Status of the Virgo

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on behalf of the Virgo Collaboration

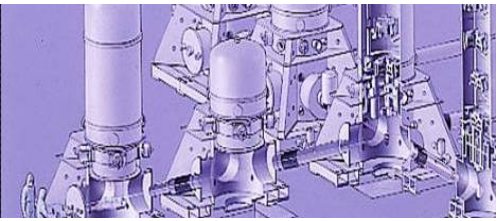
Lisa symposium, September 2016 @ Zurich, Switzerland

Talk outline

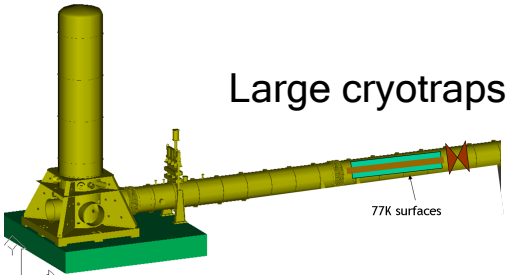
- Advanced Virgo Integration
- AdV Commissioning
- Preparing O2 for new discoveries: EM follow up & Computing effort
- A vision of the AdVirgo future
- Conclusions

Advanced Virgo Integration

AdV in summary

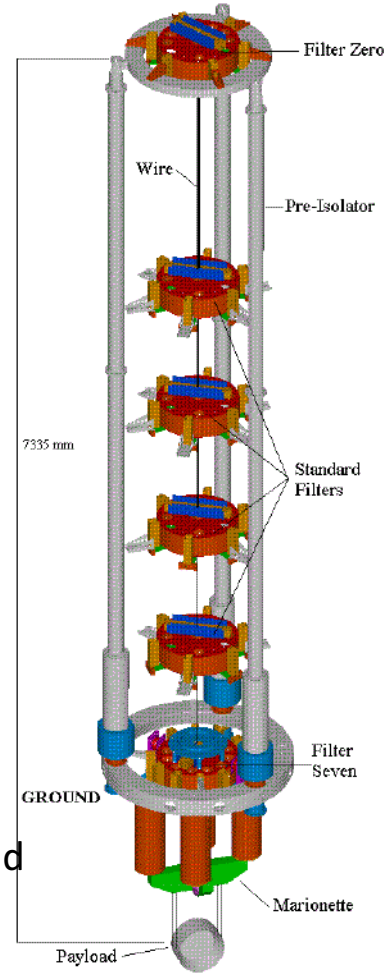


Larger central vacuum links



Large cryotraps

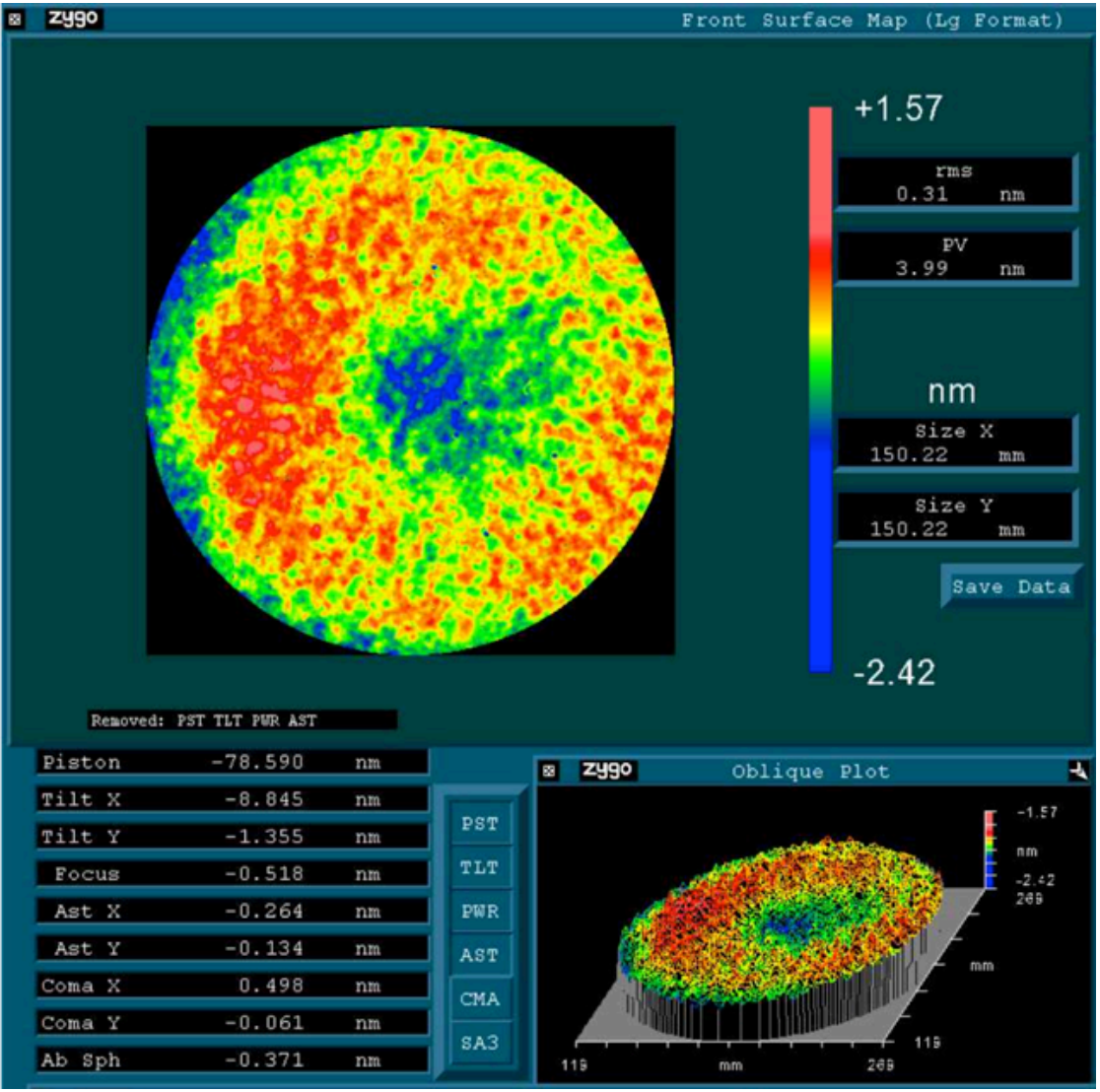
new IP
tilt control



new payload


Four Cryotraps
in operation

The new mirrors



Absorption < 0.5 ppm

Flatness ϕ 150 cm < 0.5 nm

Test mass I ROC 1424 m
Test Mass E ROC 1690 m

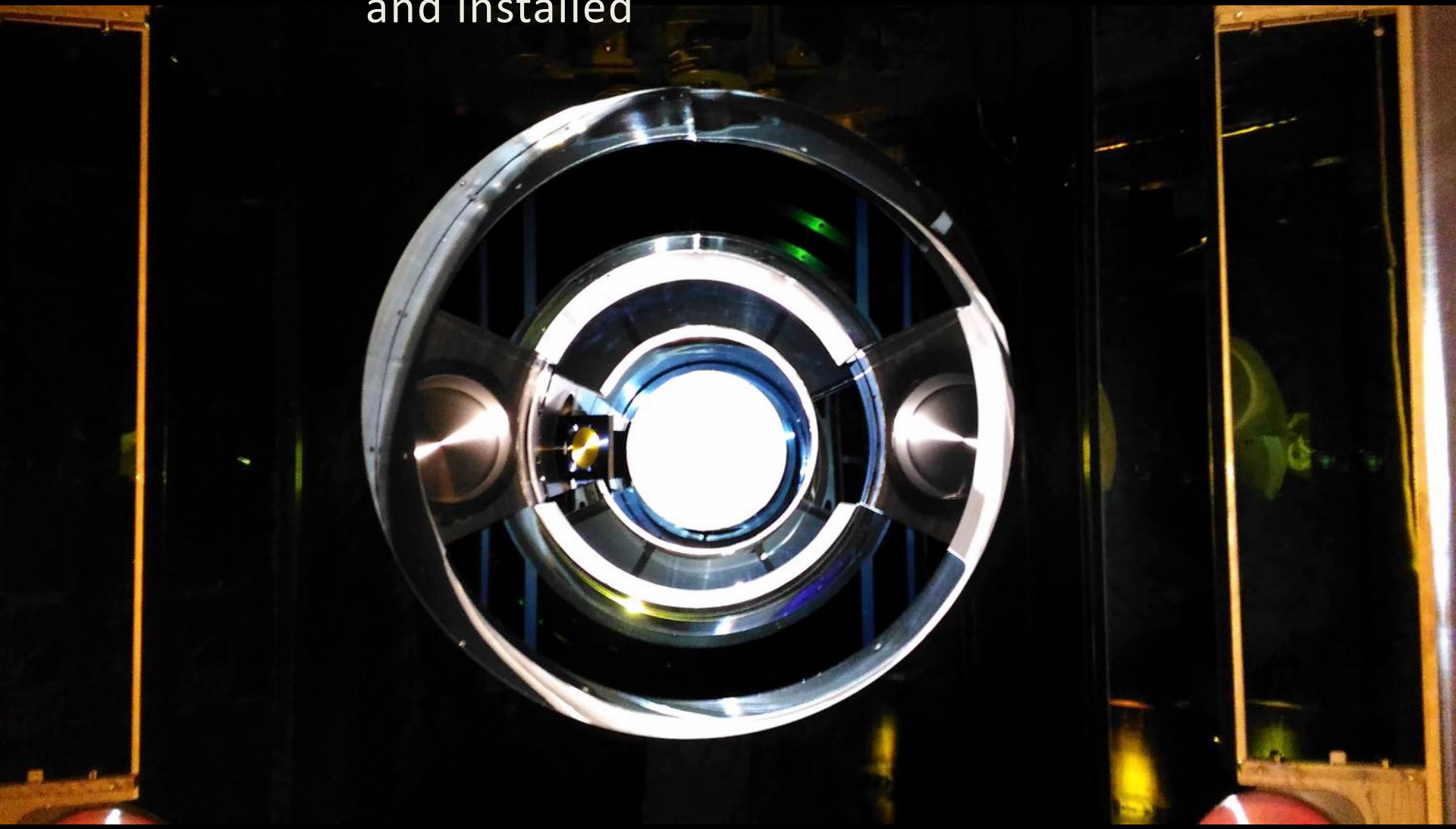
Test Mass 42 kg
Diameter 350 mm
Thickness 200 mm

