome
  - LIGO and Virgo agreed to pursue together the development of TiO_2:GeO_2/SiO_2 coatings at LMA
  - Joint LIGO-Virgo working group settled up
    - Chair: G. Vajente (Caltech) and C. Michel (CNRS/LMA)
  - First monolayers and multilayers produced in the Grand Coater at LMA
  - Critical path for AdV+
- Final decision on the coating for O5 to be made in a few months



Large Payloads for Large Mirrors

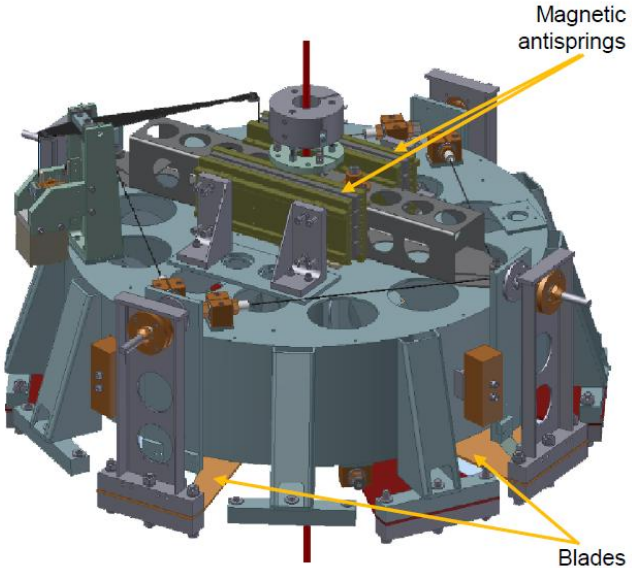
EGO - VIRGO

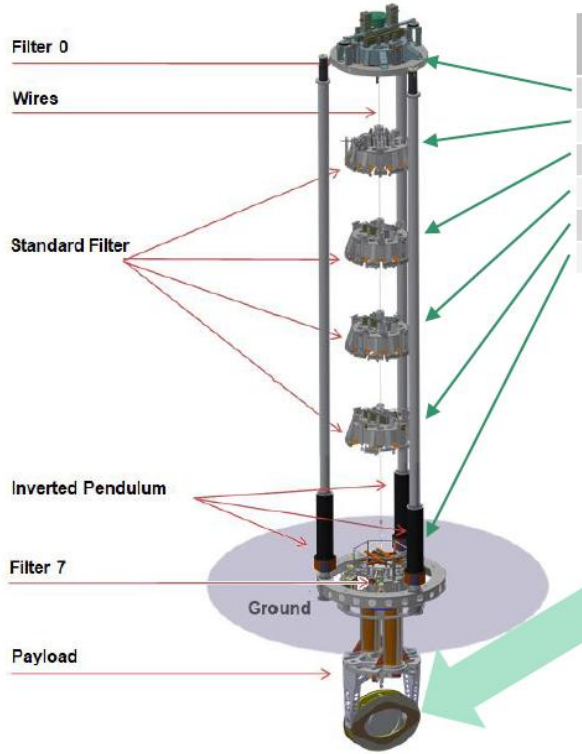
- Goal: suspend 100 kg mirrors
- Large Payload for Large End Mirrors
  - Design done
  - Prototype built
  - Including fused silica fibers ø 640 μm
    suspending 100 kg dummy mirror

Super Attenuators for Large Payloads

EGO - VIRGO

- Super Attenuators for Large Payloads
  - Need to revisit the design of several elastic elements
  - Design done
  - Prototypes under construction/validation





