TCS-Aberration Control: status and perspectives

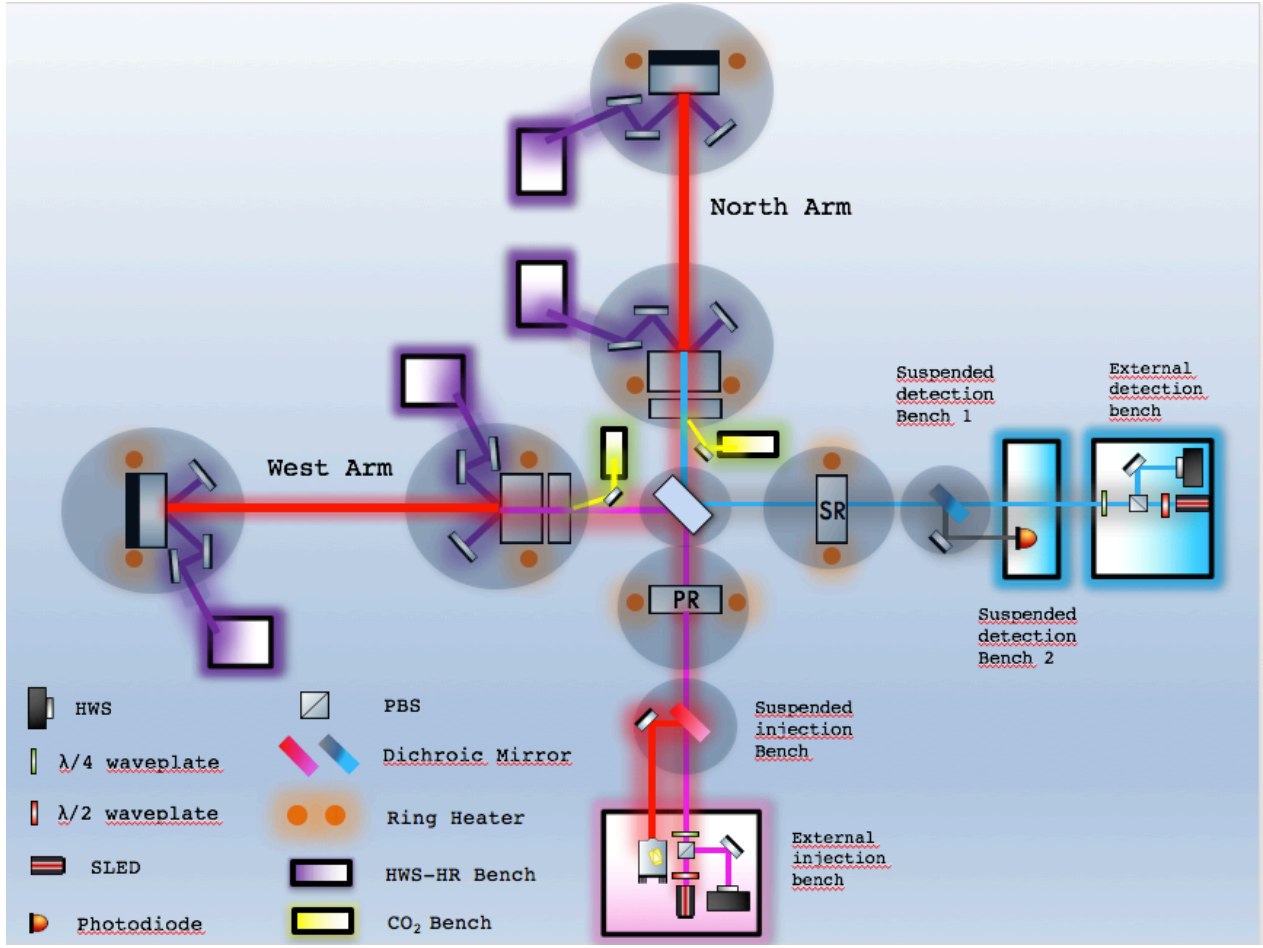
V. Fafone

Outline

- AdV TCS overview;
- TCS performances in AdV:
  - In-situ absorption measurement with HWS (@ 13 W input power);
  - ITF input power increase from 14W to 26.5W;
  - Double Axicon System tests;
- Lessons learned for future upgrades:
  - AdV+

AdV TCS overview

- HWS-RC (on INJ and DET benches) to measure thermal distortions in recycling cavity;
- HWS-HR (4) to measure change in TM RoCs;
- RHs, to control the arm cavity mirrors RoCs (and PR as well…);
- CO2 projectors: correct optical aberrations (cold and thermal) in the recycling cavity.



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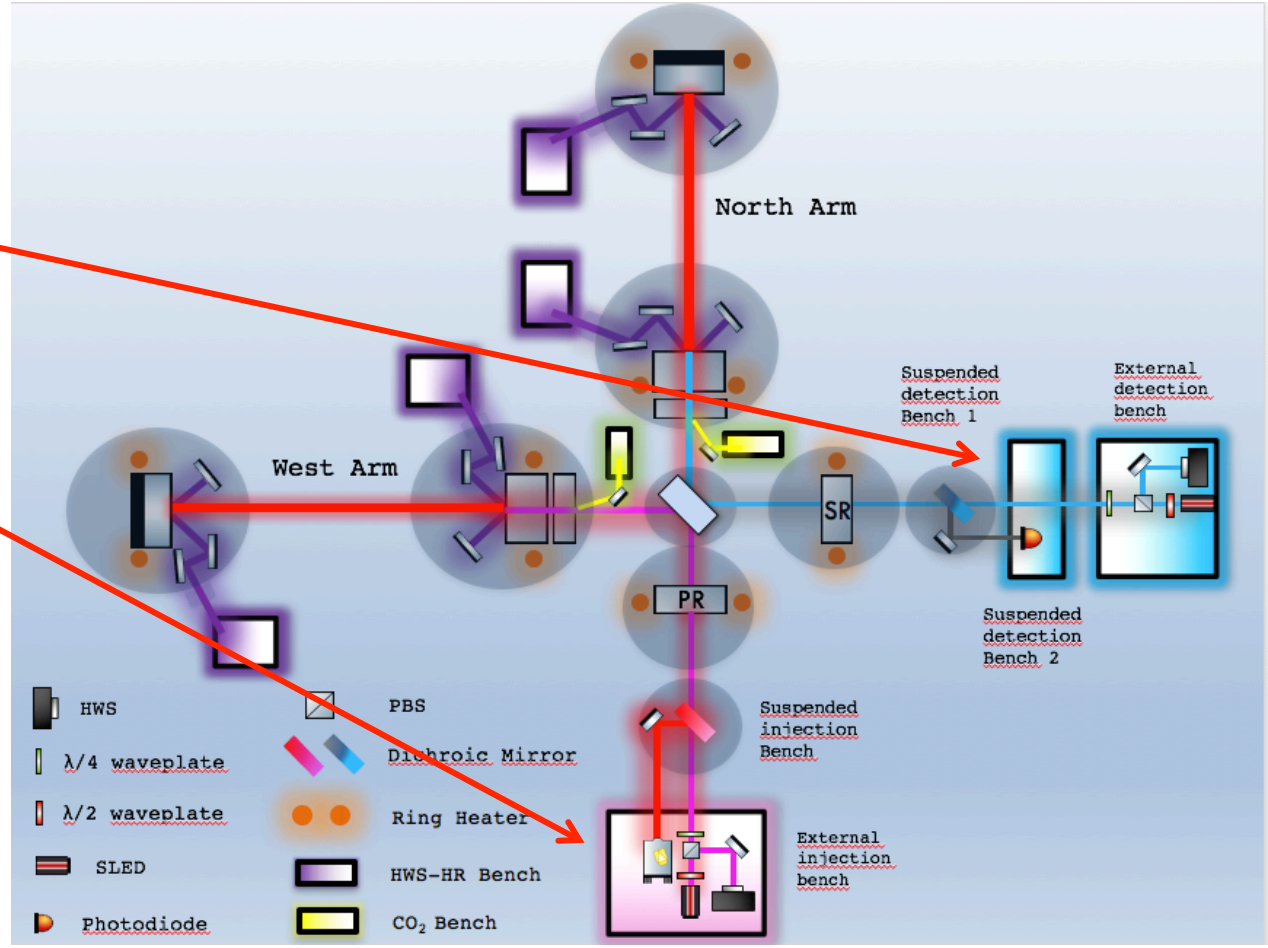