Beam Splitter 50%
Weight 43 kg
Diameter 500 mm
Thickness 100 mm

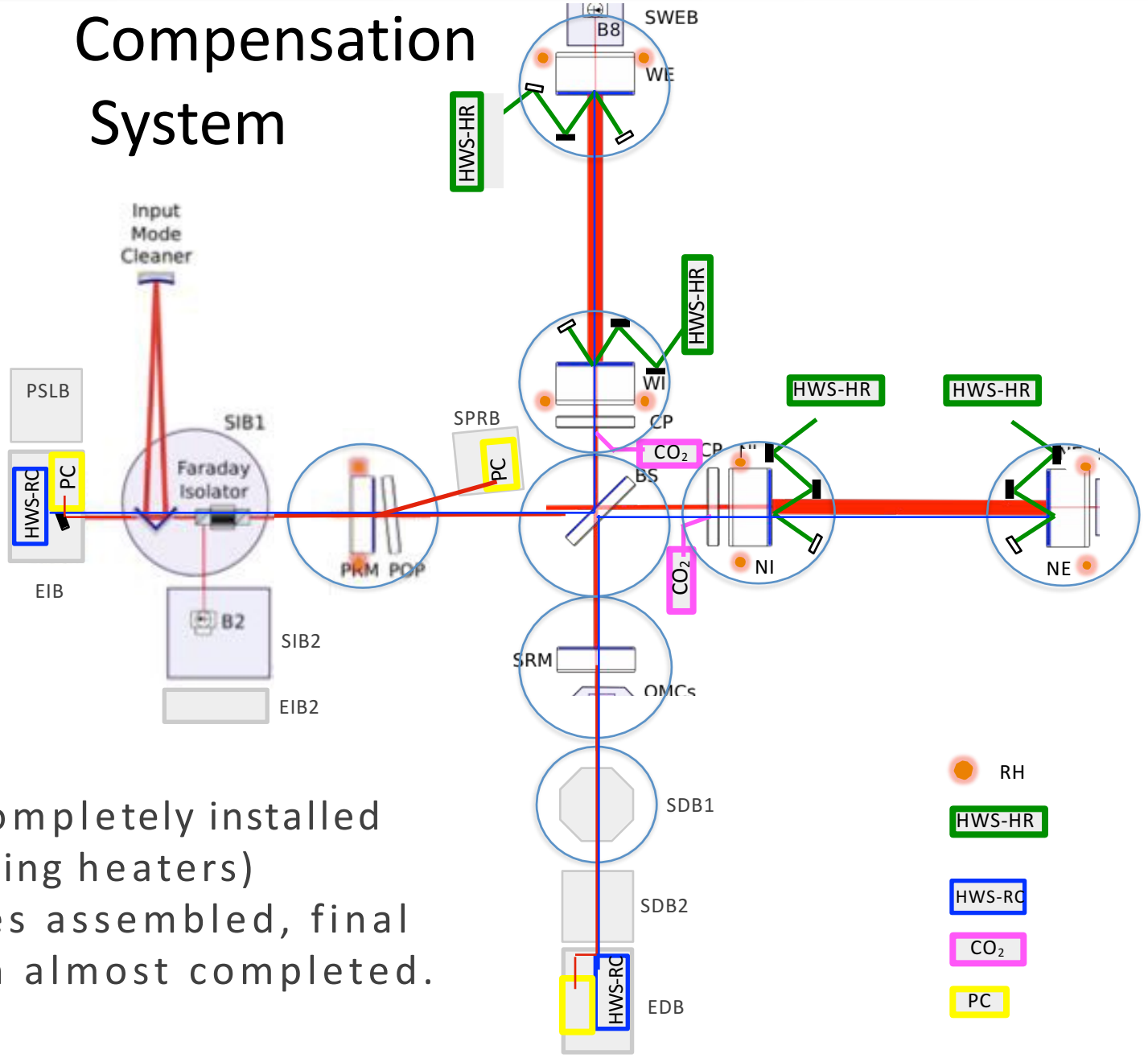
BS flatness ϕ 220 cm $\leq$ 1 nm

Preventing stray light