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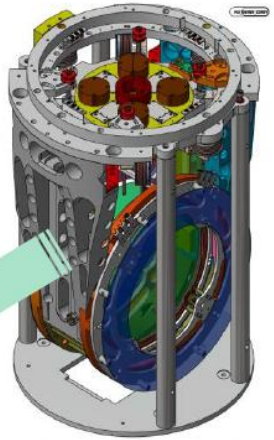
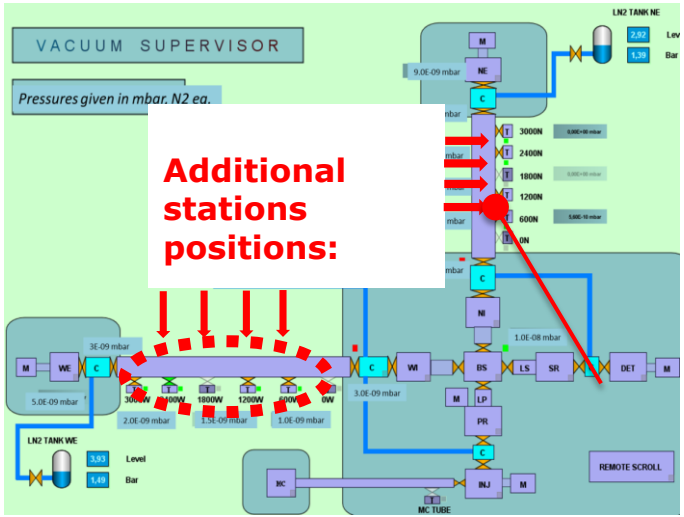
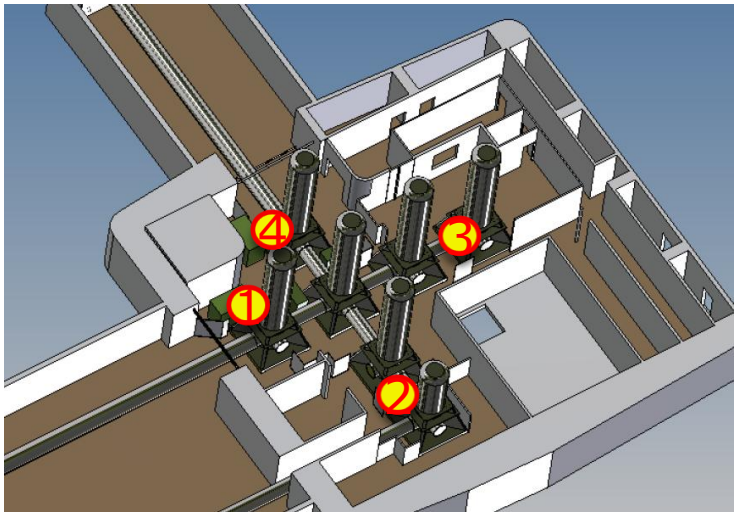


Vacuum

- Several upgrades foreseen for the vacuum system
  - Additional pumping stations along the tube
  - Low noise ion pumps for most critical vacuum chambers (TBC)
  - Cryogenic pump in the central area to reduce noise
  - Electrostatic mirror discharging device