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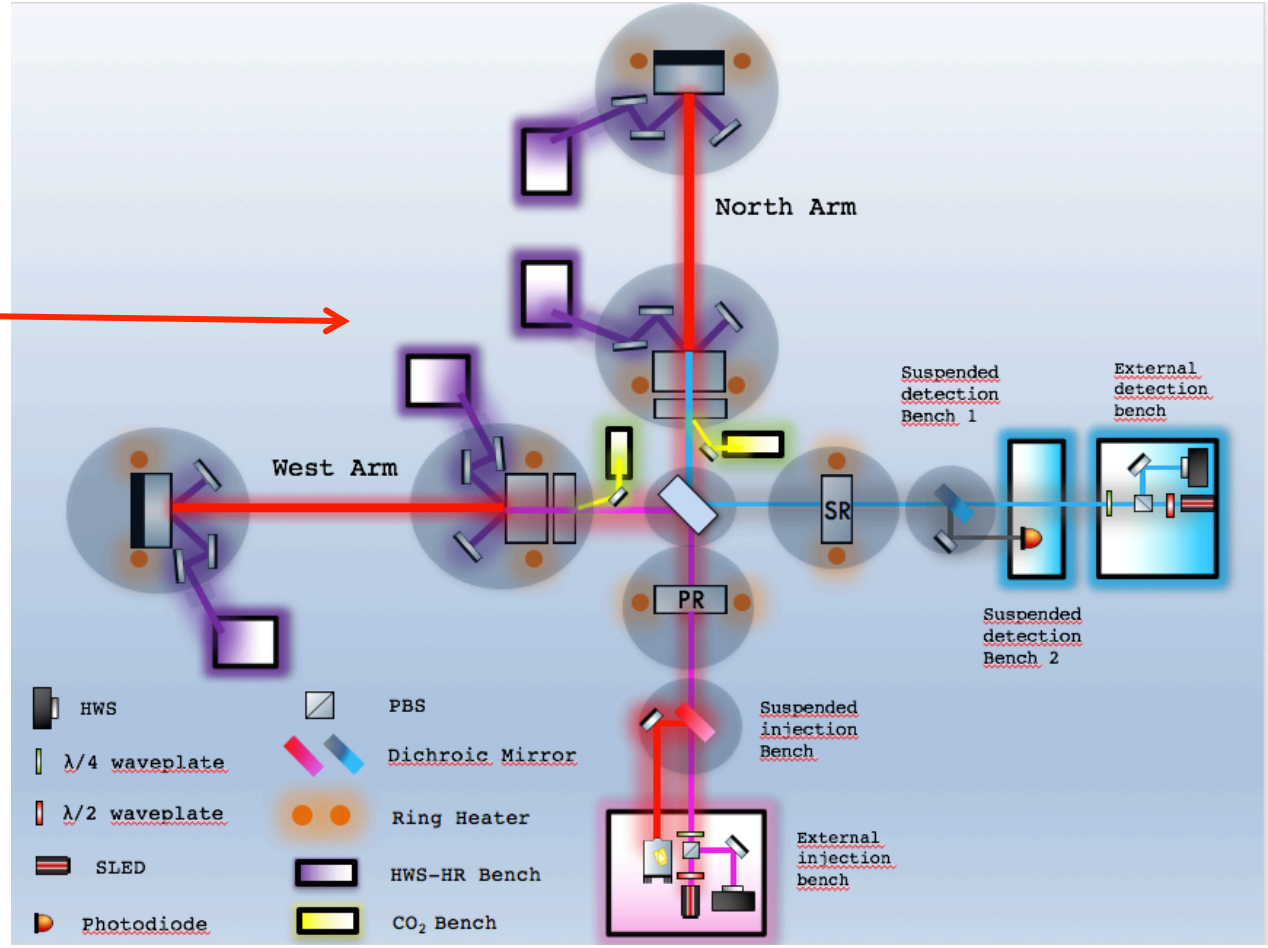

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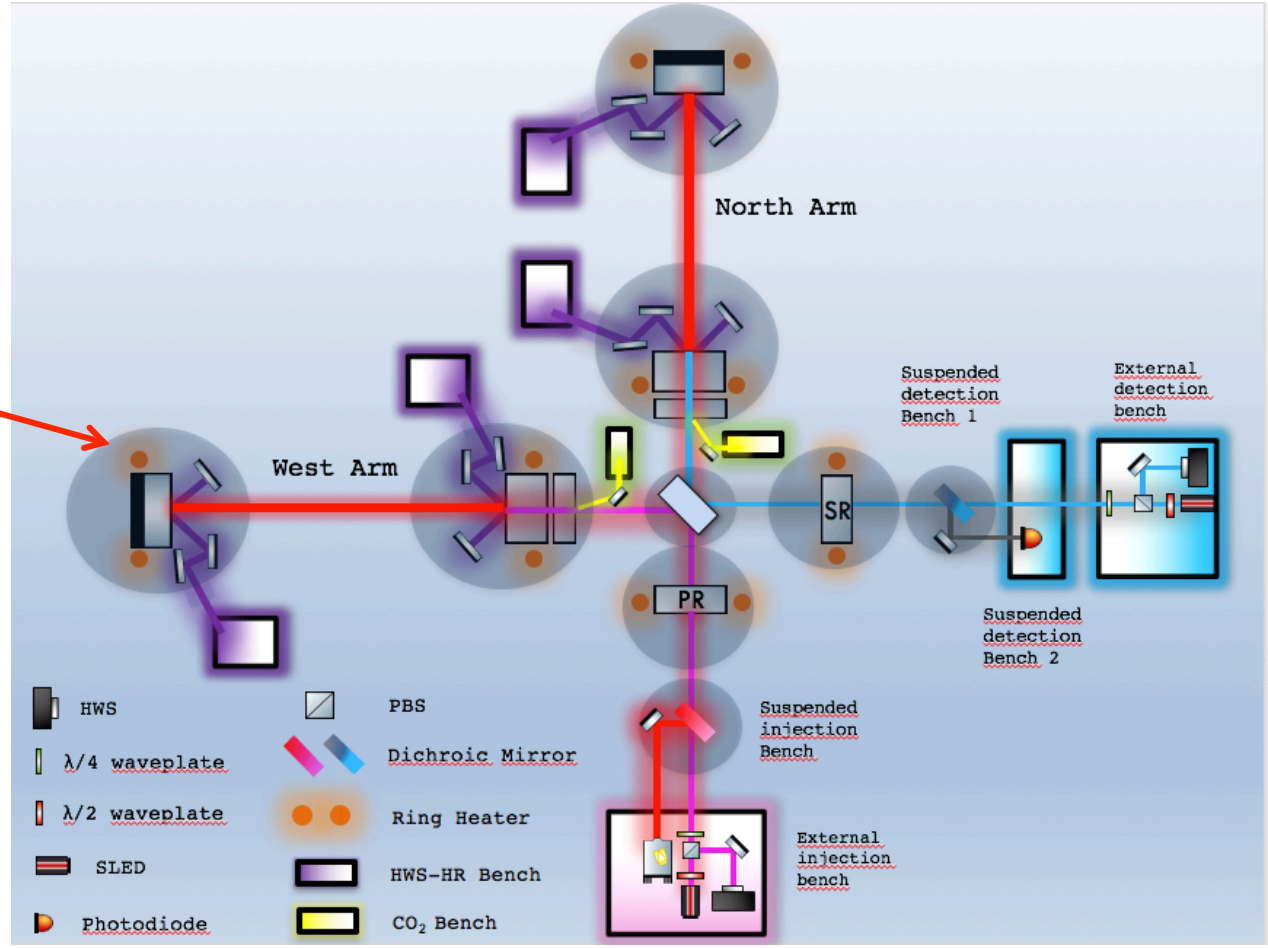

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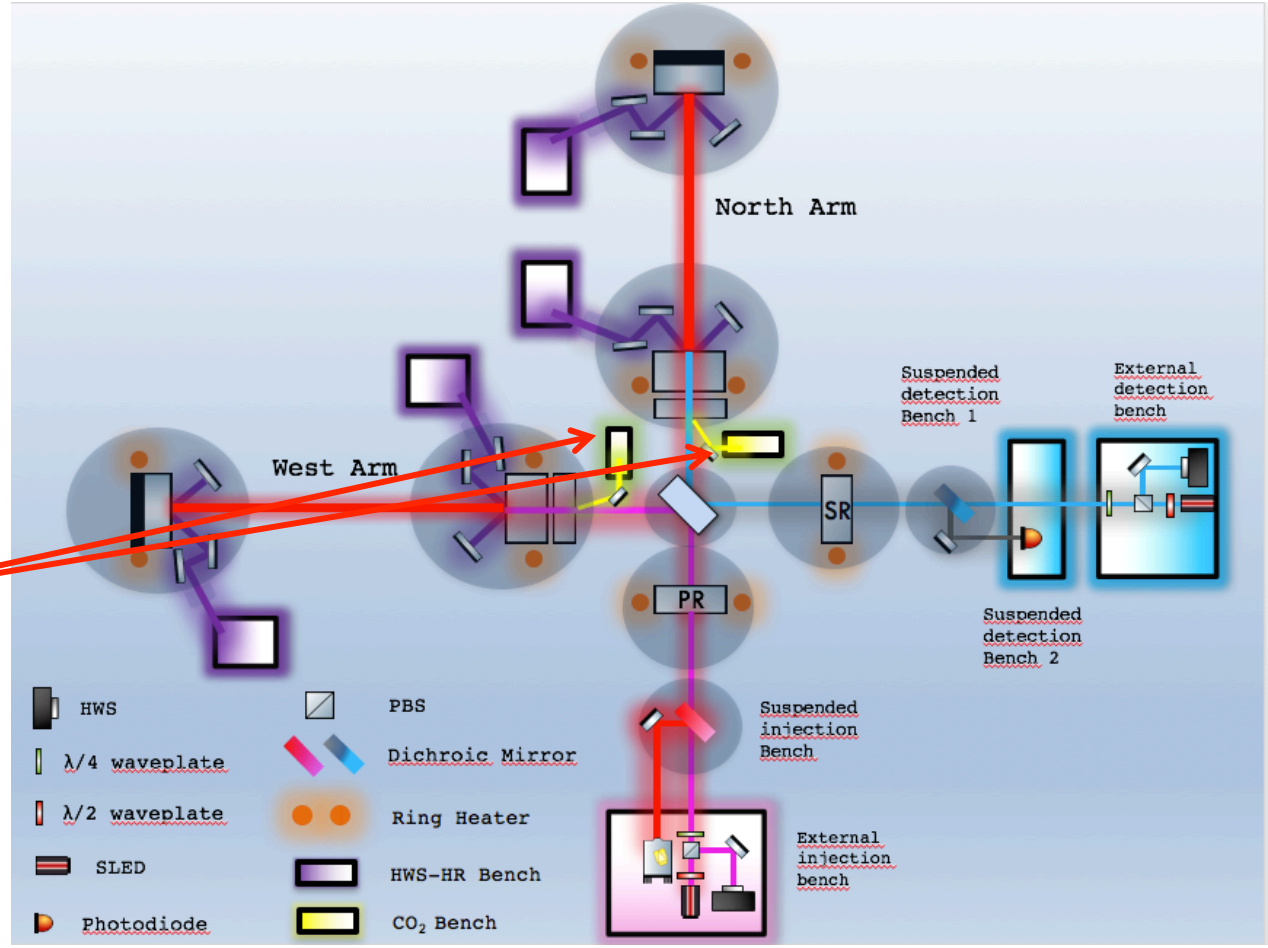
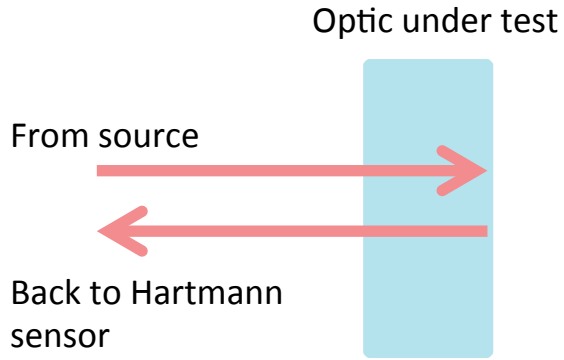
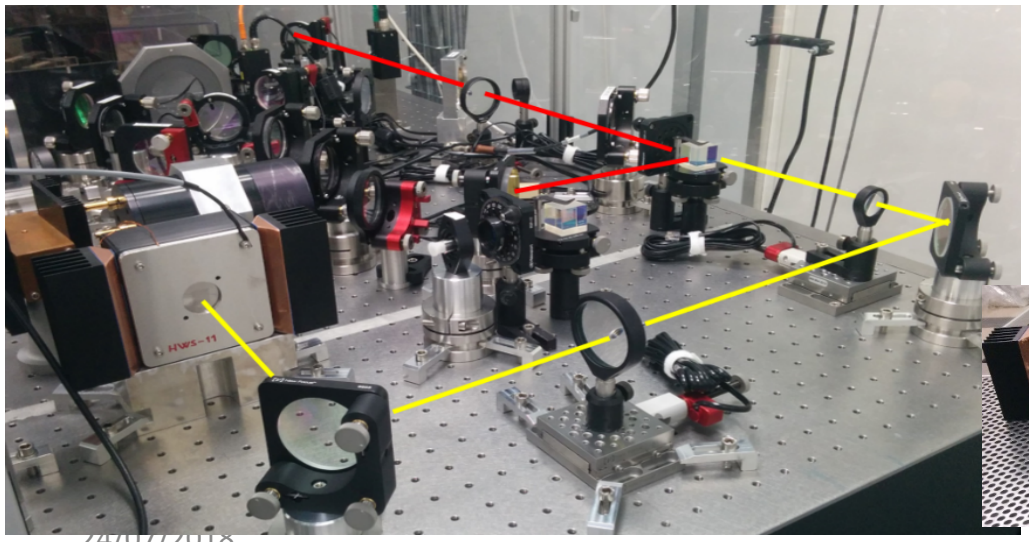
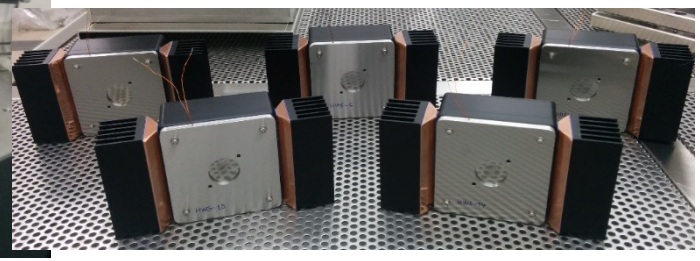


