Status of the Advanced Virgo detector

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on behalf of

The Virgo Collaboration

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Talk outline

- The Advanced Virgo challenges
- Where we stand and what we are going to do
- Construction and integration highlights
- Perspectives and conclusions

The Advanced Virgo project

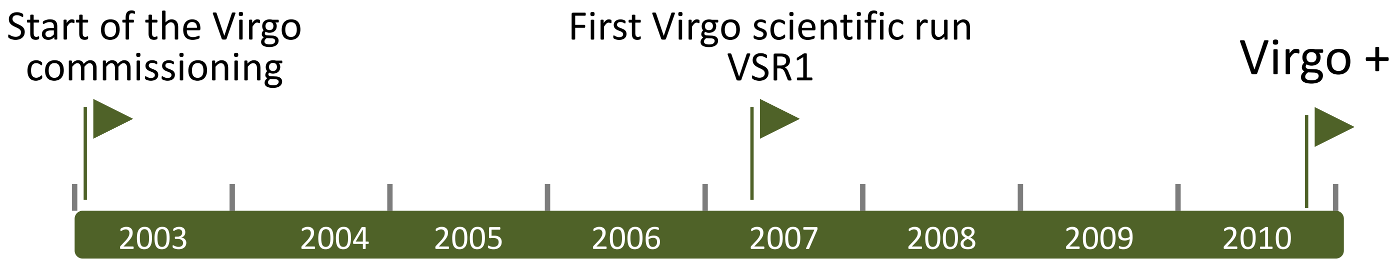
Advanced Virgo is a major upgrade of the Virgo ground based gravitational wave interferometric detector

The project involves:
5 countries, 20 labs and ~200 authors.

APC Paris
ARTEMIS Nice
EGO Cascina
INFN Firenze-Urbino
INFN Genova
INFN Napoli
INFN Perugia
INFN Pisa
INFN Roma La Sapienza
INFN Roma Tor Vergata
INFN Trento-Padova
LAL Orsay – ESPCI Paris
LAPP Annecy
LKB Paris
LMA Lyon
NIKHEF Amsterdam
POLGRAW(Poland)
RADBOUD Uni. Nijmegen
RMKI Budapest

The short history

- 1st generation of interferometric GW detectors:
  LIGO, Virgo, GEO600



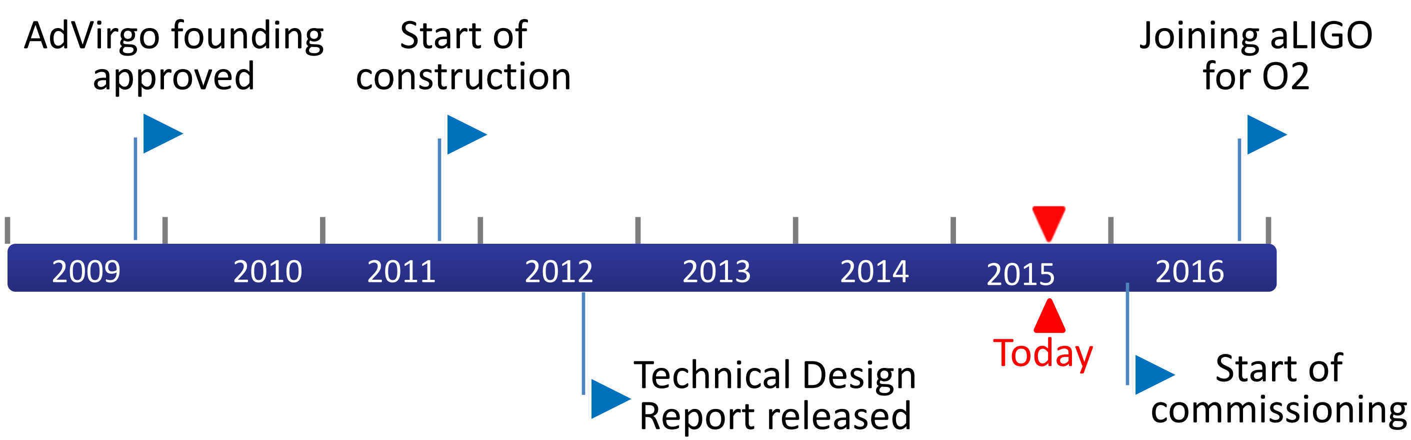
Unlikely detection

Validation of GW ground based interferometric technologies

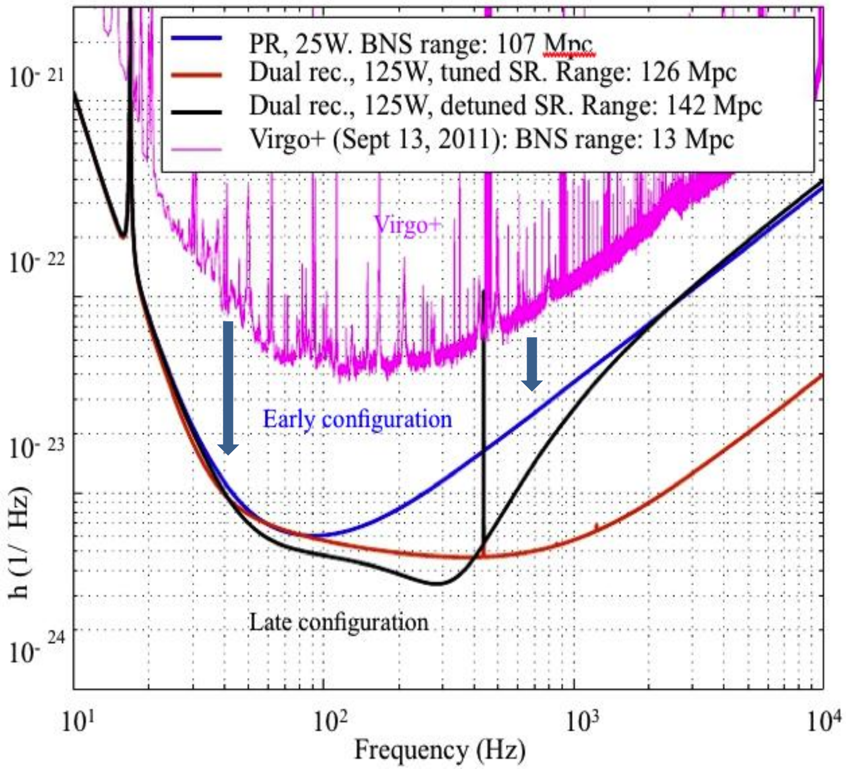
- 2nd generation of interferometric GW detectors :
  aLIGO, AdVirgo, GEOHF, KAGRA, LIGO India

Likely detection

Beginning of routine observation towards a GW astronomy

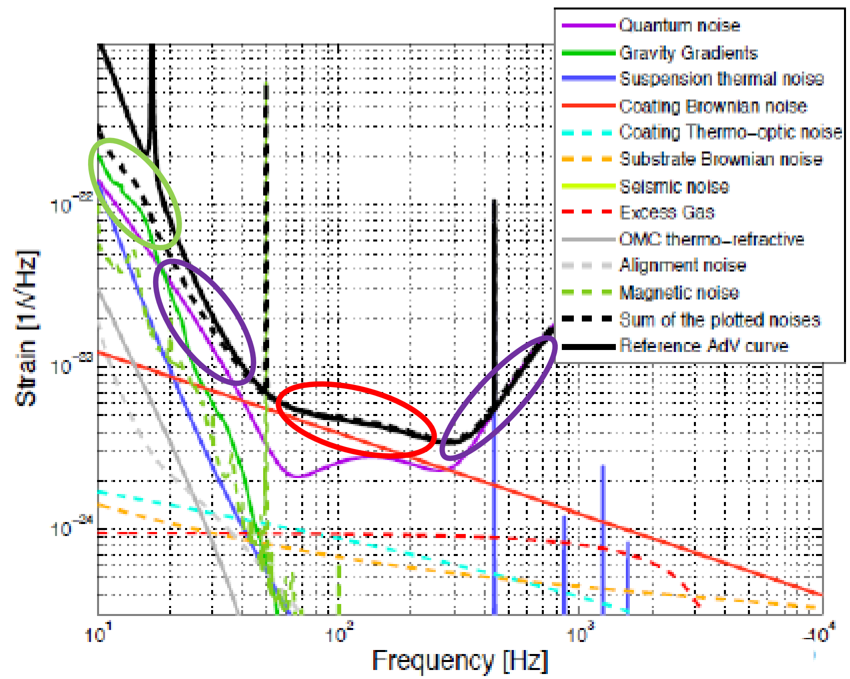


The sensitivity curve



The sensitivity improves by a factor 10 compared to initial Virgo

An increment in volume & event rate of a factor 1000



The AdVirgo limiting fundamental noise:

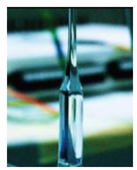
- Gravity gradients (f < 20Hz)
- Quantum noise
    - ✓Radiation pressure noise (20Hz < f < 40Hz)
    - ✓Shot noise (f > 300Hz)
- Thermal noise, mostly from mirror coating (40Hz < f < 300Hz)

The main changes: how to gain a factor 10

The low and medium frequency range

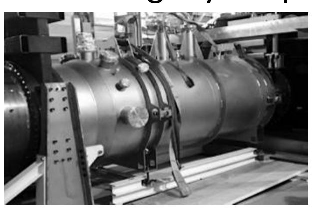
• Lowering the thermal noise of suspensions and mirrors:

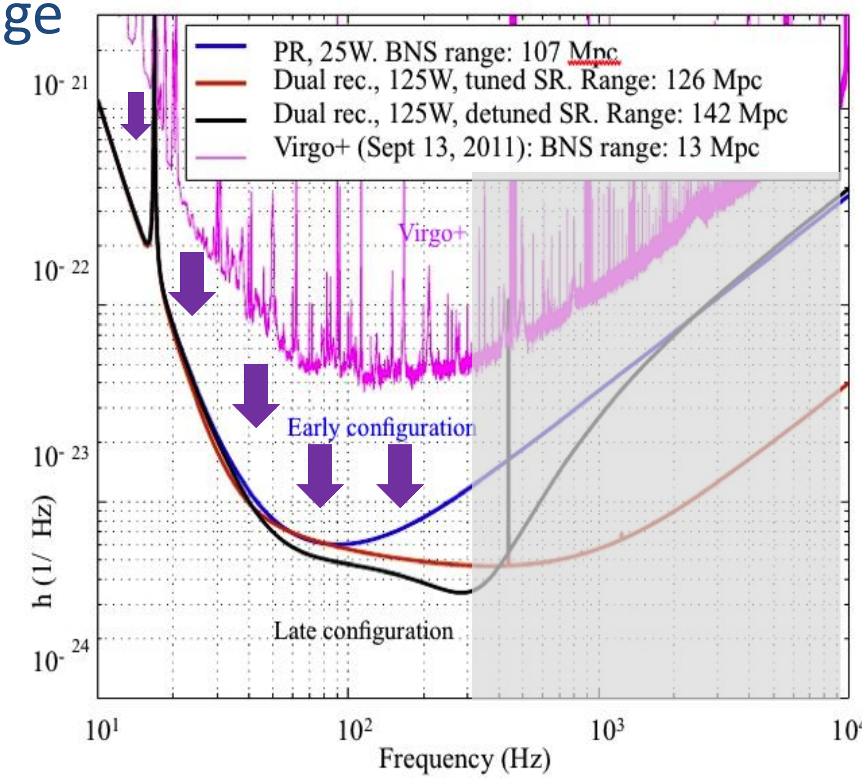
✓Doubling the mirror weight (42kg)
✓Suspending the mirrors with fused silica fibres
✓Enlarging the beam size on the test masses
✓Mirror coatings engineered for low dissipations



• Lowering the residual gas noise:

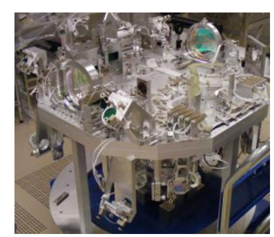
✓ installing cryotraps

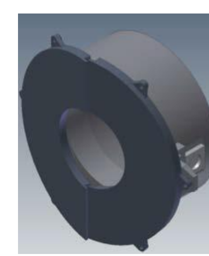




•Limiting the environmental noise:

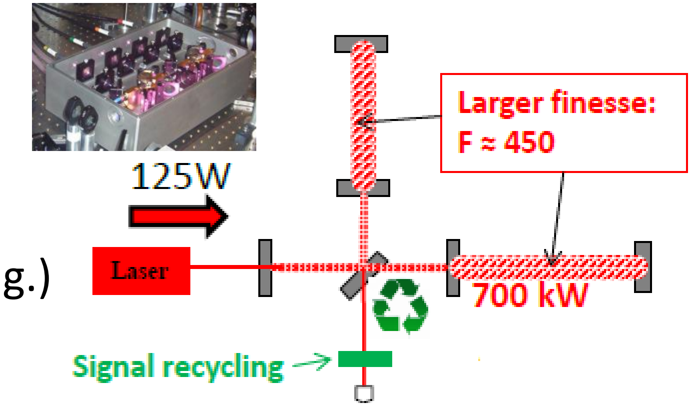
✓Photodiodes under vacuum on suspended benches
✓Baffles to shield tubes, mirrors, vacuum chambers preventing scattered light diffusion



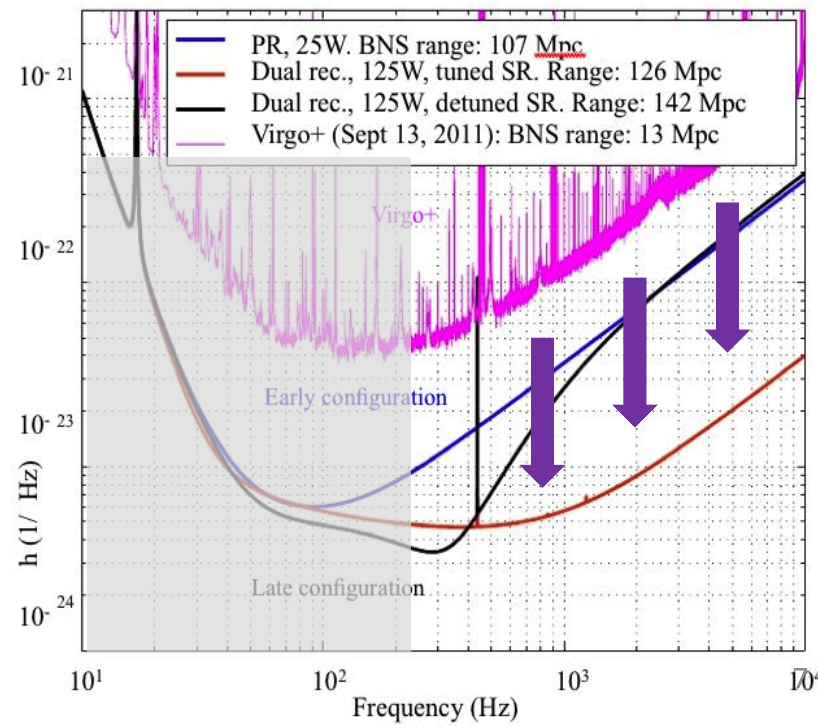


The main changes: how to gain a factor 10

The high frequency range



- Lowering the shot noise:
  - ✓ High power laser (125W in last config.)
  - ✓ High finesse Fabry-Perot cavities
  - ✓ Signal recycling technique
  - ✓ DC detection



High power requires:
- New laser system
- Very high quality optics with very low absorption
- High performance thermal compensation system

A step by step approach

The mail goal is to join aLIGO in 2016 observational runs

Reach the early configuration sensitivity :
- no signal recycling
- no high power laser (up to 25W)

Reducing :
- locking complexity (optics configuration similar to Virgo+)
- the thermal effects and the compensation system requirements

Further steps towards the full sensitivity will be planned with the partners

BNS inspiral range evolution (1.4-1.4 Mo)