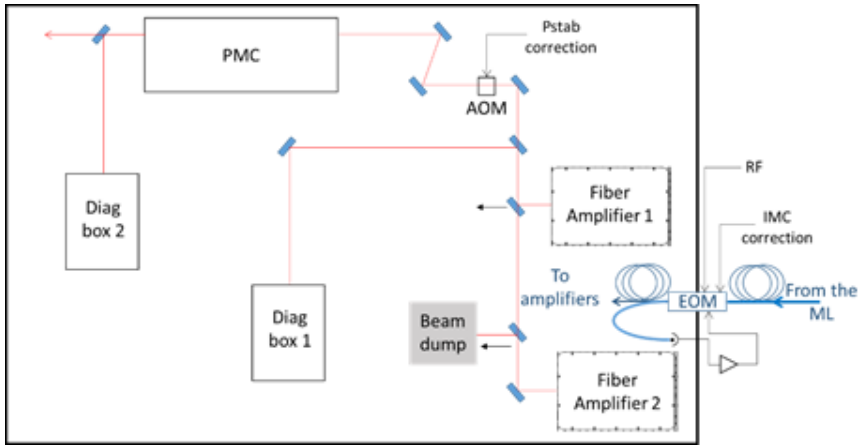


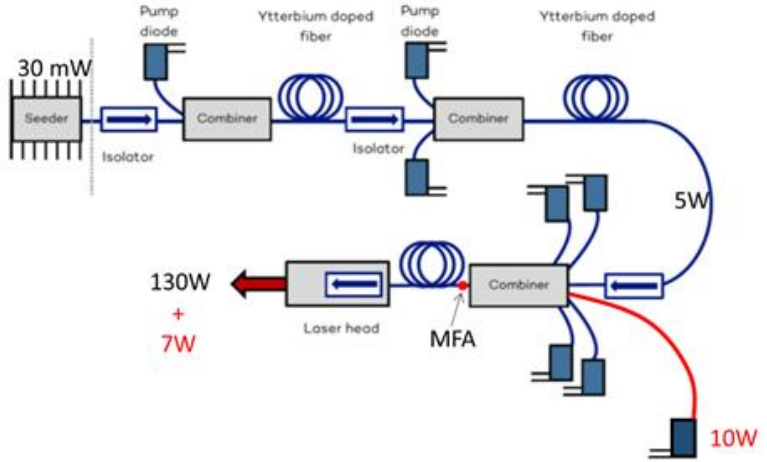


Pre-stabilized Laser

EGO - VIRGO

- PSL upgrade
  - Upgrade present Fiber Laser to higher power
  - Replace present Slave laser + Fiber Amplifier (NEOVAN) with new Fiber Laser
  - Goal: two high power fiber lasers on the same table (redundancy)