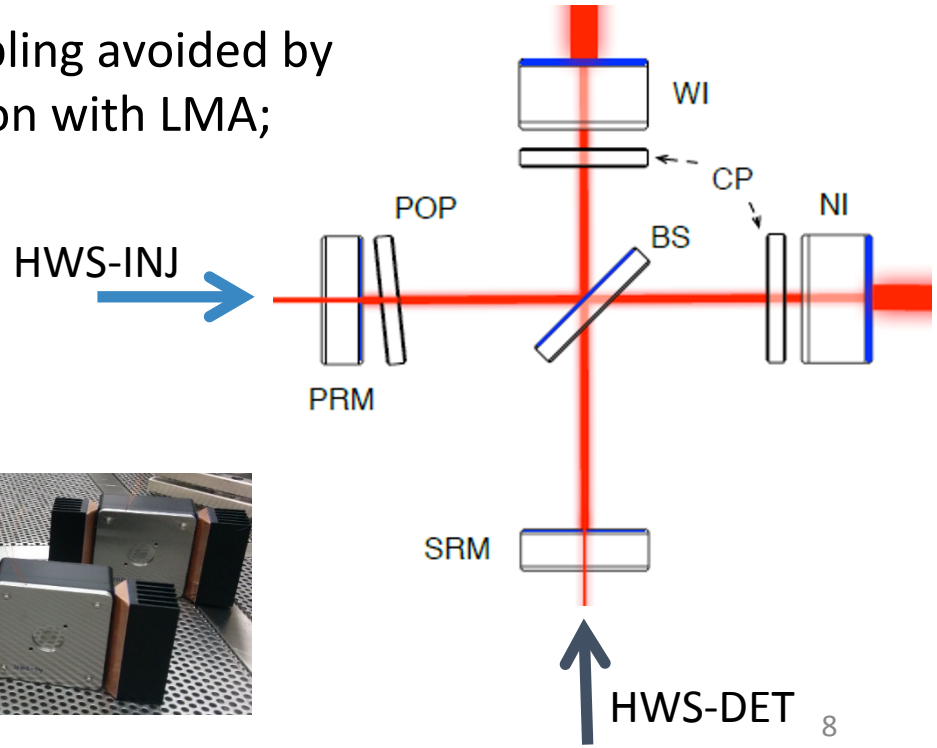
HWS-RC

- On-axis double pass measurement in reflection with auxiliary dedicated beams on each ITM+CP pairs;
- HWS optics installed on EIB and EDB:
  - Exploit magnification of injection and detection MMTs;
- POP and BS also sensed (all PR cavity optics optimized in collaboration with LMA for HWS sensing beams since the TCS design phase);
- INJ and DET HWS beams at the same wavelength: cross-sampling avoided by custom BS HR coating (>98%R @ 790 nm) thanks to interaction with LMA;



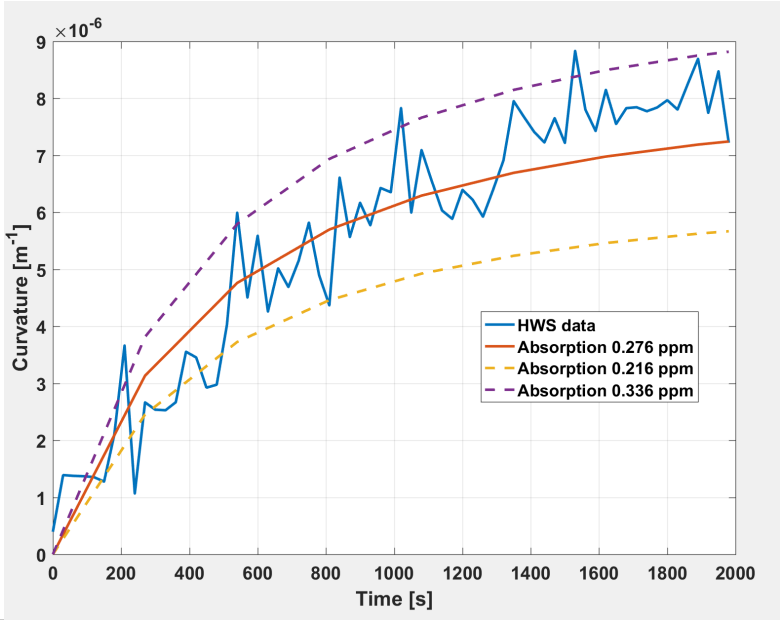


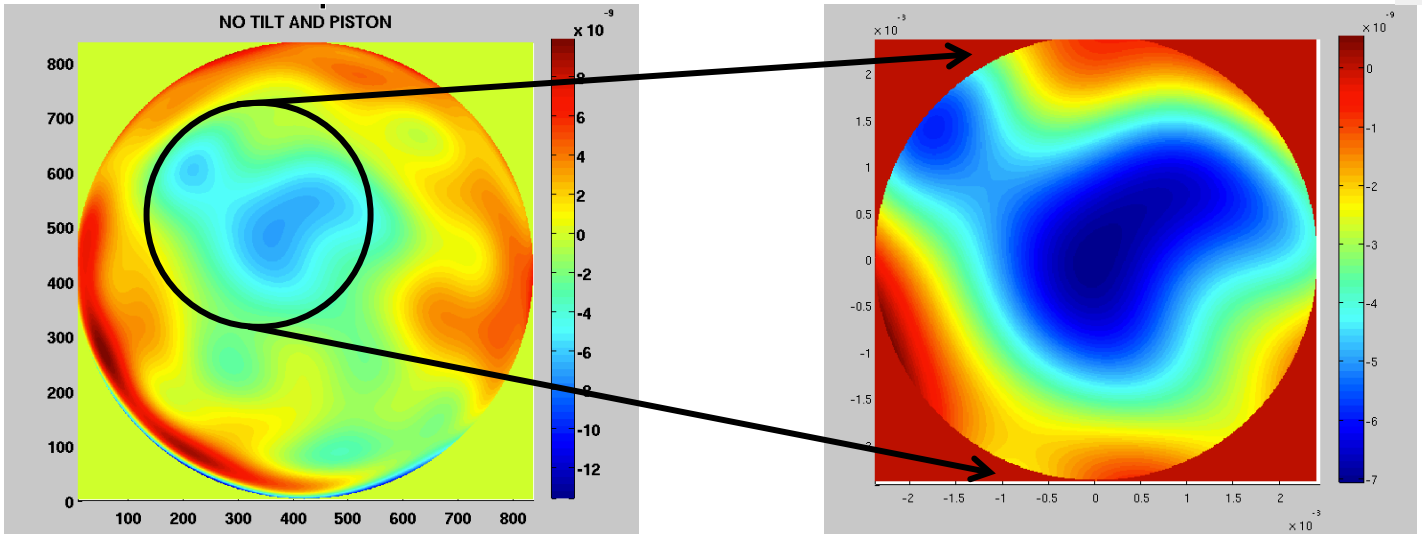




WITM absorption measurement

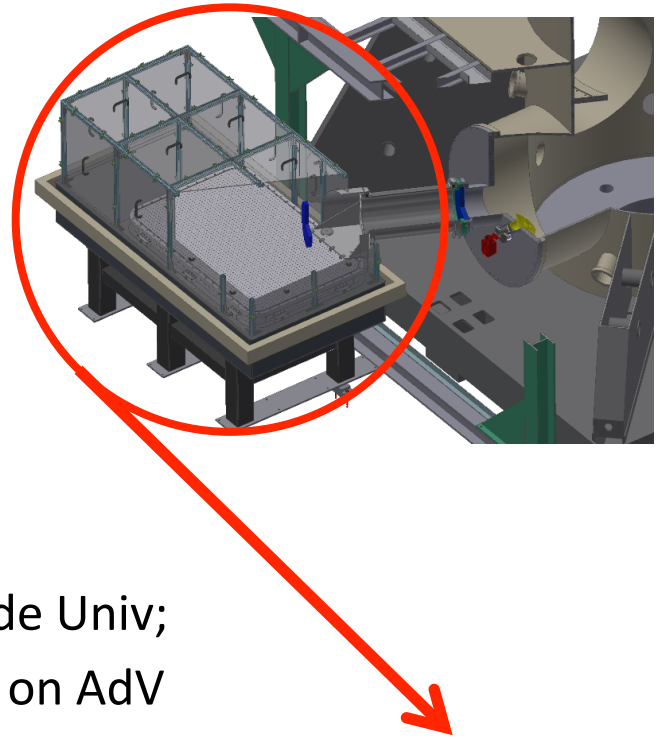
- HWS-INJ data collected during the short TCS commissioning phase before O2 (on 28/03/2017 at 18:14 UTC for 5 hours);
- We measure the thermal lens induced by the YAG whose main contributor is the absorption in the HR coating
- Estimated coating absorption: (0.28±0.06) ppm
- LMA measurement (VIR-0543A-14) is: (0.22±0.06) ppm