150 Mpc

100 Mpc

15 Mpc

Virgo+ AdVirgo early AdVirgo full

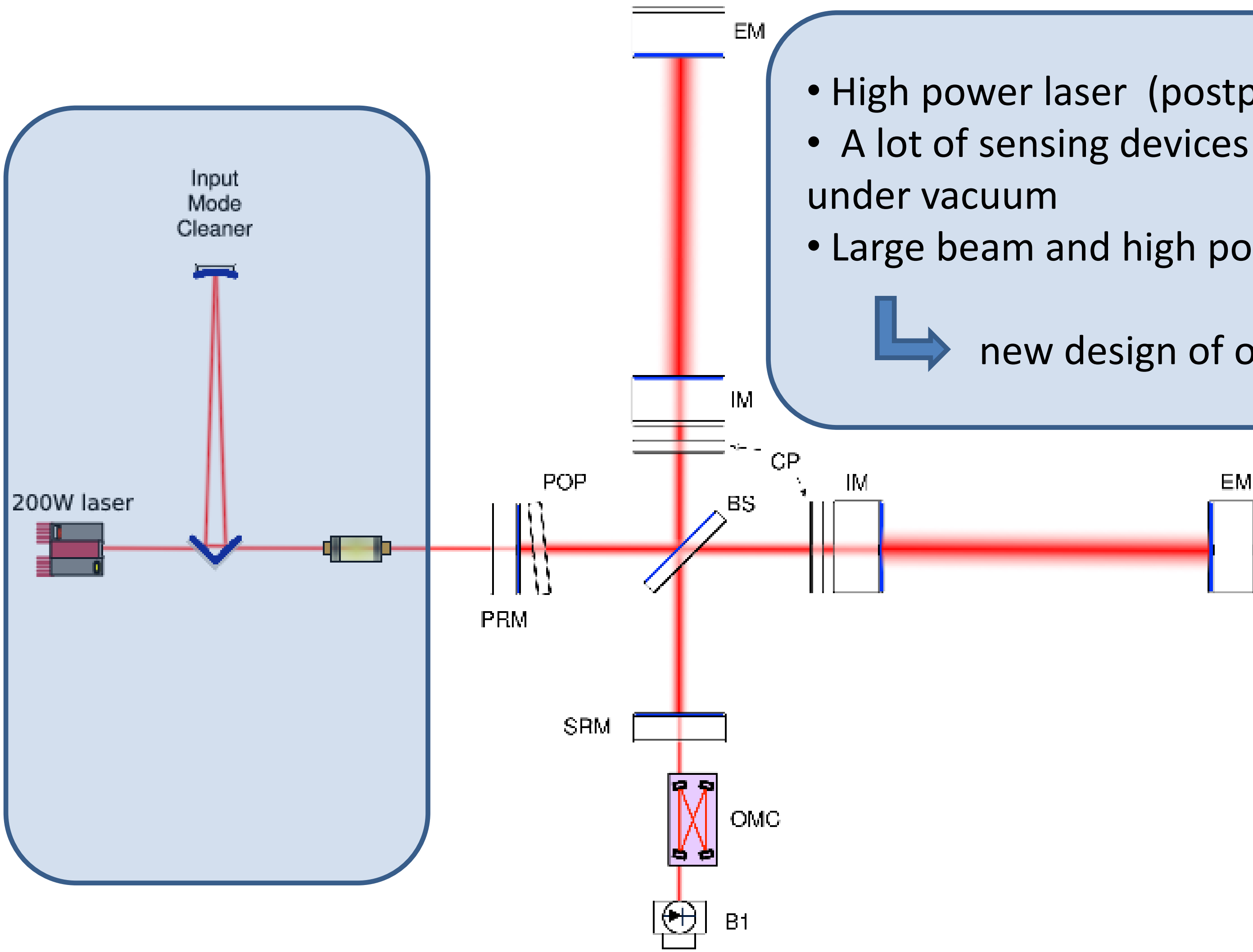
Construction and integration highlights

Construction and integration highlights

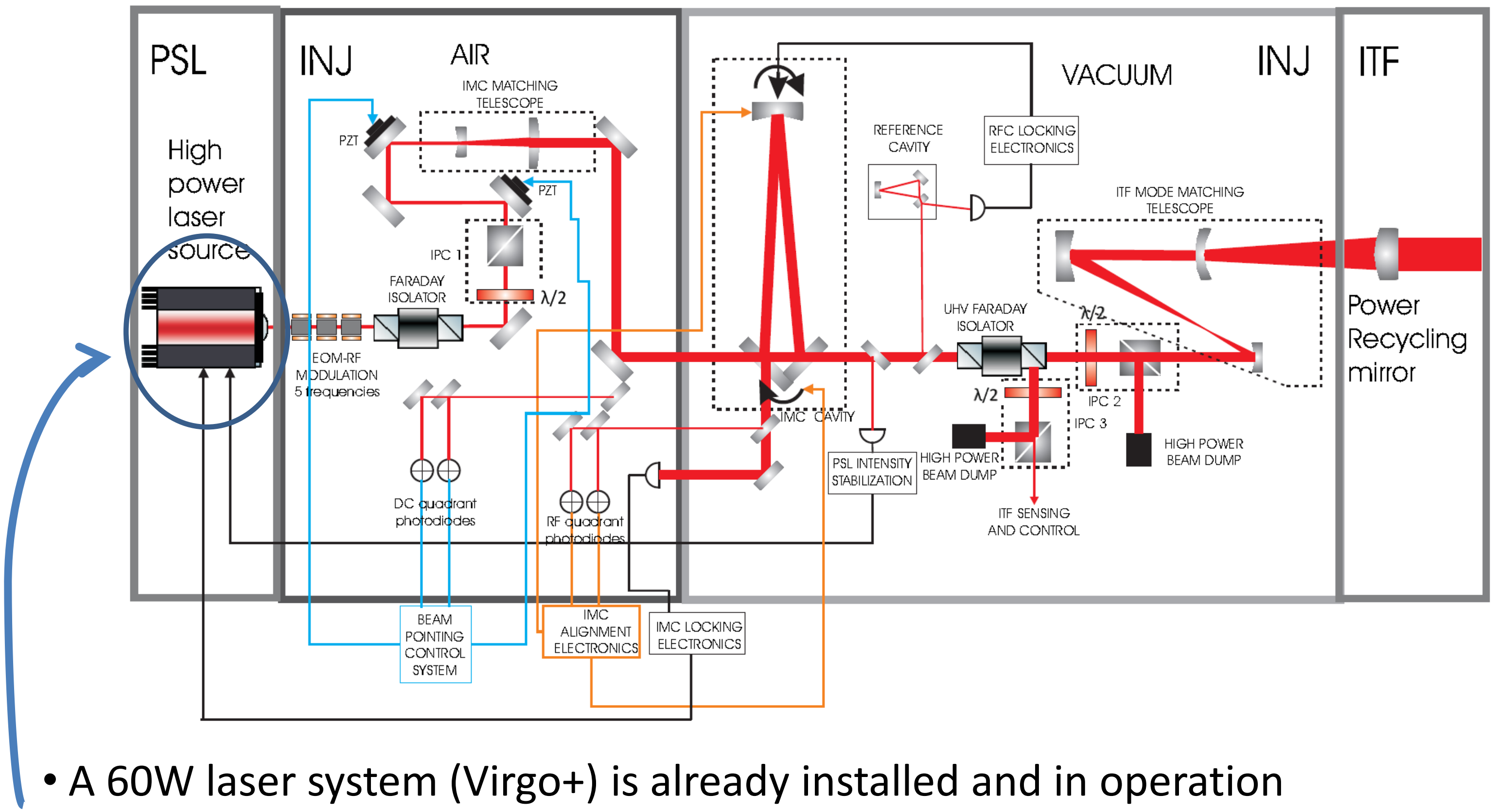
The light source and injection

- High power laser (postponed)
- A lot of sensing devices and electronics under vacuum
- Large beam and high power

  ↳ new design of optical benches

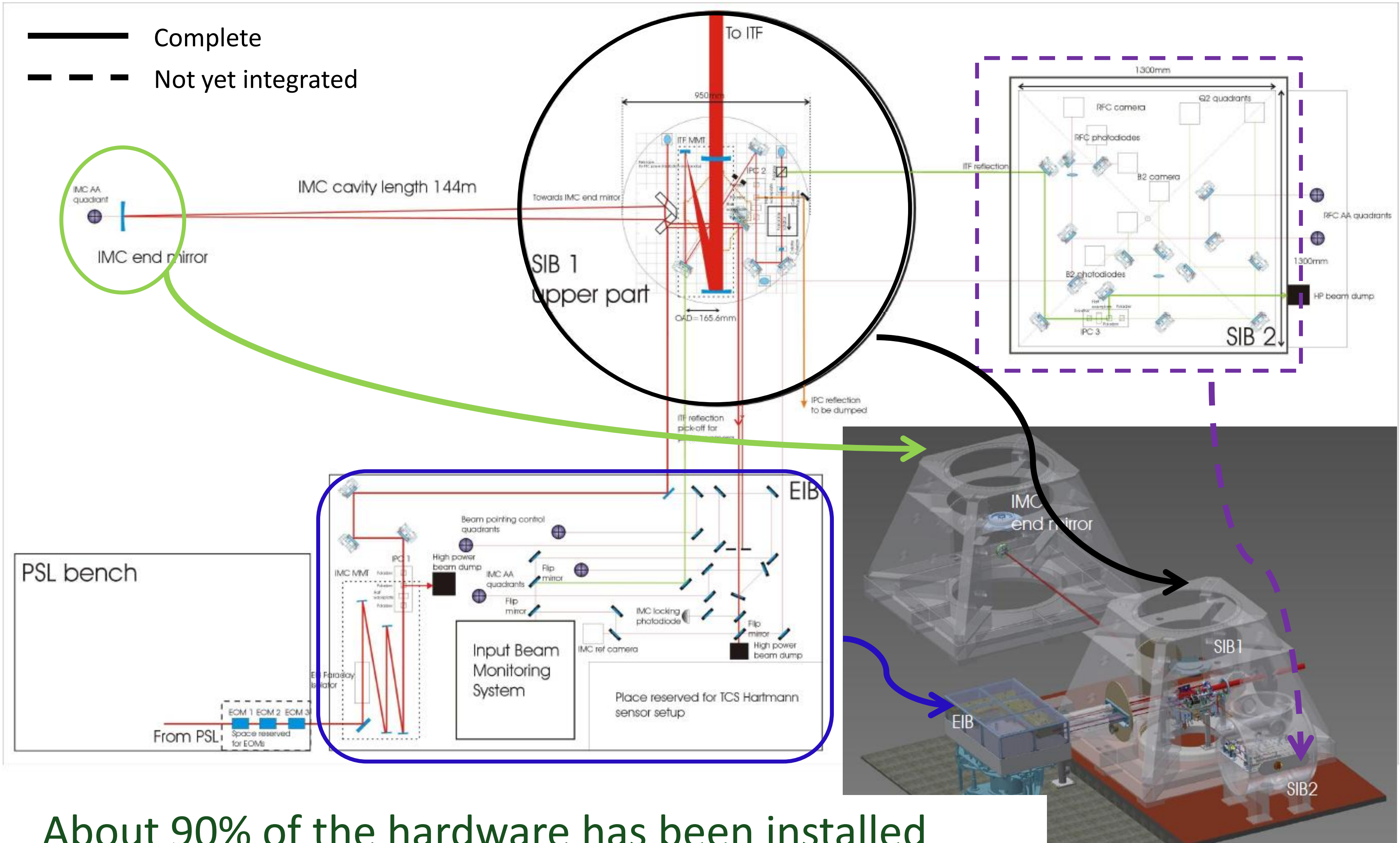


Light source and injection



- A 60W laser system (Virgo+) is already installed and in operation
  - The power stabilization works at 23W and all the noise spectrum is well understood
- The high power laser amplifier is under tests:
  - ✓the AdVirgo requirements are satisfied in terms of lifetime stability and intensity noise
  - ✓Full scale integration test are ongoing.