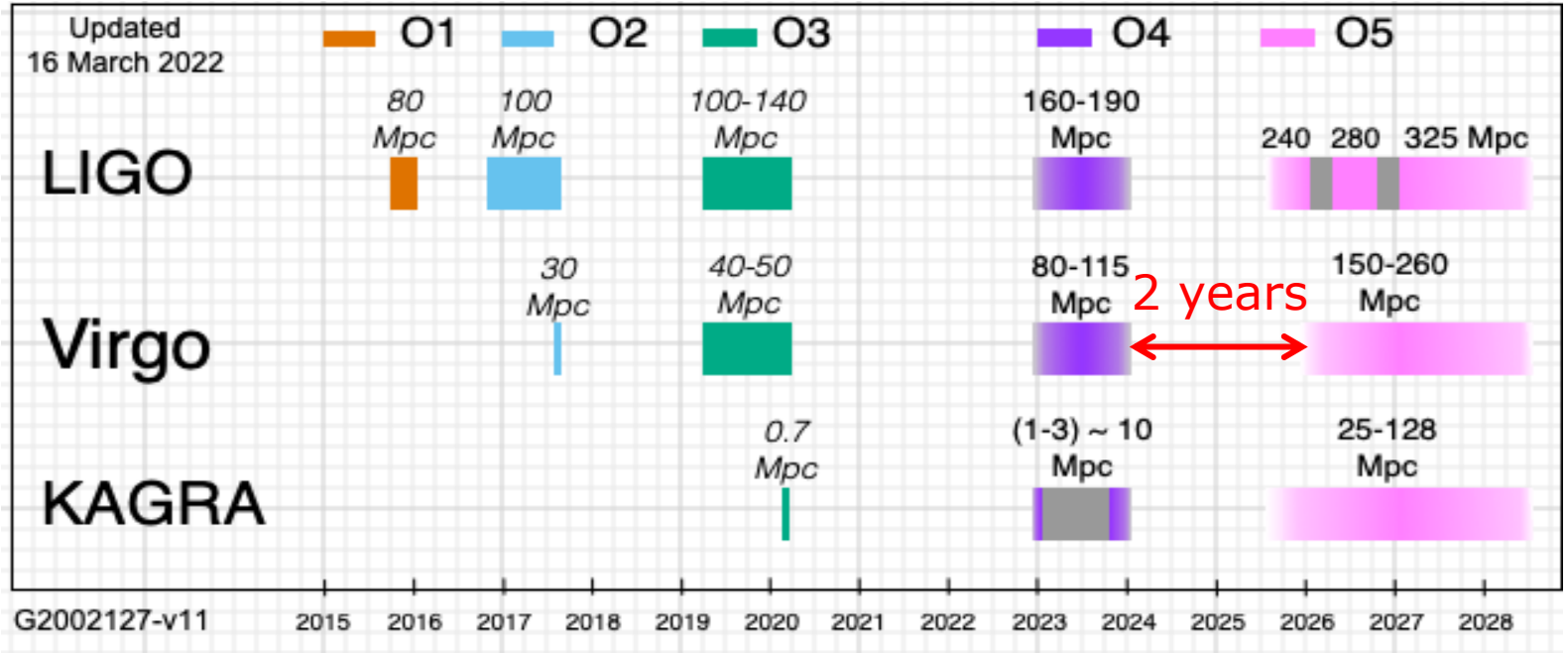




Installation & Commissioning schedule

EGO - VIRGO

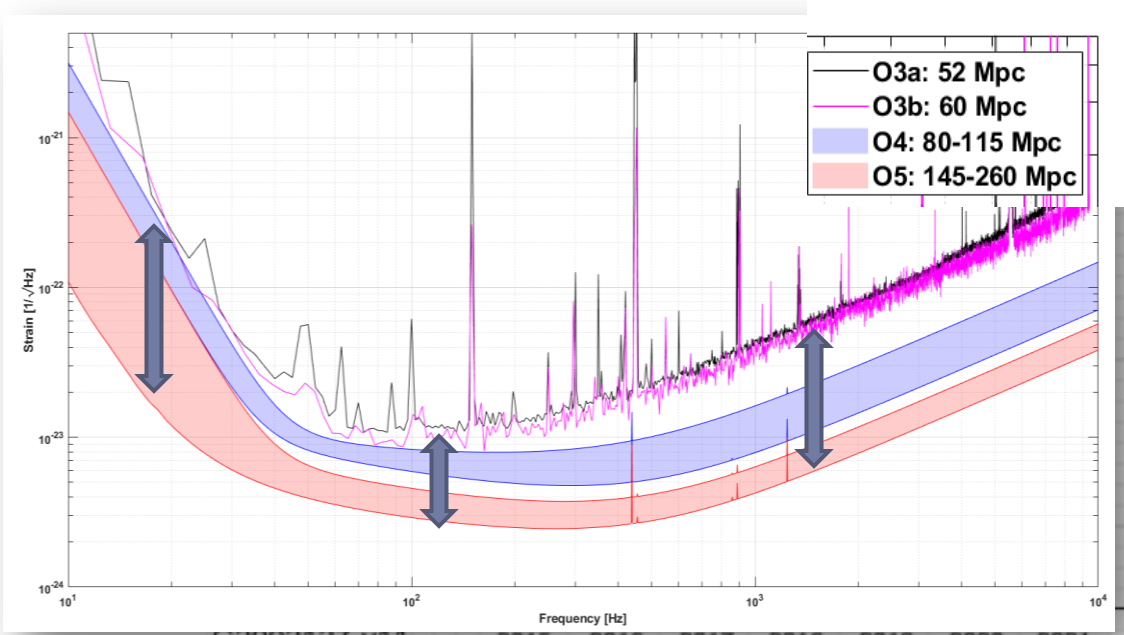
- A challenging schedule

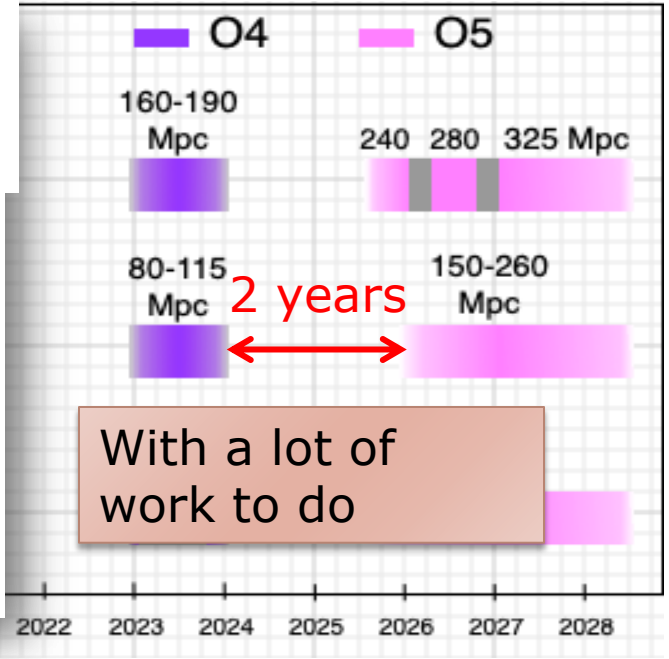


Installation & Commissioning schedule

EGO - VIRGO

- A challenging schedule





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Conclusions

EGO - VIRGO

- AdV+ Phase II
  - While commissioning for O4, preparing the upgrade for O5
  - The main goal is to push down the coating thermal noise via R&D on coating friction and enlarging the beam size on the test masses
    - Mirrors
      - Construction in progress
      - Construction of Tools & Metrology tools started