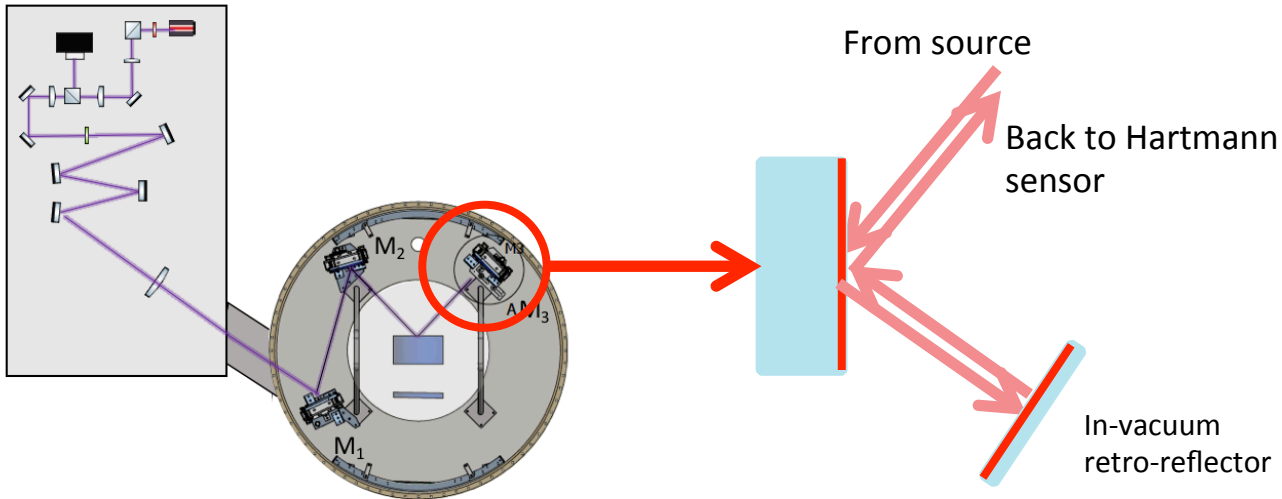


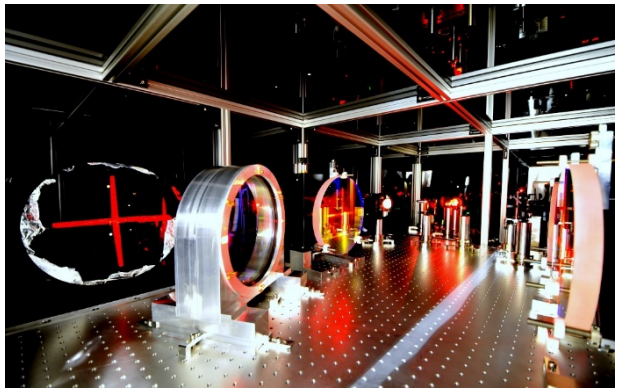


HWS-HR

- Off-axis double pass measurement in reflection with auxiliary dedicated beams on each TM – unique feature of Virgo;
- HWS optics installed on dedicated benches;
- In-vacuum optics required for beam steering and back-reflection;
- Same HWS sensors as for recycling cavities;
- Senses the change of RoC due to absorptions with a sensing beam about 15 cm in diameter on the TMs;
- Wavefront reconstruction software developed in collaboration with Adelaide Univ;
- Pre-installation tests at Rome Tor Vergata University. First characterization on AdV done during MS installation (March 2018);

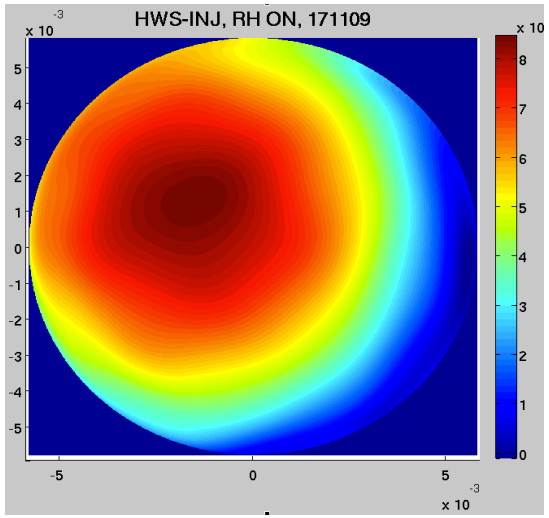


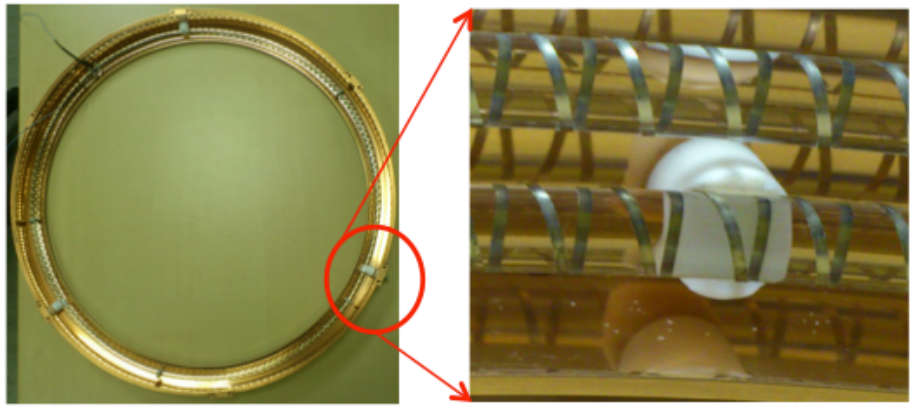




RHs

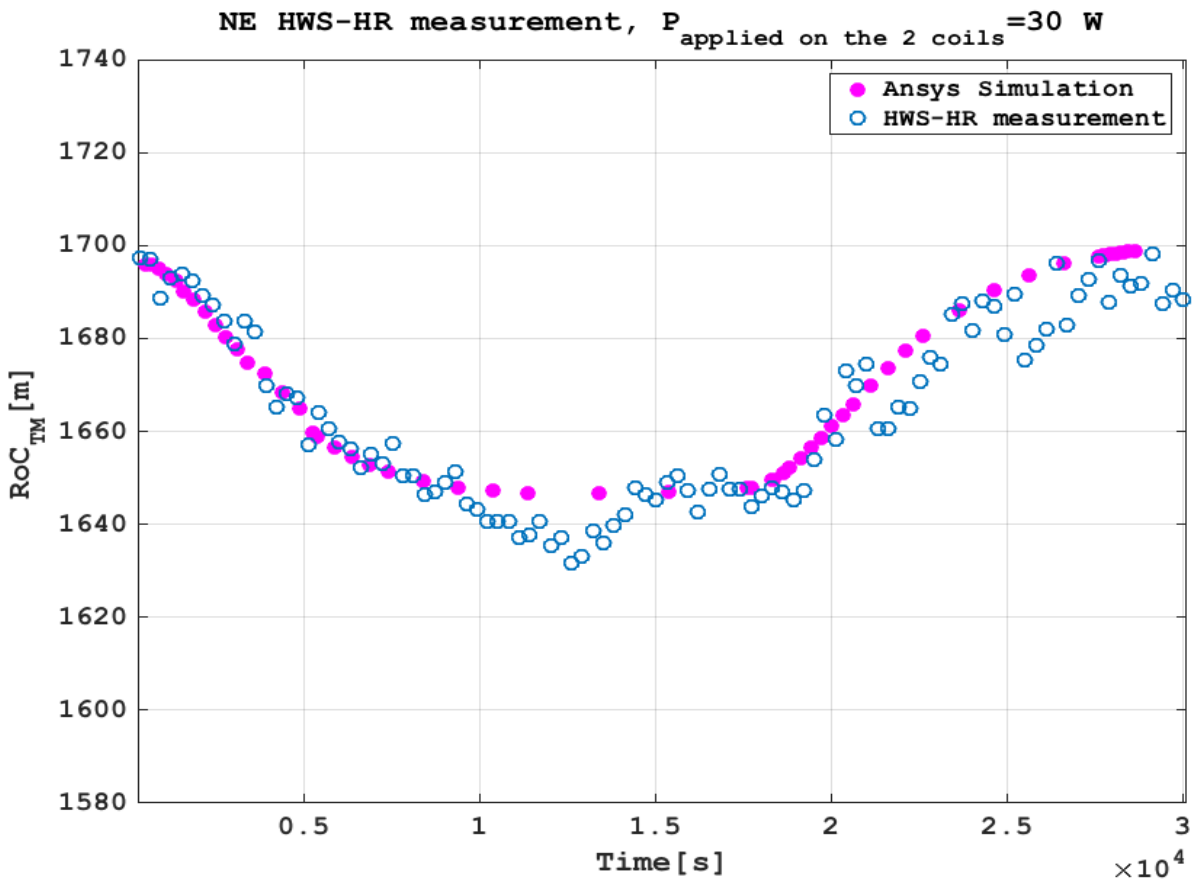
- Control RoCs of all test masses and PR mirror;
- For the ITMs, provide limited compensation of thermal lensing;
- Can be used to mitigate parametric instabilities: tuning the RoC moves the resonant frequency of higher order modes;
- Provide almost spherical lens and identify ITMs centers in HWS images;