Light source and injection



About 90% of the hardware has been installed

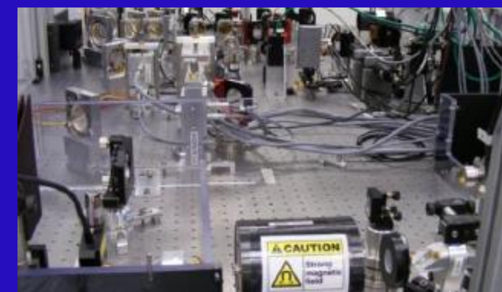
Advanced Virgo

Light source and injection

SIB1

Installed & integrated in tower

The EIB in the Laser lab



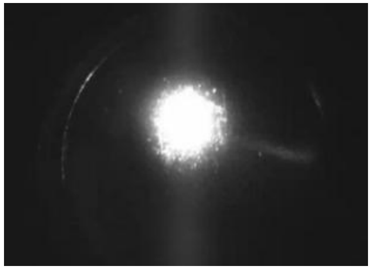
SIB2 completed

Minitower installed

Integration is ongoing

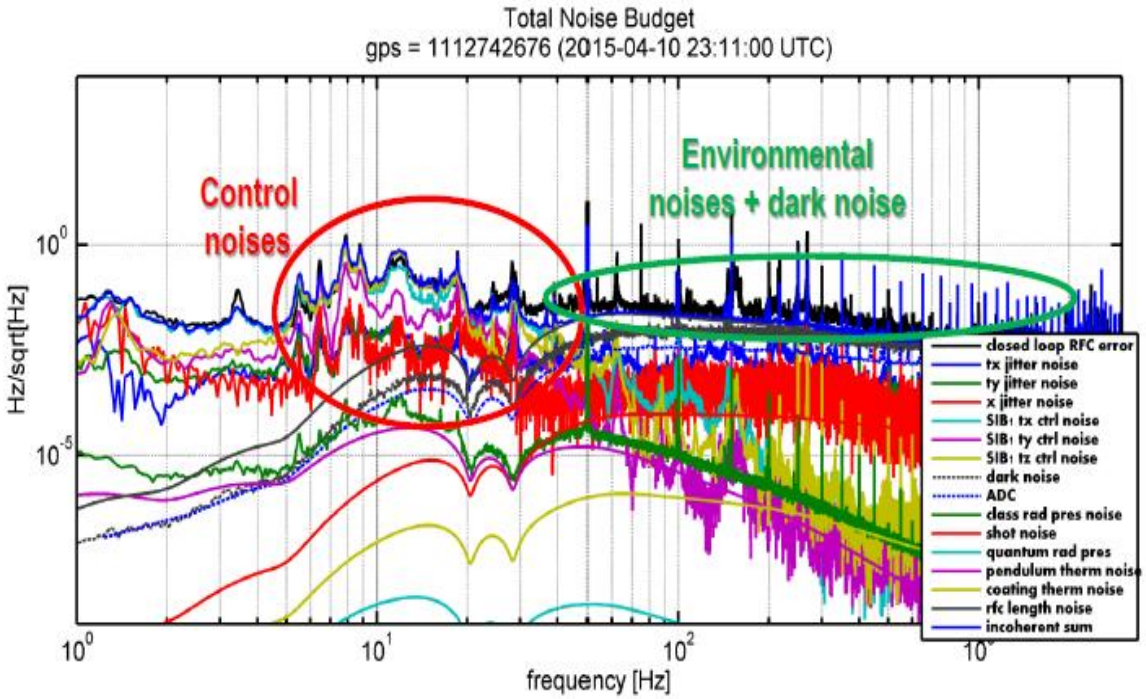
The IMC end mirror in tower

Light source and injection



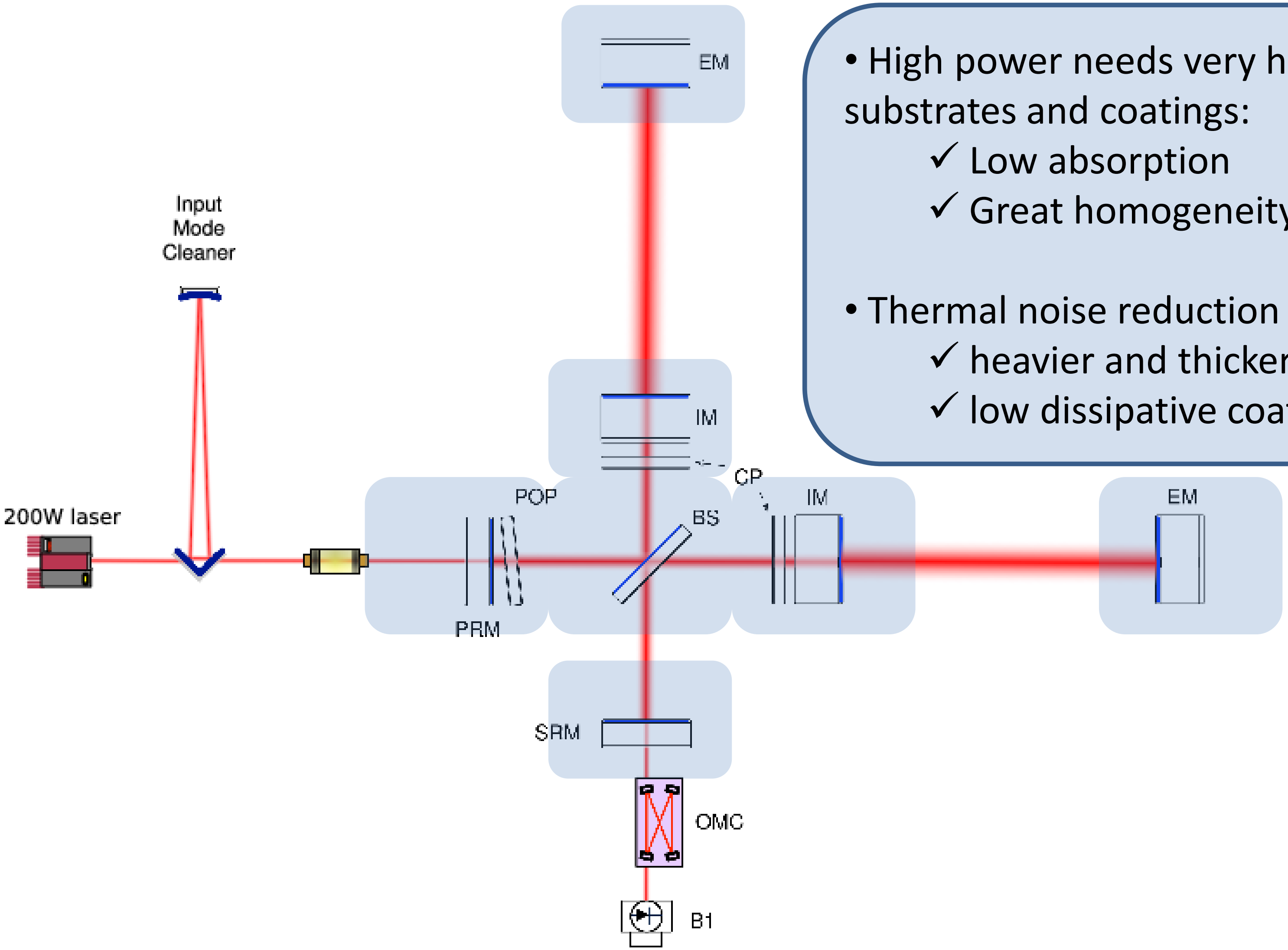
- The Input Mode Cleaner commissioning has started one year ago
- Duty cycle continuously improving (99% during weekends)
- Tested up to 31W of input power

- Reference cavity locked since November 2014
- The noise has been reasonably well understood
- The noise hunting is ongoing



Construction and integration highlights

Mirrors



- High power needs very high quality substrates and coatings:
  - ✓ Low absorption
  - ✓ Great homogeneity
- Thermal noise reduction needs:
  - ✓ heavier and thicker mirrors
  - ✓ low dissipative coatings

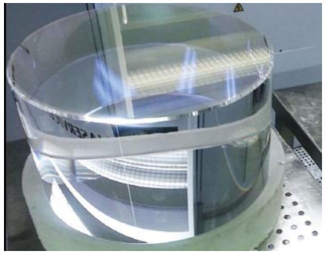
Mirrors

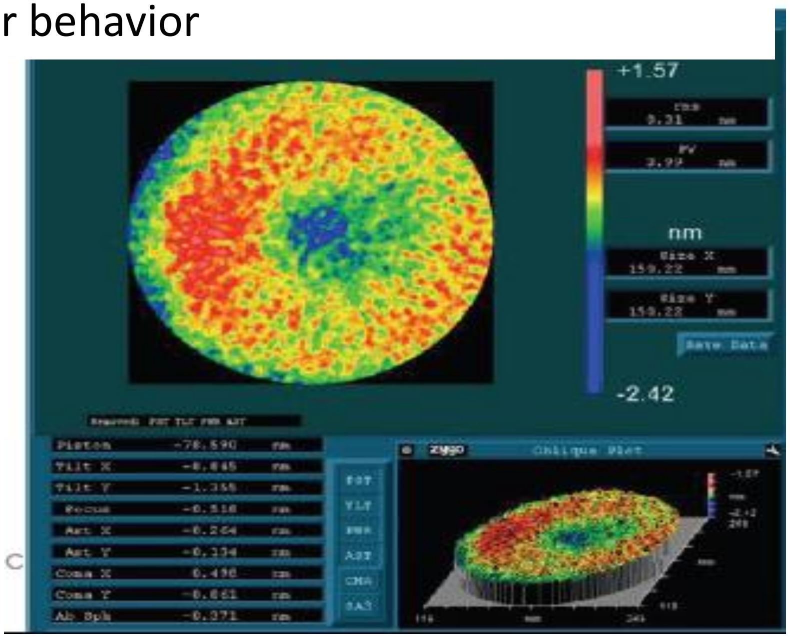
- All the AdVirgo large mirrors have been completed on schedule