    - Coating pre-selection done, development in progress
    - First version of design report released (including costing, personpower, milestones and risks)
    - First version of WBS finalized for many deliverables
    - Budget from INFN and CNRS available
  - Challenging schedule: 2 years for very invasive installation and then commissioning, and let's not forget about *technical noises*
  - Aiming to increase the reach by almost a factor 3 wrt phase I: challenging but exciting quest, with huge impact on observational science (see T. Dal Canton talk)

Thank you


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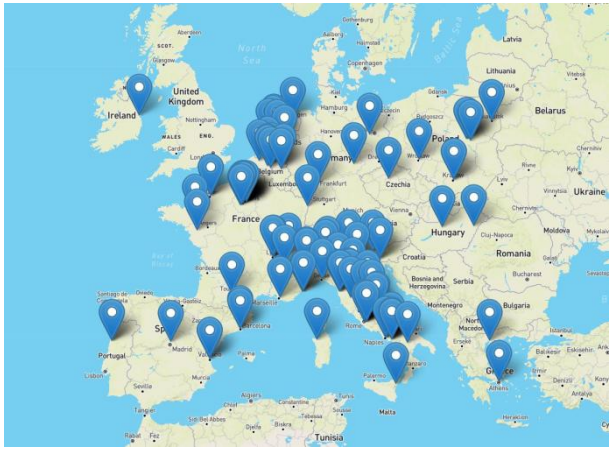
INFN
Istituto Nazionale di Fisica Nucleare
cnrs
Nikhef