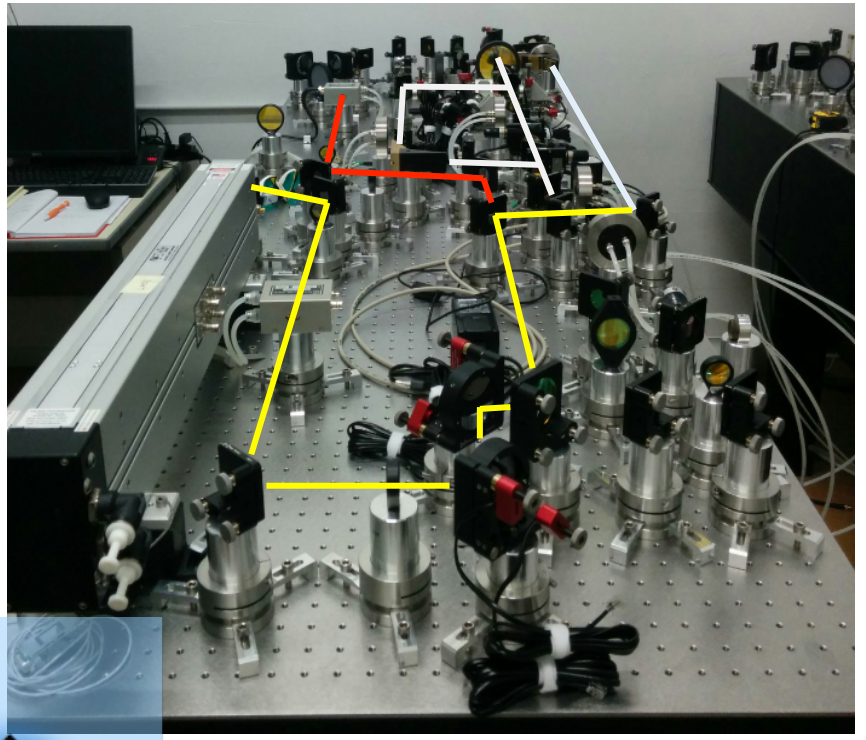
RHs

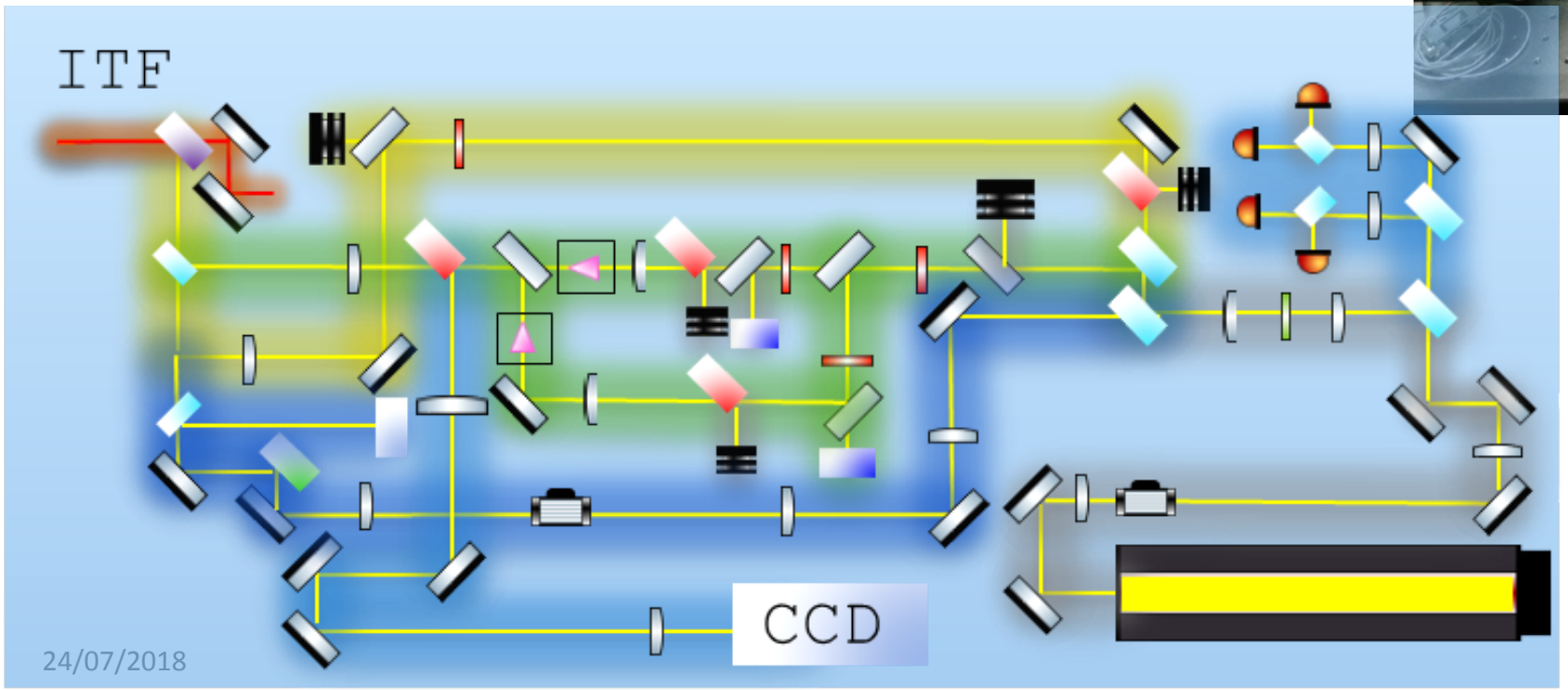
- Comparison with expected behavior shows very good agreement → the system is well understood and well behaving;



CO2 projectors

- Three actuation lines:
  - Double Axicon System (DAS): correct for thermal lensing or axisymmetric aberrations;
  - Central Heating (CH): add for thermal lensing, optimize contrast defect;
  - Scanning System (SS): correct for non-uniform aberrations;

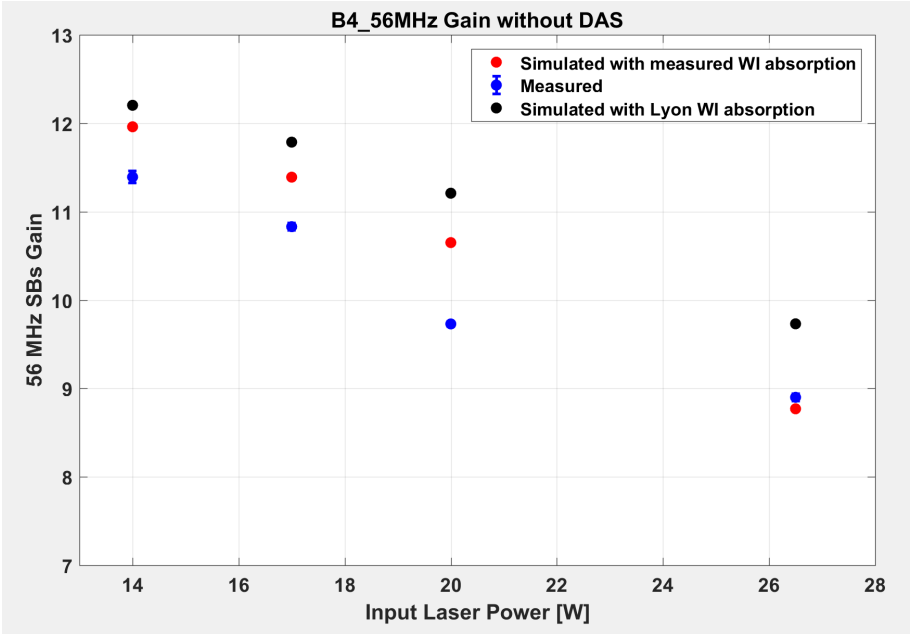




ITF input power increase

- Sidebands recycling gain measured at different ITF input powers with no thermal compensation;
- Two sets of optical simulations carried on using absorptions measurements done :
  - at LMA before installation. See VIR-0543A-14: 0.22 ppm for WI and VIR-0544A-14: 0.19 ppm for NI;
  - on site with the HWS on the West ITM (VIR-0244A-17): 0.28 ppm; North ITM absorptions left at the LMA value.
- On-site measurement of NI absorption needs to be performed;
- Comparison with simulations will be repeated after measurement of NI absorption.

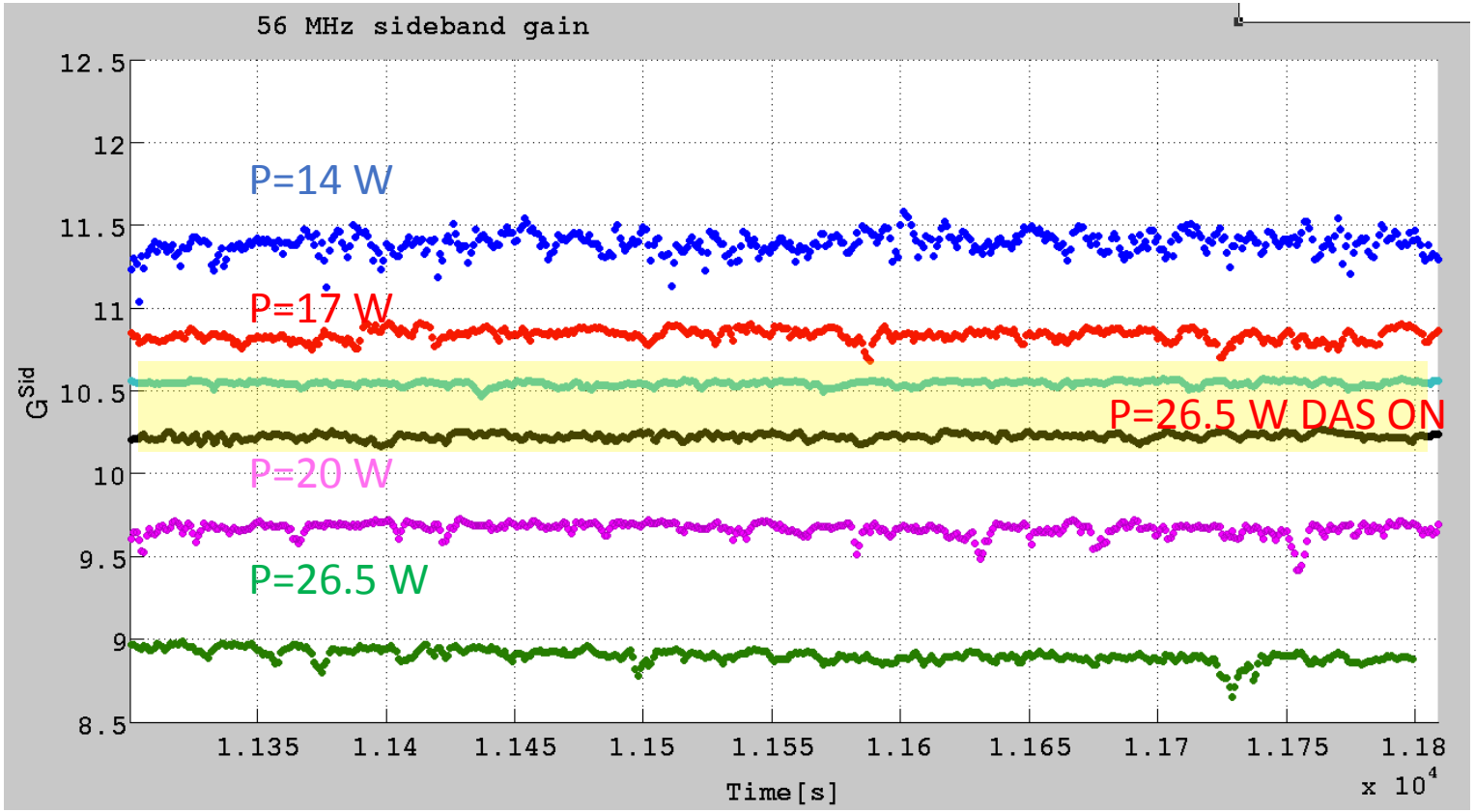
Comparison of measurements and simulations