✓The mirror figures are better than the specifications

Risk reduction for aberration and scattered light

Mirror “maps” are used in simulations to predict the interferometer behavior



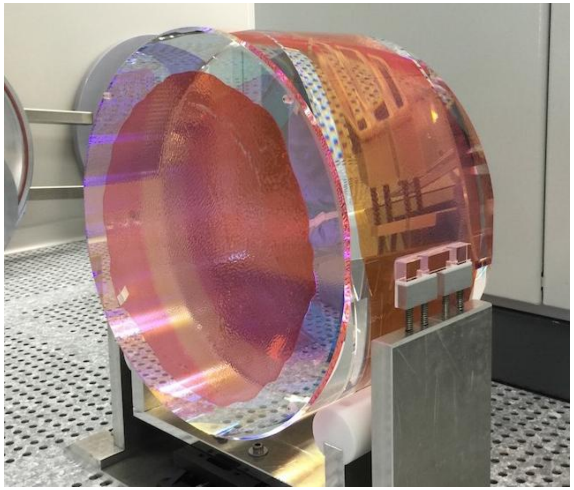


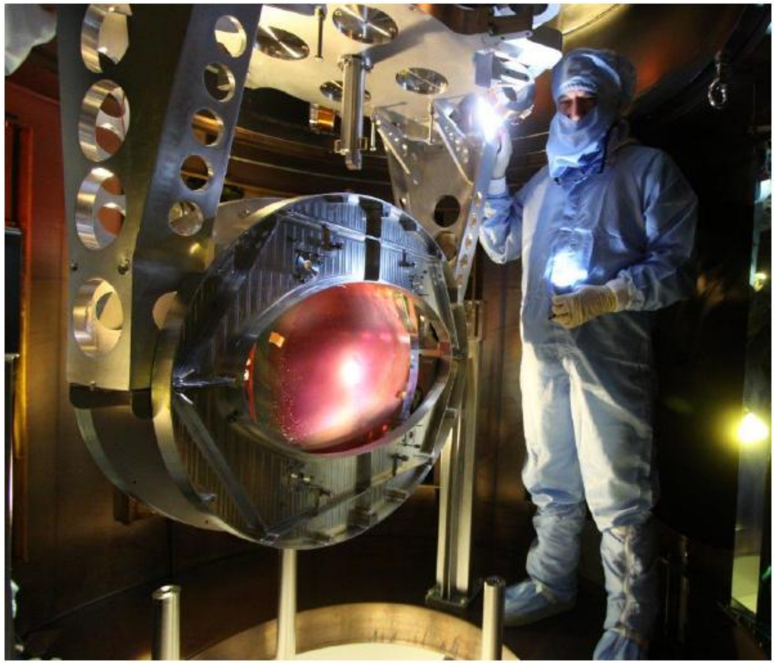
	Advanced VIRGO Requirements	LMA Measurements
Incidence 0°	removed)	∅150 mm
Radius of Curvature (m) Surface 1	1425 +/- 10 m ∅ 150 mm	1424.56 m ∅150 mm
Astigmatism amplitude (Zernike term)°	< 5nm ∅ 150 mm	0.52 nm ∅150 mm
Transmitted wavefront Incidence 0° (before coating)	x	0.77 nm RMS ∅150 mm (Curvature removed)
Average Scattering (45° incidence) Surface 1	< 10 ppm ∅ 150 mm	3 ppm ∅ 150 mm
Absorption HR Surface 1	< 0.5 ppm	0.22 +/- 0.06 ppm ∅150 mm
Transmission at 1064 nm 1° incidence	1.4 +/- 0.1%	1.375 % +/- 0.007% ∅150 mm
Transmission at 532 nm 0° incidence	0.5% < T< 2%	1.01% (witness sample, spectrophotometric measurement)
Reflectivity AR Surface 2 at 1064 nm 3° incidence	<100 ppm	58 +/- 9 ppm ∅ 150mm
Reflectivity AR Surface 2 at 800 nm 0° incidence	<1%	# 0.1% (witness sample, spectrophotometric measurement)
Reflectivity AR Surface 2 at 532 nm 0° incidence	<2%	# 0.2% (witness sample, spectrophotometric measurement)

Mirrors

• The “ears” have been silicate bonded to the mirror flats on 3 over 4 test masses

• Each bonding strength is tested



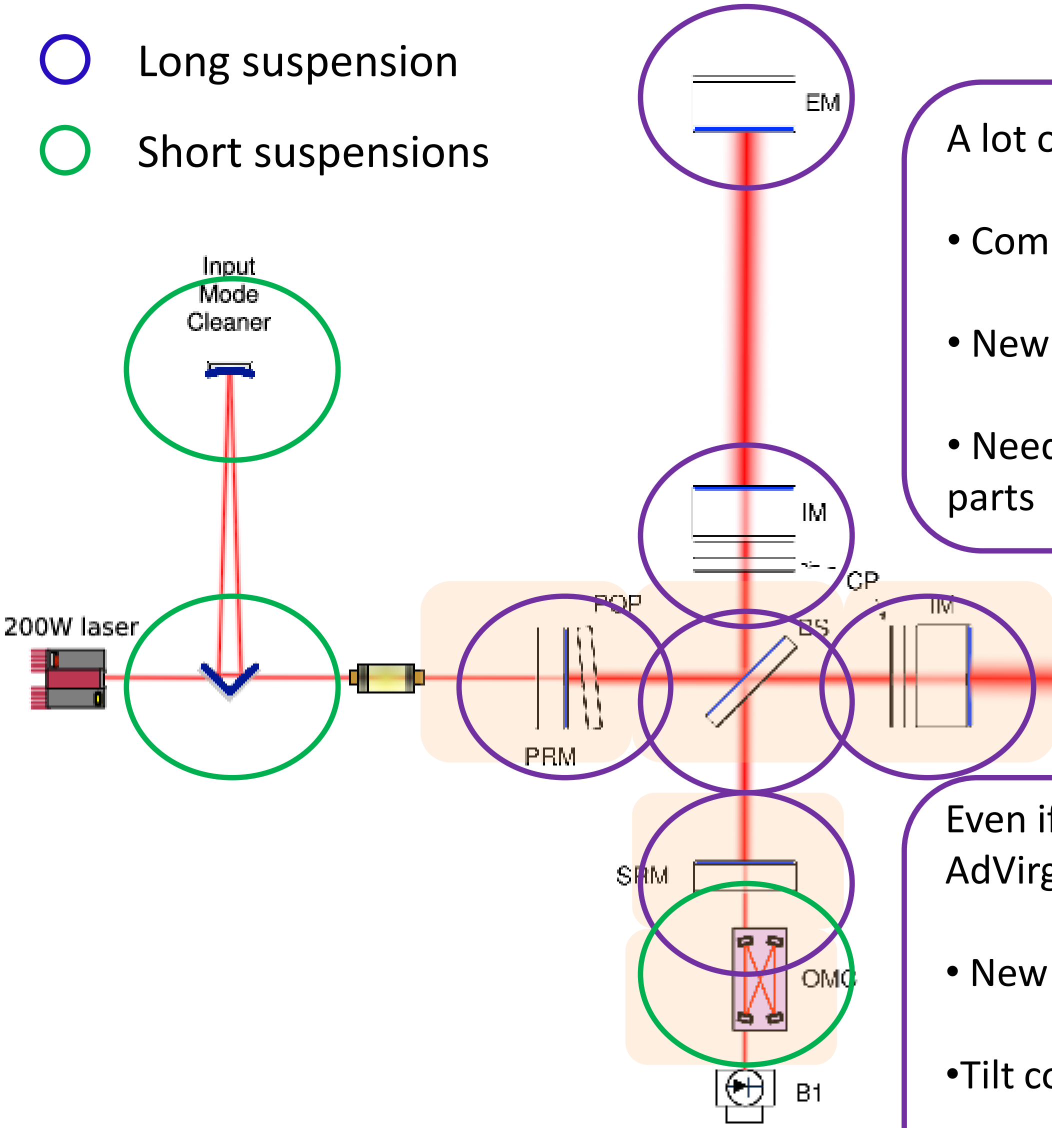


The beam splitter has been the first large mirror integrated in tower

A large beam needs a large BS: 550 mm diameter

Construction and integration highlights

The Suspensions



A lot of changes on the last stage:

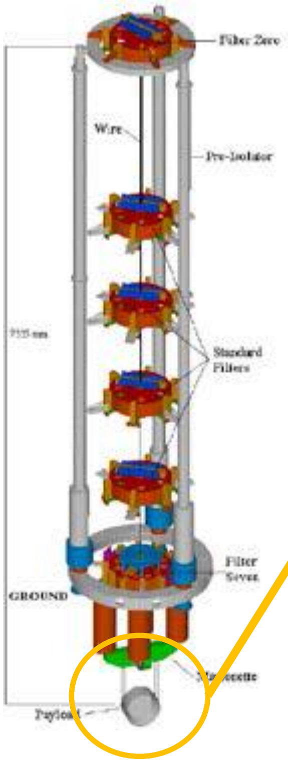
- Compliant with the new mirrors
- New Fused silica fibres design
- Need to host many new optical and mechanical parts

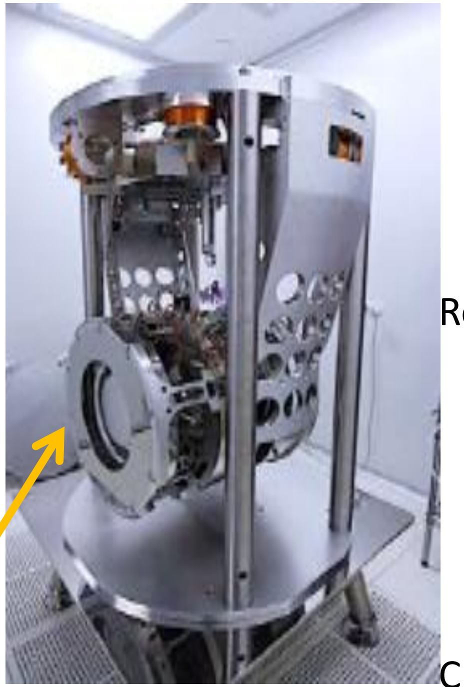
Even if Virgo SAS performances already fit the AdVirgo general specifications:

- New filter 7 matching the new payloads
- Tilt controls
- New electronics

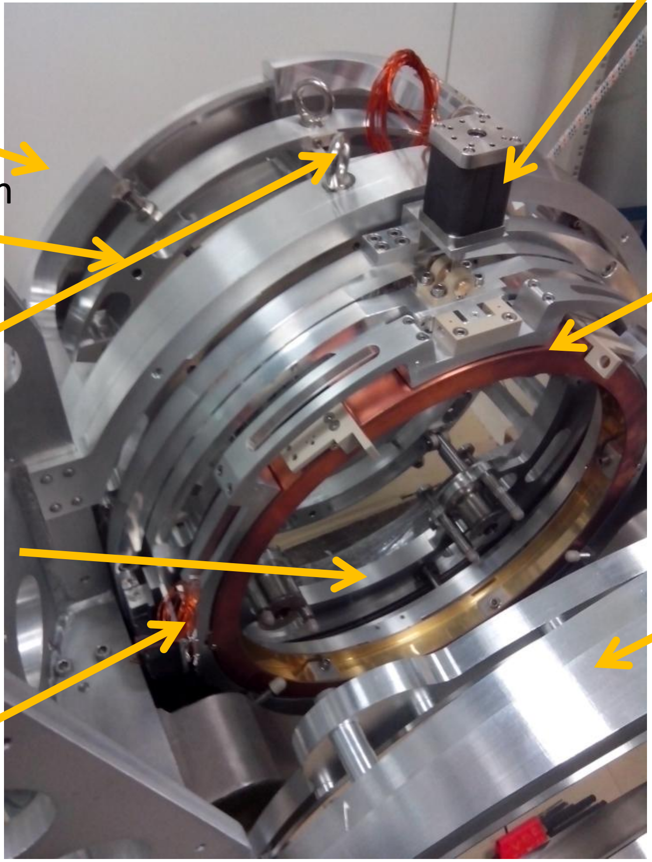
Suspensions

The last stage





- Completely redesigned to host the new mirrors and many other optical and mechanical components:
ring heater, compensation plates, baffles, adjustment motor…



Many critical elements to be crammed into the available space and weight

Suspensions

The Mirrors fused silica suspension

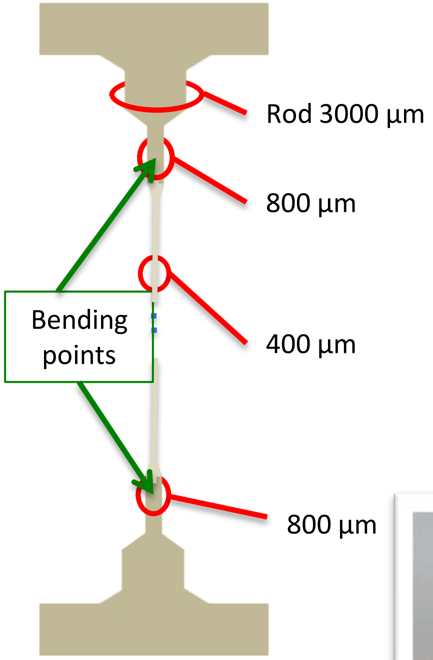
The monolithic test mass suspension of Virgo+ has been largely upgraded:

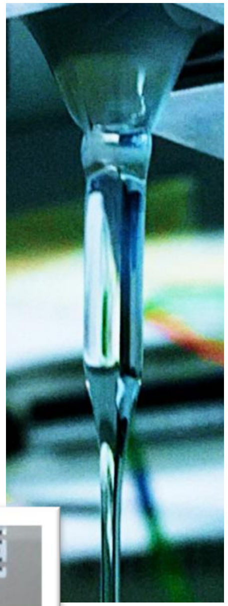
- Less dissipative fused silica-steel upper clamp
- Dumbbell fiber shape to cancel thermoelastic dissipation
- Improving the fibers production and characterization, increasing the fiber length and profile accuracy and reproducibility

⇓

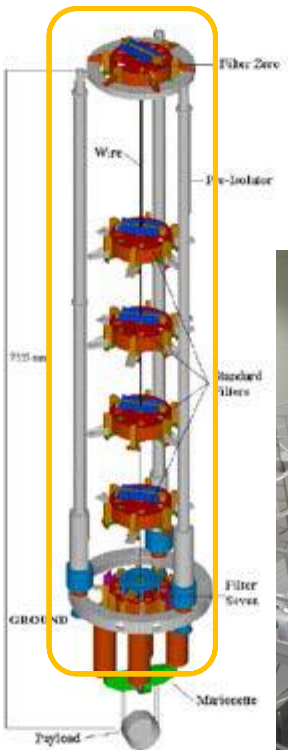
The AdVirgo specification on mirror positioning and maximum tilt angle (1mrad) can be fulfilled

- Better accuracy of the bending points placement





Suspensions



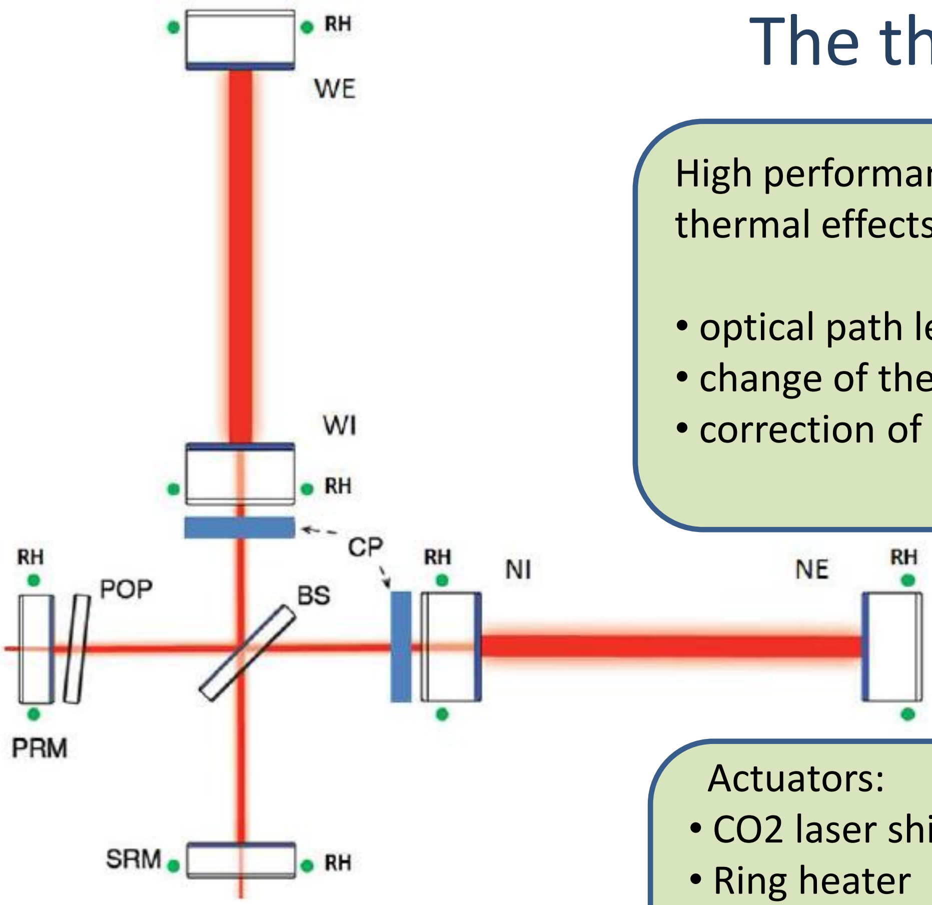
Works are ongoing to upgrade the suspension system:

The upgrades/integration table:

Tower/ minitower	SA/MSAS completed	Mirror/bench integrated
IB		
MC		
DET		
BS		
WI		
NI		
PR		
SR		
WE		
NE		

The electronics has been redesigned from scratch: integration foreseen in fall 2015

Construction and integration highlights



The thermal compensation

High performance system to reduce aberration due to thermal effects and cold mirror defects:

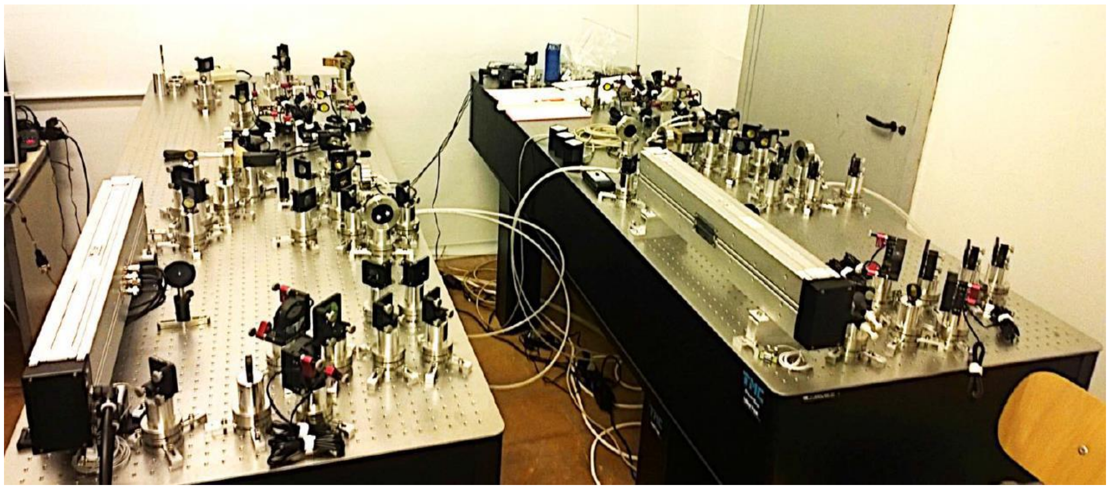
- optical path length distortions
- change of the mirror surface profiles
- correction of the radius of curvature errors