The Virgo Collaboration

~760 members, ~450 authors,
128 institutions from 15 countries

9 countries represented in the VSC Virgo



Credits G. Losurdo

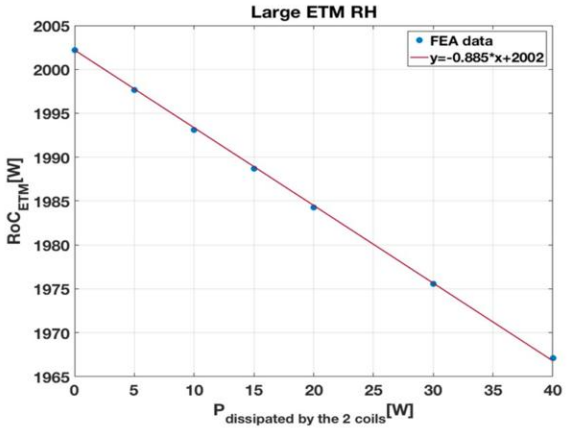
Bonus Slides

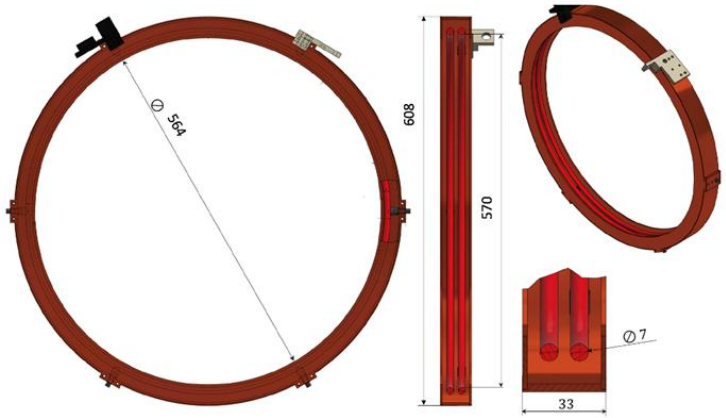
EGO - VIRGO

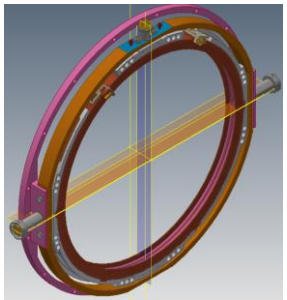
Large Ring Heaters

EGO - VIRGO

- Goal: fine control of RoC i.e. cavity g-factor
- Large ring heaters for large mirrors
  - Prototype being built



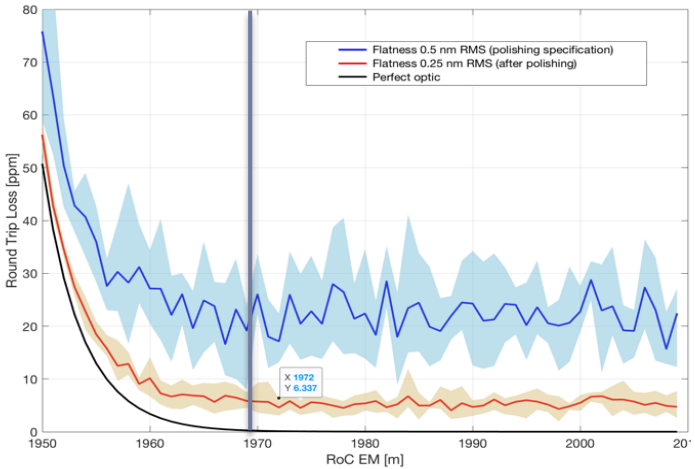


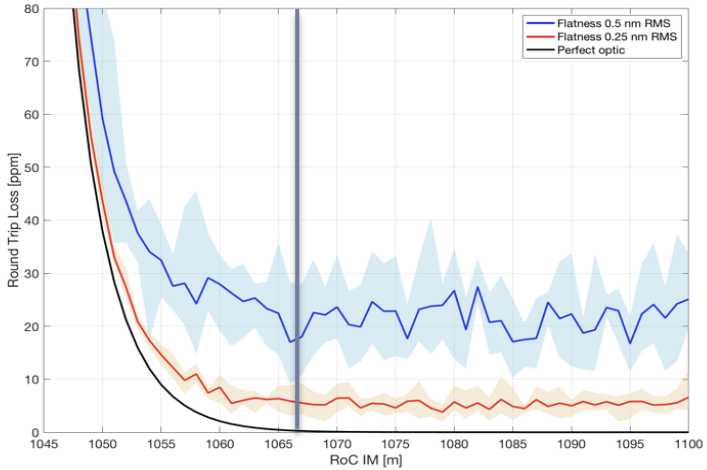


Cavities geometry

EGO - VIRGO

- Round trip losses
  - Polishing specifications
    - AdV-like specifications are OK
    - To be realized on 235 mm aperture (it was 150 mm for AdV)