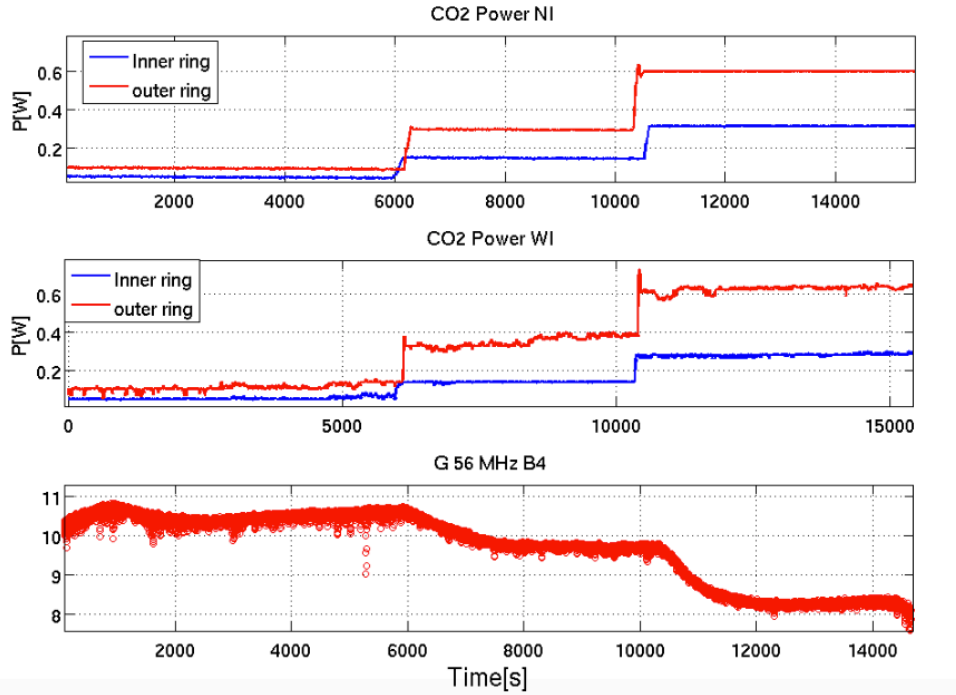


P_{ITF}[W]	Simulated G_{sid}	Measured G_{sid}	ΔG/G
14	12	11.35 +/-0.07	6%
17	11.4	10.83+/-0.04	5%
20	10.8	9.73+/-0.03	10%
26.5	8.8	8.90 +/-0.04	2%

Double Axicon System tests: November 2017

- **14 W ITF:** according to simulations, correction of thermal lens with DAS makes the recycling gain to decrease → confirmed by measurements;
- **25 W ITF:** DAS required to correct lens in order to improve recycling gain → confirmed by measurements;





Summary of the first commissioning rounds

- All TCS components tested and working as per specifications;

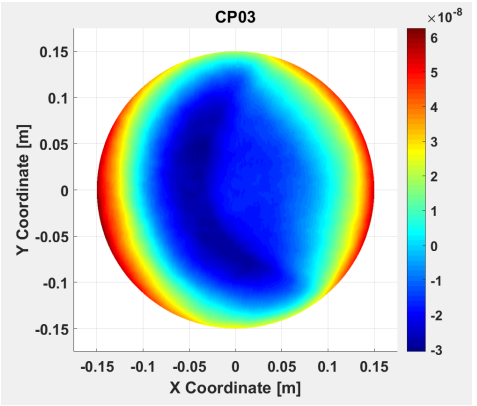
- First commissioning tests done last November:
  - results seem to go in the right direction:
    - recycling cavity gain improved with DAS ON
    - RC gain was better with a differential power applied (as expected from simulations)
    - also ITF stability appeared positively influenced by the DAS action
  - comparison of the measured and simulated 56 MHz rec gain reasonably good

- Path to make the ITF work @ 25W seems to be understood, no showstopper due to aberrations found

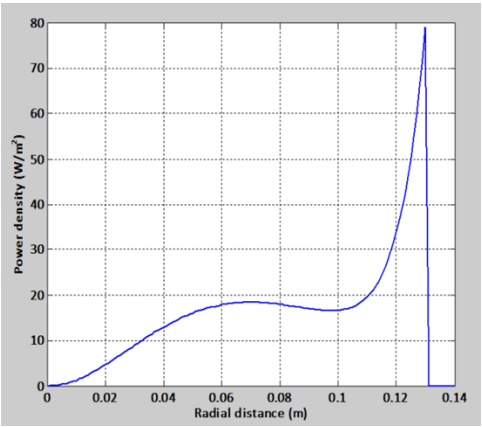
- …. Then….
  - ITF sensitivity
  - Etalon
  - **Parametric instabilities**
  - …..
- TCS can help improving things

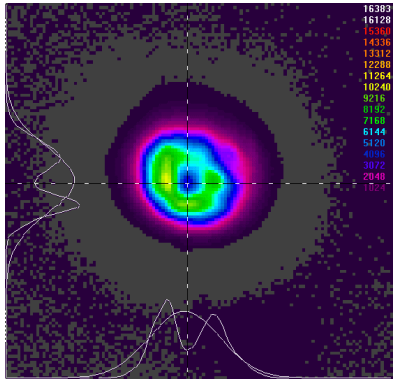
Lessons and requirements for AdV+

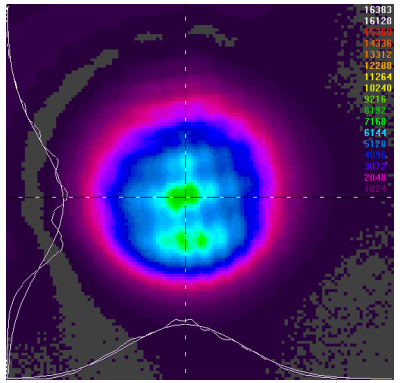
- Correction of wavefront aberrations:
  - CO_2 lasers extensively used so far:
    - SiO_2 absorbs all radiation at $\lambda > 5$ μm;
  - AdV+ with increased beam size in recycling cavity more sensitive to aberrations than AdV;
  - Quality of compensation relies on capability of producing the optimal heating pattern:
    - In the future there will be an increased need for non-symmetric heating patterns;
    - Precise laser beam shaping requires good quality laser output beam:
      - Spatial beam filter installed on AdV CO_2 benches;
      - Ongoing activity to build a mode cleaner at UToV.