Actuators:
- CO_2 laser shining compensation plates
- Ring heater

Sensing:
- Hartmann sensor
- Phase camera

Thermal compensation

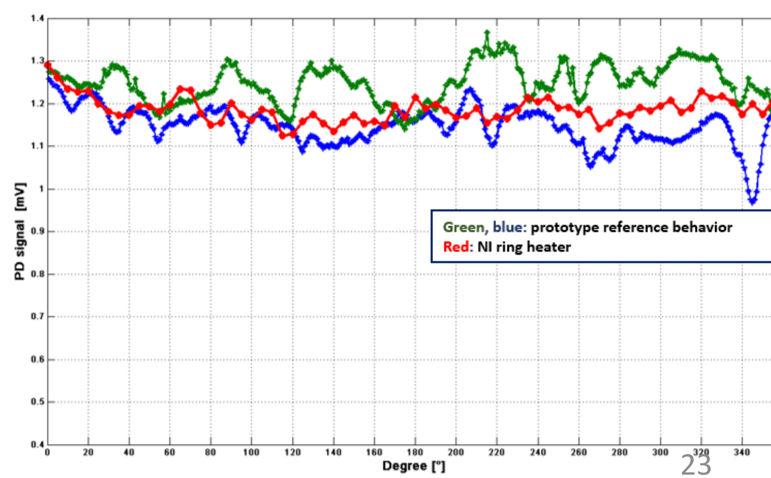
The actuators



- CO2 laser has been characterized
- CO2 laser benches almost complete
- Acoustic enclosure already on site

- The ring heaters production and integration will follow the payloads integration planning

- The first installed RH follows the prototypes behavior



Thermal compensation

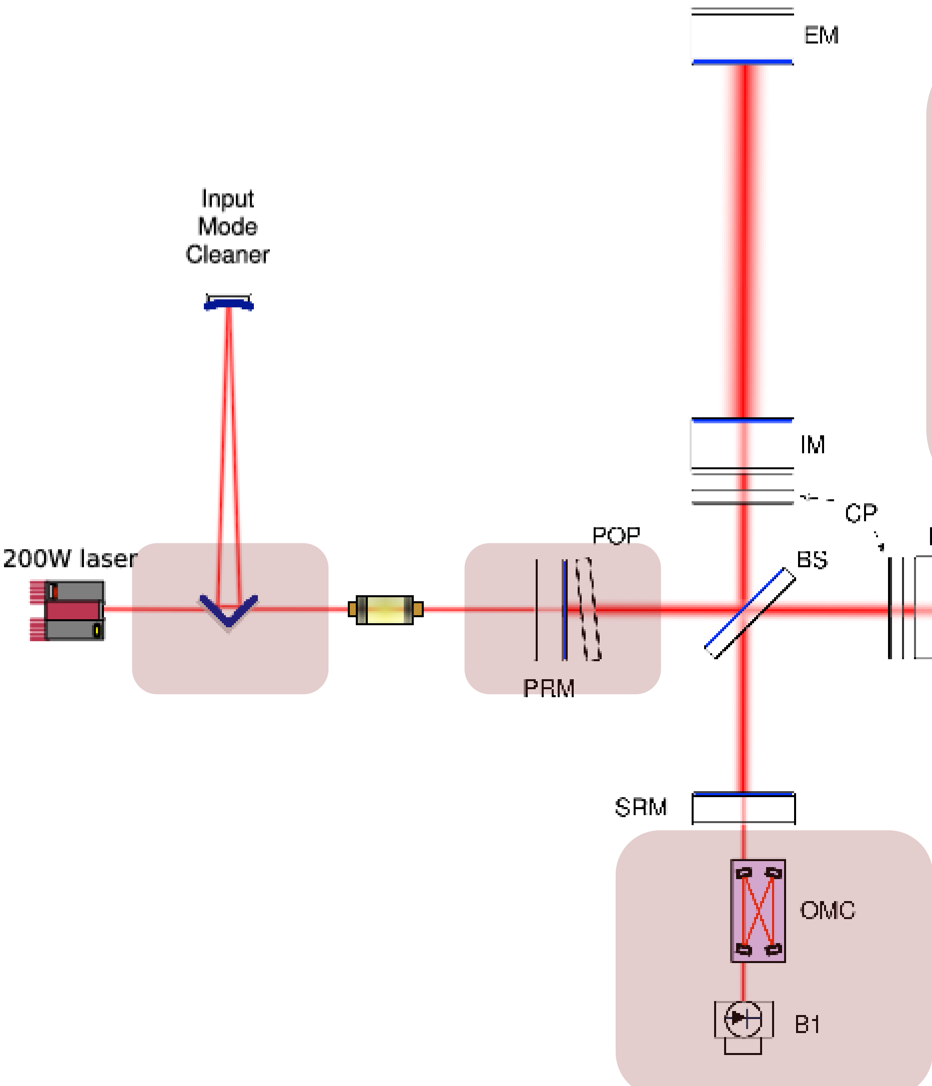
The sensors

- The Hartmann wavefront sensor:
  - ✓ The design has been finalized
  - ✓ The installation is in progress
  - ✓ Many tests are underway on a dedicated test facility

- The phase camera:
  - ✓ Installation and tests on the devices are underway
  - ✓ Integration with the compensation system is in progress

Construction and integration highlights

The signal detection

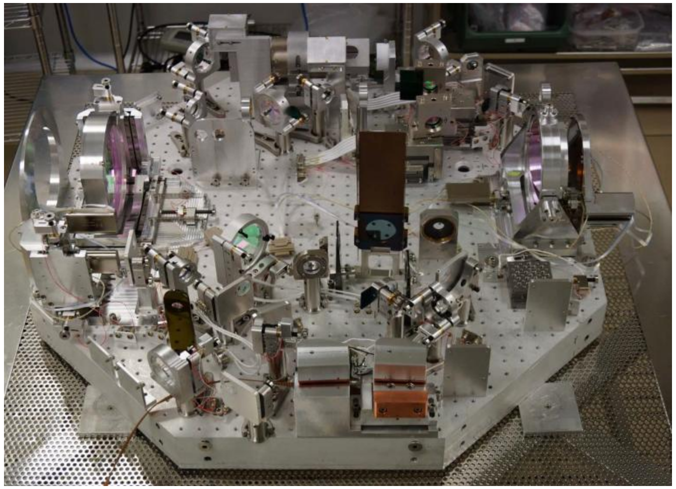


To extract AdVirgo signals:

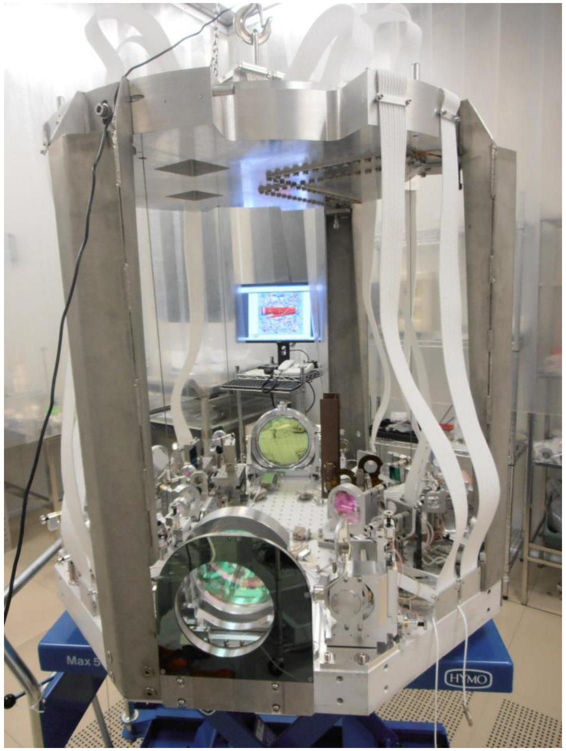
- Adjust the detection optics to the enlarged beam (new telescope design)
- Separate the overlapping beams

- Rejects high order modes enhancing the dark fringe contrast
- Rejects optical fields to be compliant with DC detection

Signal detection



- The detection system main optical bench has been installed
- Integration is foreseen soon



A new Output Mode Cleaner has been realized:

- Developed for DC detection
- Two monolithic cavities in series
- Filtering high order modes and optical field