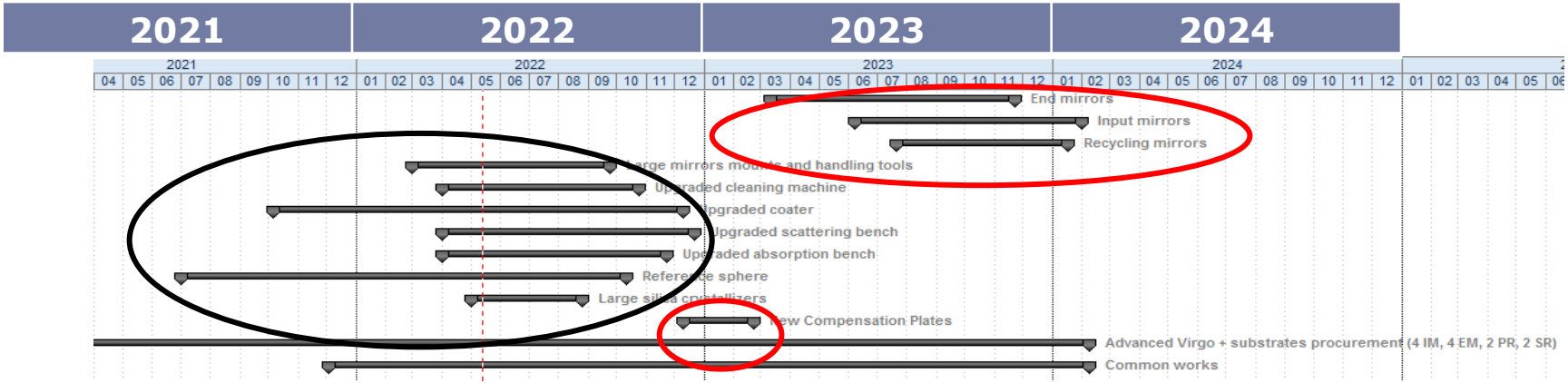
Large Mirrors: Schedule

EGO - VIRGO

- Project critical path since the beginning

Tools & Metrology

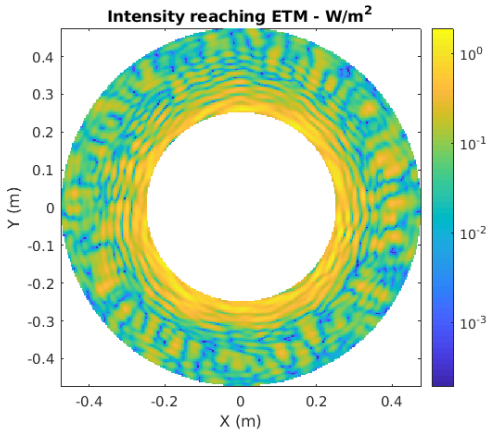
Coatings

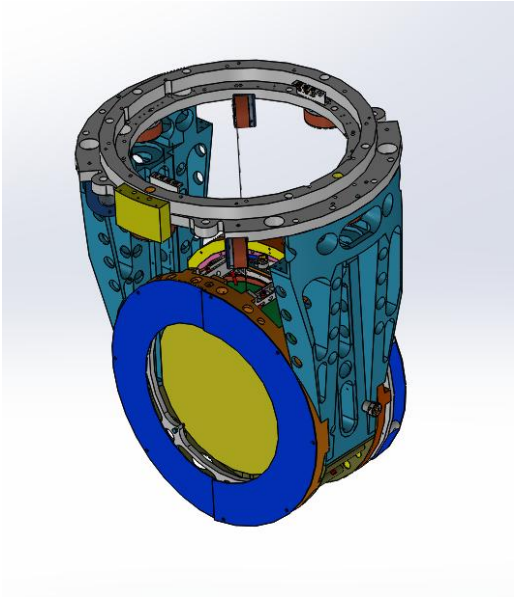


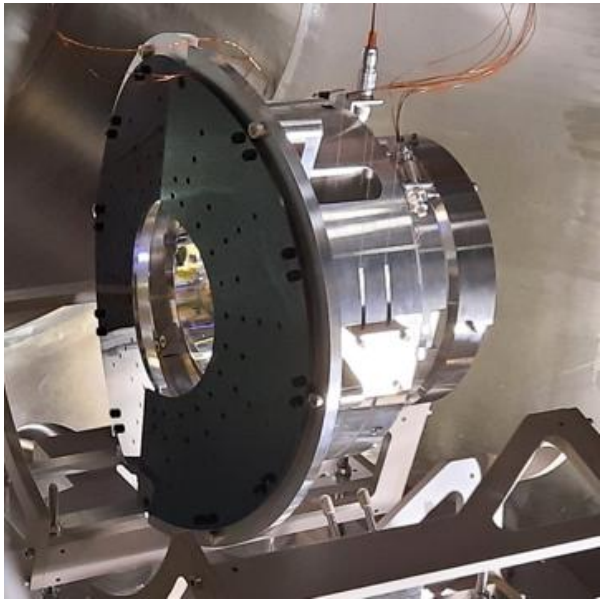
Instrumented Baffles for Large Mirrors

EGO - VIRGO

- Goal: monitor scattered light in the arm cavities
- Large payloads will be equipped with instrumented baffles

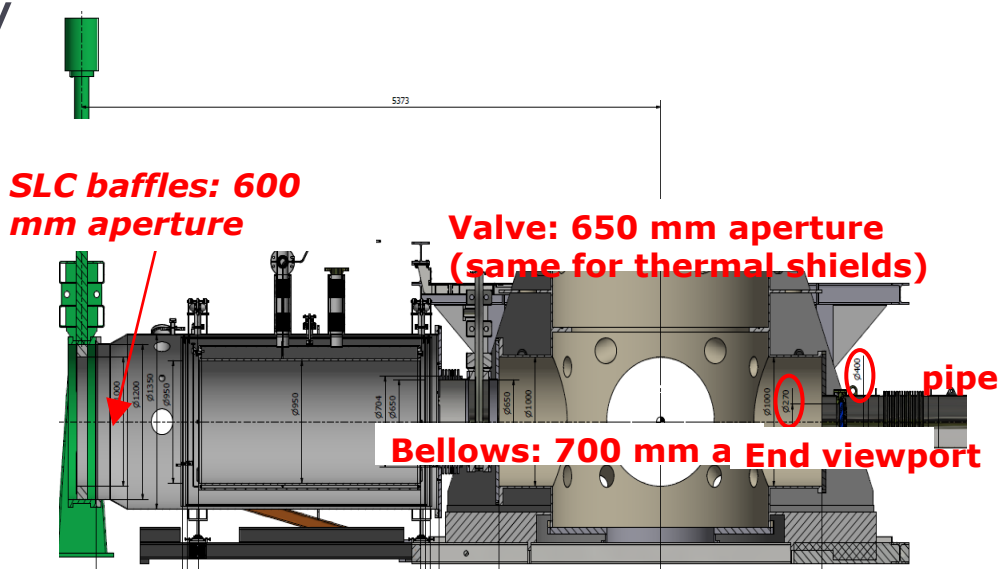






Vacuum

- Enlarge end links to mitigate scattered/diffracted light risk due to large beam
  - Necessity under study



Vacuum

EGO - VIRGO

- Question:
  - Given the beam size (20 cm diameter, 2w) and the end baffle aperture (60 cm diameter) are we going to have scattered/diffracted light noise from the baffle?
- Two effects considered
  - Backscattering from cryo-baffle
  - Diffraction from baffle edges
- Results
  - Effect should be negligible
  - Only exception: point absorbers and high power in the cavities (390 kW)
    - Could be solved if no point absorbers in O5 mirrors