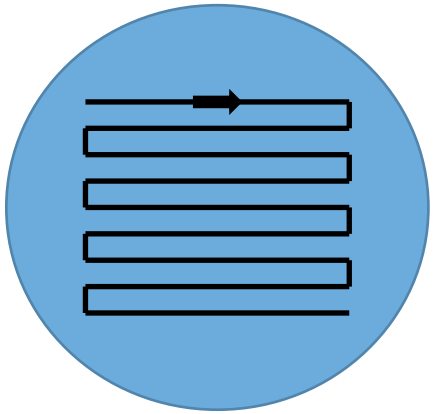
Optimal heating pattern



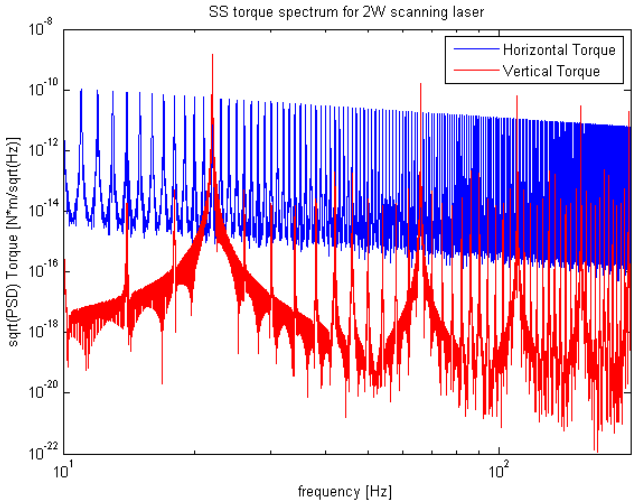




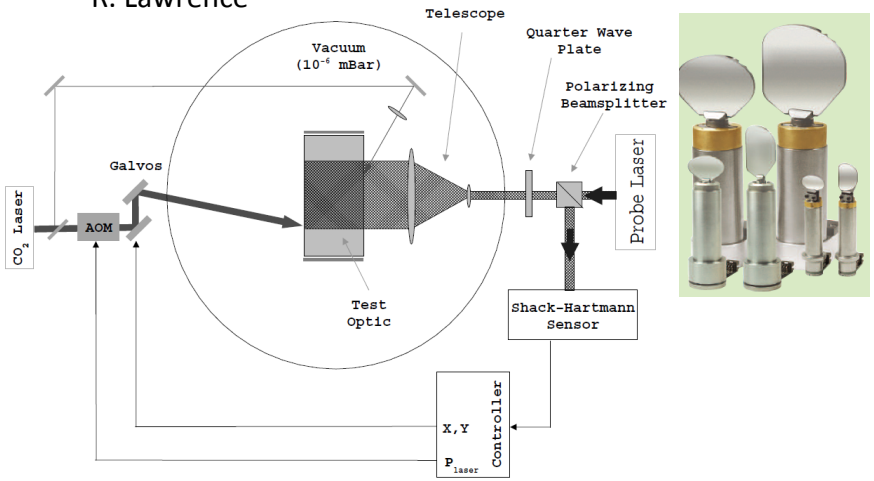
Lessons and requirements for AdV+

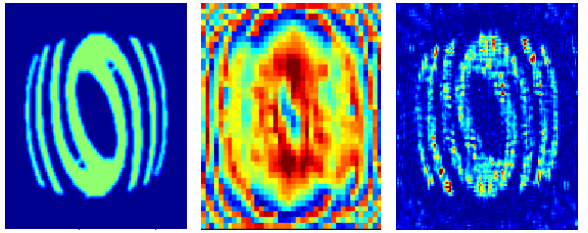


- Laser based techniques:
  - **Scanning system** – installed in AdV;
  - Injects displacement noise into the ITF:
    - Peak due to thermo-refractive coupling at the scanning repetition frequencv (and harmonics);
    - Comb of lines due to torque applied on CP (radiation pressure);
- Development of DC actuator mandatory;
- MEMS deformable mirrors – under investigation at UToV;
- Large area high sensitivity CCD required (**pyroelectric sensor array**).



R. Lawrence



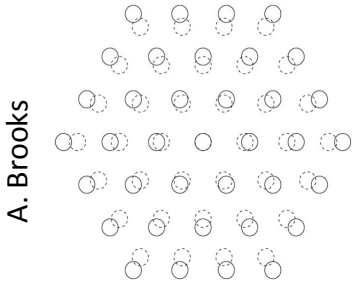


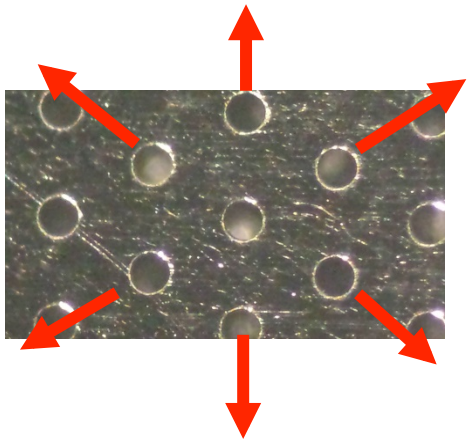
The simulation is obtained for flat incident intensity on an array of 40x40 micromirrors with 1 mm side

M. Lorenzini

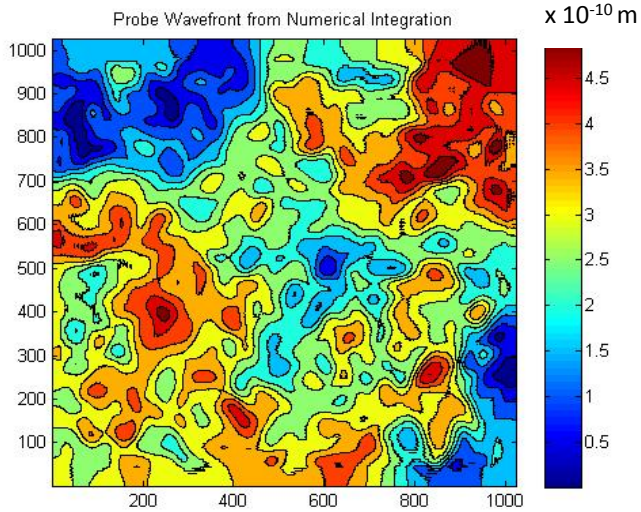
Lessons and requirements for AdV+

- Not much to complain about the HWS:
  - Noise floor and accuracy are very good.
- However… there is room for improvement:
  - The sensor is affected by room temperature changes;
  - More, a change in temperature will also modify the distance between the optics of the imaging telescope, inducing a fake curvature (thermal de-focus);

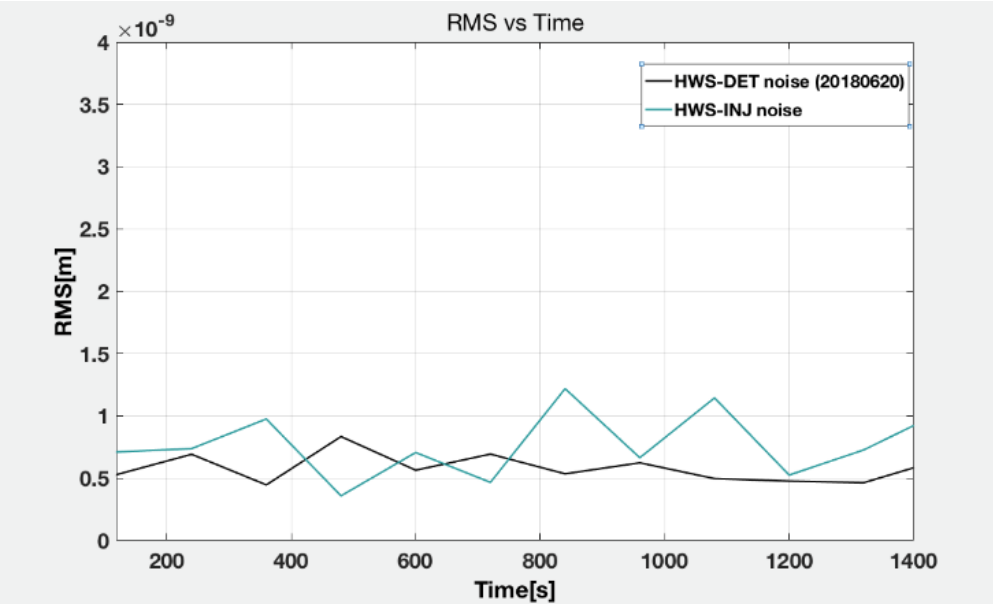




Measured in the Tor Vergata test facility (TETIS)

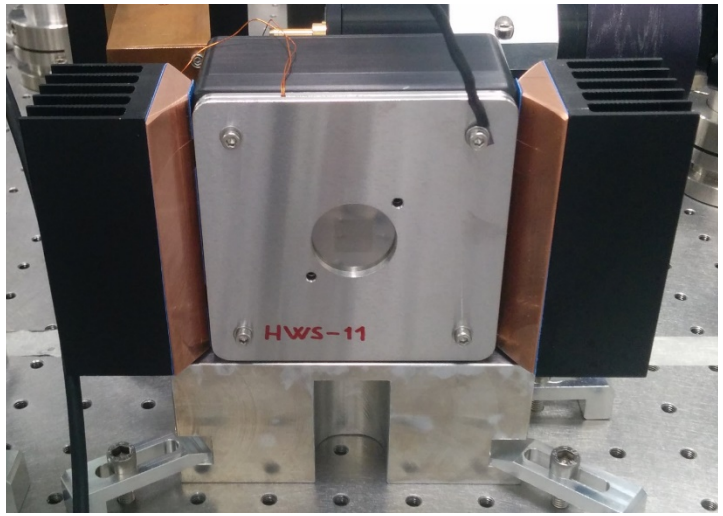


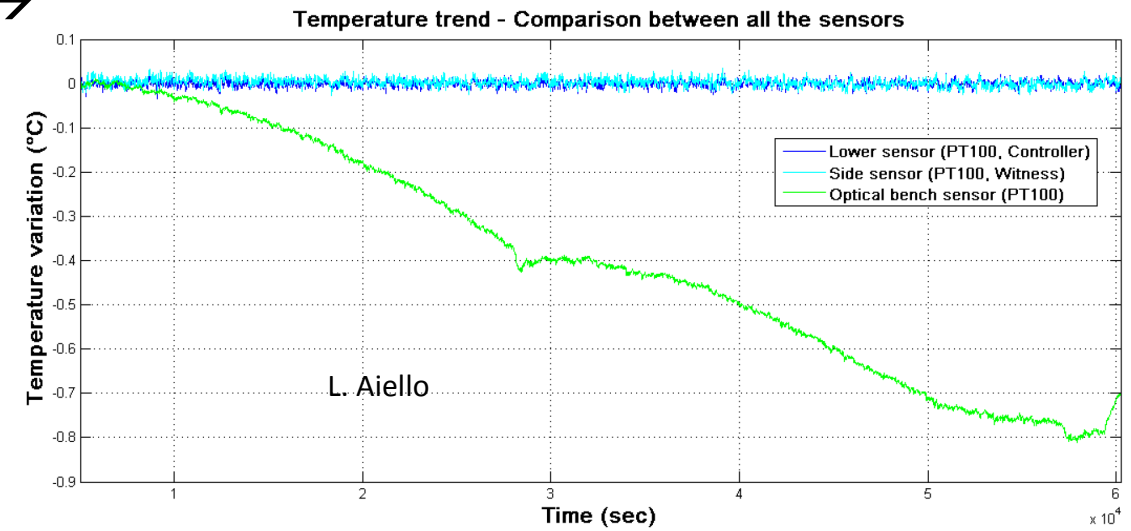
Measured in Virgo



Lessons and requirements for AdV+

- Known solutions:
  - Temperature stabilization of the HWS – done at UToV;
  - Two color system: an additional beam (at a different λ wrt to the sensing beam) that measures the thermal de-focus → may work fine in the lab, may be less practical on AdV+ (requires special coatings on core optics…);
- Spatial resolution:
  - At present, area on TM probed is about 200 mm in diameter;
  - Considering the telescope magnification and distance between the holes → resolution about 7 mm;
  - AdV+ implies larger beam size, resolution will degrade;
- The presently used CCD is **no longer being produced** → implies a re-design and optimization of the HP;
- Request concerns a set up for CCD candidate characterization.