Signal detection

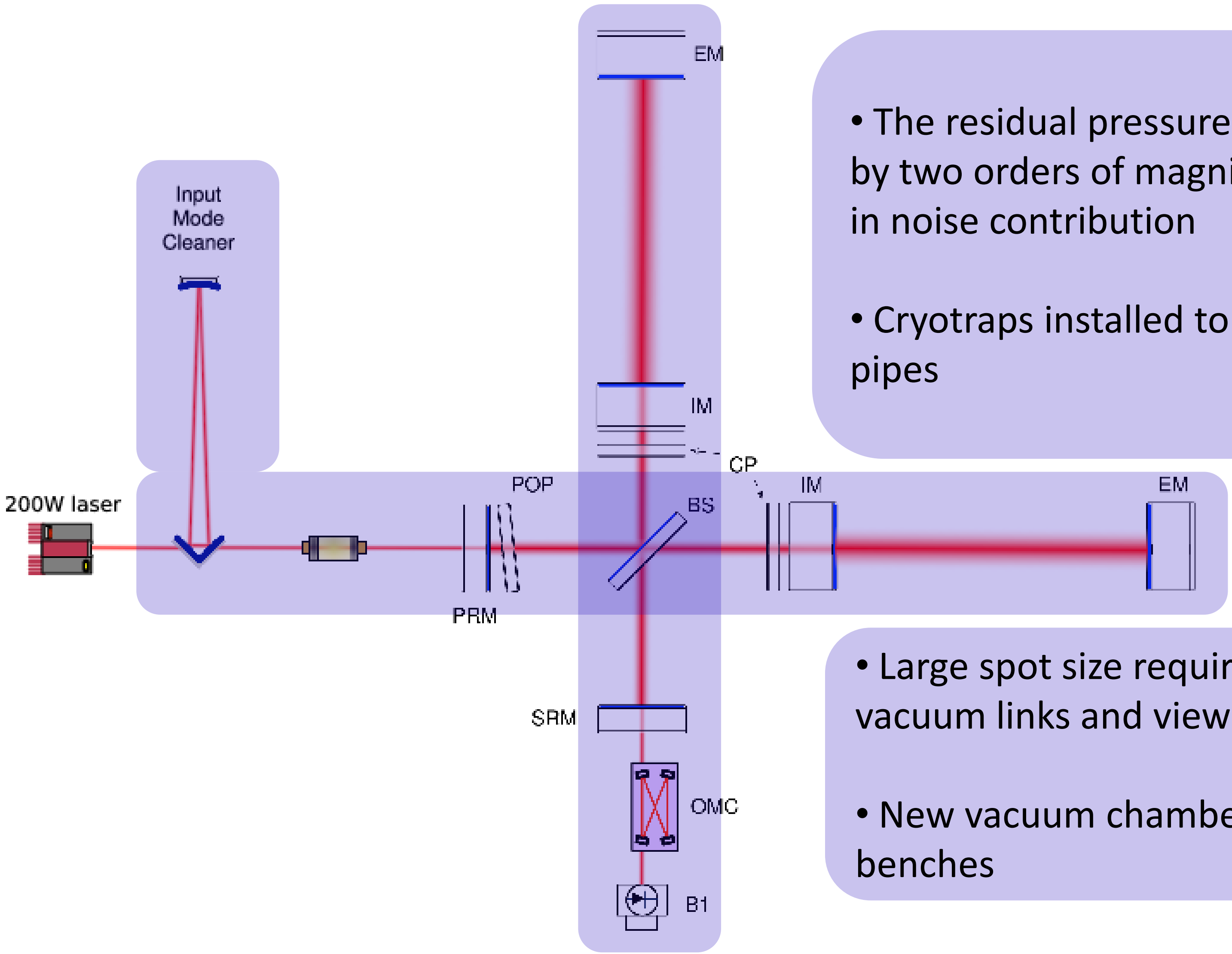
Mini-towers:

- Five new minitowers have been produced to suspend in vacuum photodiodes benches

- Pre-commissioning with dummy mass in progress

	Installation	Integration
SIB2	complete	in progress
SDB2		to install
SPRB		
SBWE		
SBNE		

Construction and integration highlights



The vacuum system

- The residual pressure must be reduced by two orders of magnitude, a factor ten in noise contribution
- Cryotraps installed to isolate towers from pipes

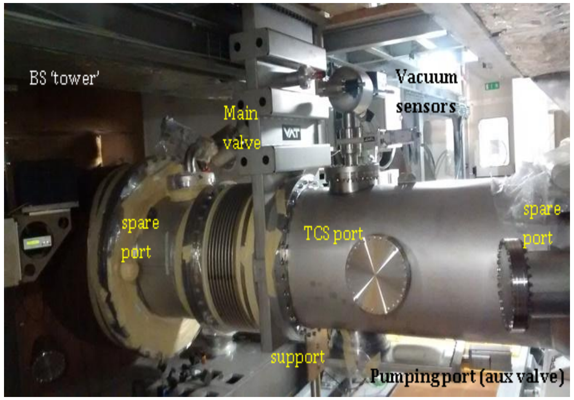
- Large spot size requires enlarging the vacuum links and viewports
- New vacuum chambers to host PD benches

Vacuum system

Cryotraps & enlarged links

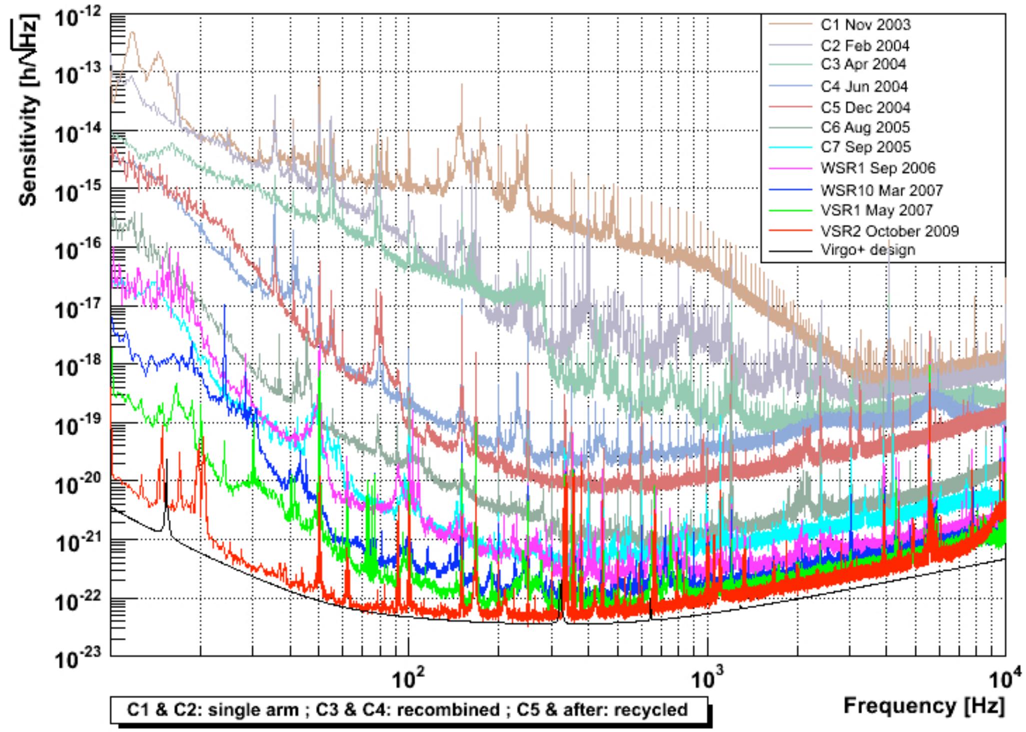
- Cooling-down test achieved for the two cryotraps placed at the end towers
- The main vessels are installed at the inputs and the integration is quite complete

- two smaller cryostats are being installed at the short tower



- enlarged links installation is almost completed

Commissioning



- Reaching the design sensitivity is a long term effort
- In spite of the increasing complexity the expected AdVirgo commissioning duration is much shorter than for Virgo

- A lot of experience gained
- Many instrumental weaknesses solved (mirror quality, new payload design, thermal compensation…)
- Environmental isolation improved (stray light mitigation, acoustic enclosures, …)
- The impressive experience of the extremely fast aLIGO commissioning

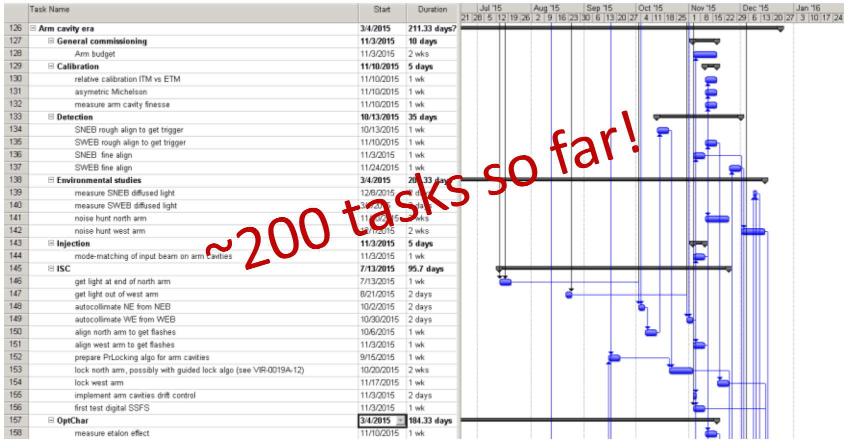
Commissioning

The plan in a sketch:

- The commissioning is already started on light injection system and IMC

- Many tests have been anticipated to save time also on other sub-systems

- The step by step procedure foresees:



~200 tasks so far!

IMC era (now)

Central Interferometer era

Arm-Cavity era

Power Recycling era

Final steps to reach the early sensitivity curve (mid 2016)

Conclusion

- Advanced Virgo is currently in a crucial phase of installation
- A lot of parallel activities are ongoing requiring a big and constant organization effort
- The schedule is very tight and all the arising issues have to be promptly faced coordinating the works of all the groups
- All the groups are fully committed to end the installation/integration phase within 2015 to achieve the first lock in the first months of 2016
- The main target is to join LIGO in observational run during 2016
- The steps towards the transition to the full configuration will be decided with the partners