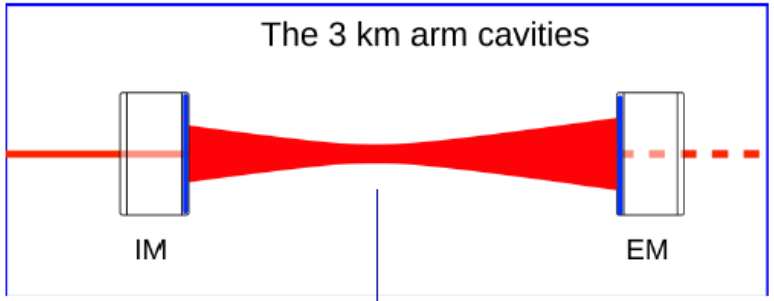


Lessons and requirements for AdV+

- AdV+:
  - Thermal noise reduction;
  - Increase size of test masses and beam dimensions on TMs;
  - Arm cavities closer to instability;

New geometry of the arm cavities

- Wavelength and cavity length fixed
- tune the radii of curvature (~ -50m), g-factor = 0.98



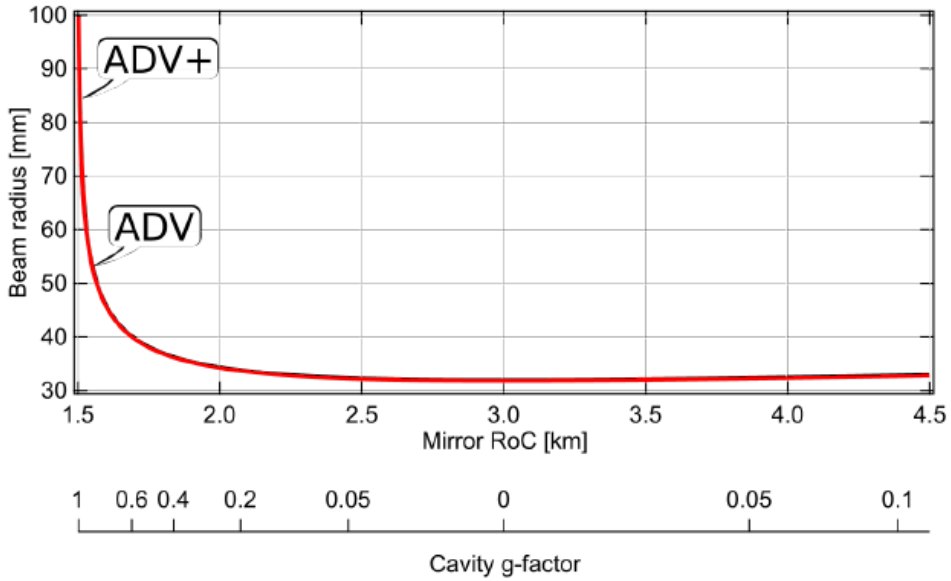
Beam on IM:
- radius: 81 mm (+66%)

Beam on EM:
- radius: 96 mm (+65%)

- waist: 5.8 mm (-40%)
- same position

11

The g-factor picture



- Optical mode frequency separation: 2.1 kHz (3 times smaller compared to AdV, FSR: 50 kHz)

12

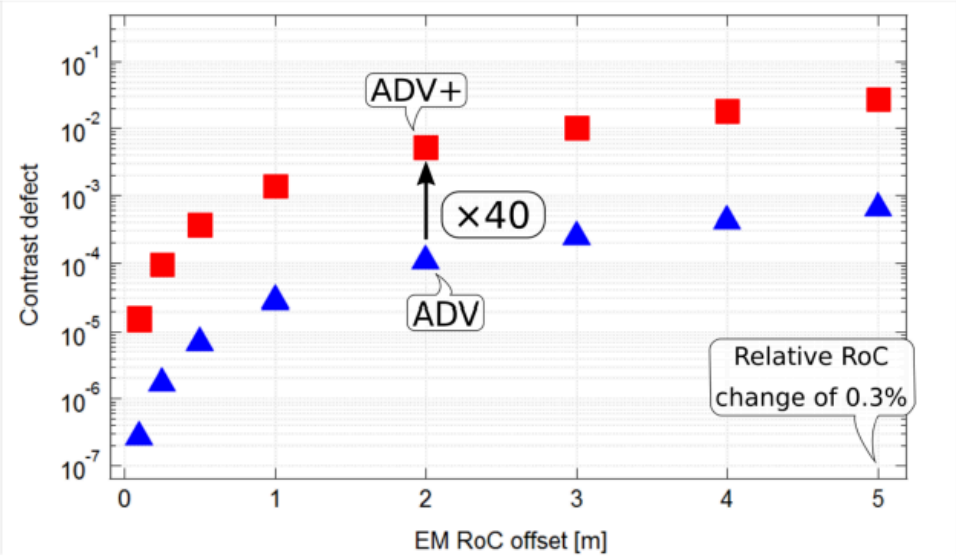
Credits: J. Degallaix

Lessons and requirements for AdV+

- AdV+:
  - Thermal noise reduction;
  - Increase size of test masses and beam dimensions on TMs;
  - Arm cavities closer to instability;

More sensitive to absolute RoC error

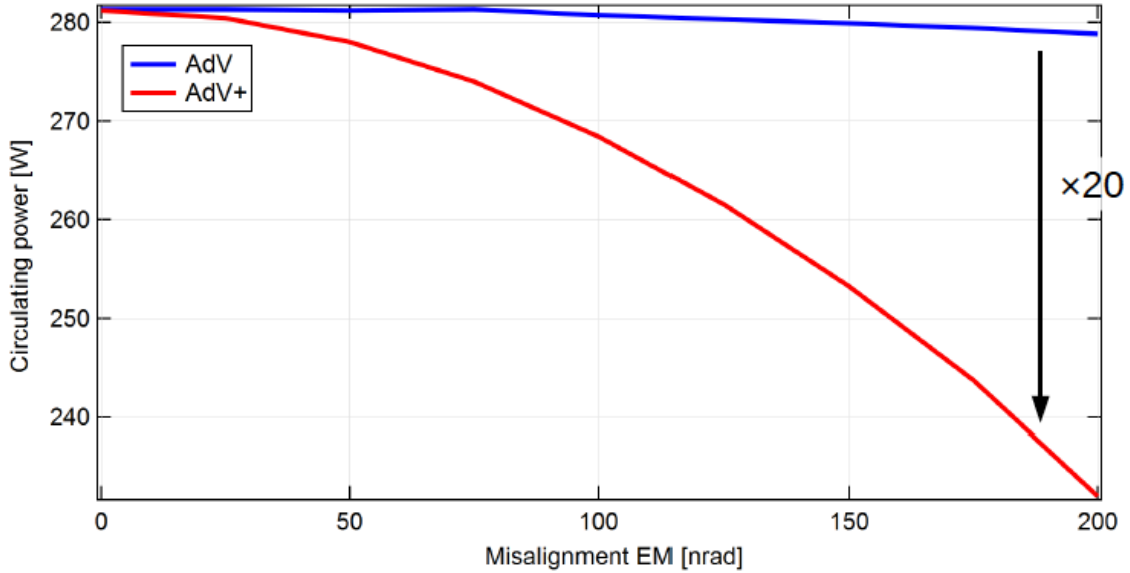
- Contrast defect = 2 * DP power / PRC power



- Much higher constraint on RoC matching, OMC filtering

More sensitive to alignment

- Single arm simulation with one misaligned mirror



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More sensitive to optical aberrations

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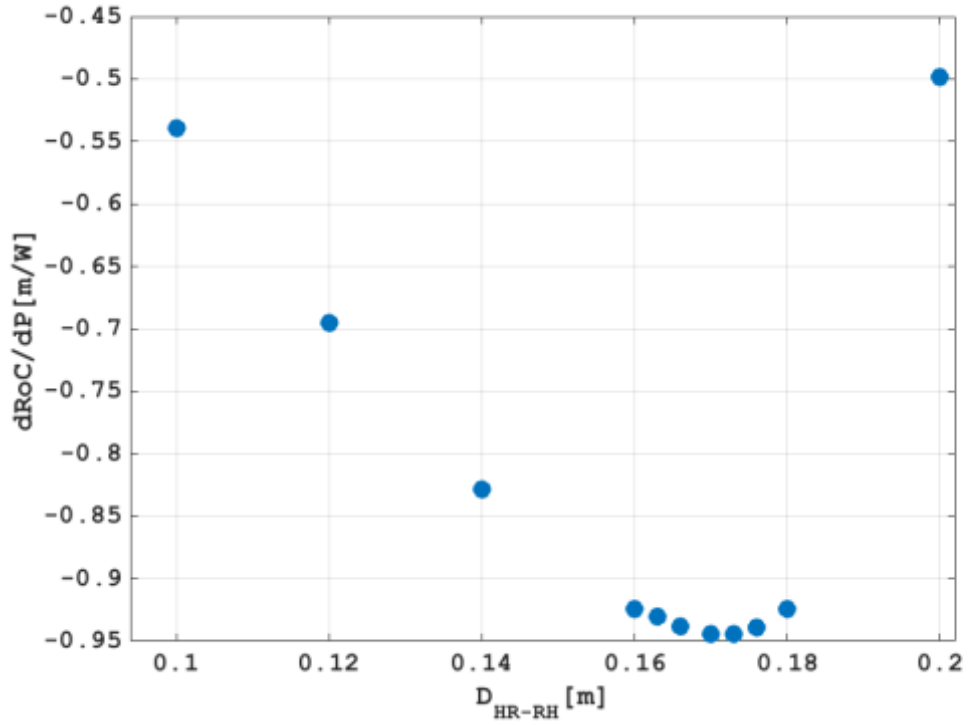

Richieste

- Le richieste finanziarie vanno sotto AdV+ (tag: AdV+LM-TCS)

Description	Cost [k€]	Duration [yr]	Yearly spending [k€] 2018	2019	2020
Prototype RH	60	3	20	20	20
DC CO2 laser beam shaper	210	3	70	70	70
New HWS and sensing system	90	3	30	30	30
			120	120	120

- Richieste: 61.5 kEuro
  - CO2: 46 kEuro
  - RH: 8 kEuro
  - HWS: 8 kEuro