New baffles have been produced and installed

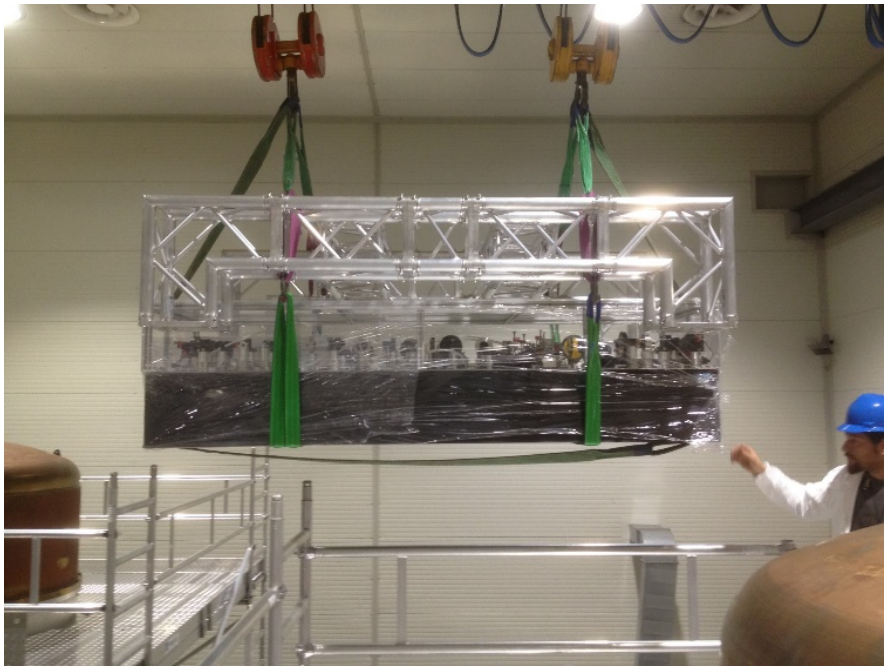


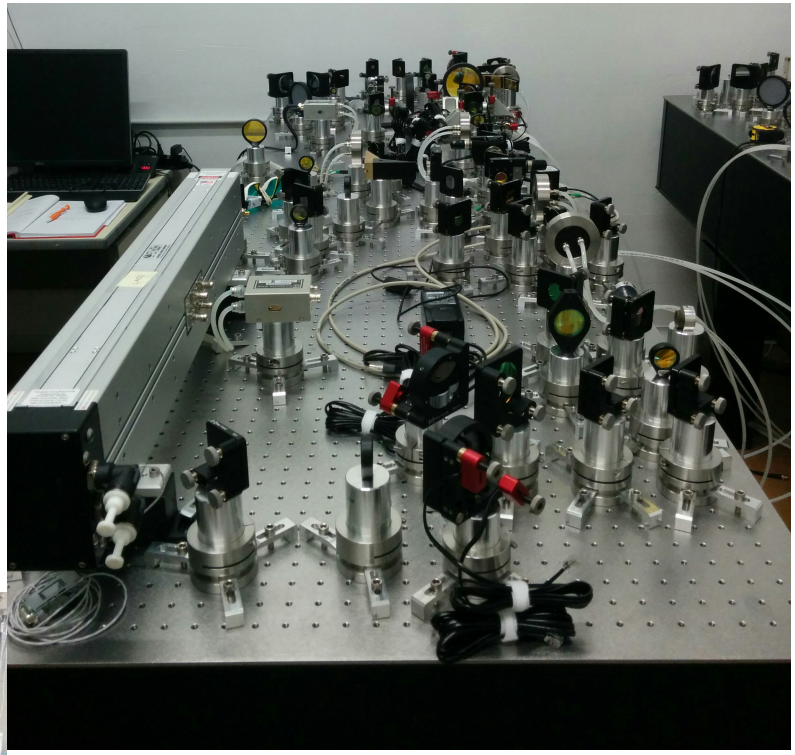
Thermo Compensation System

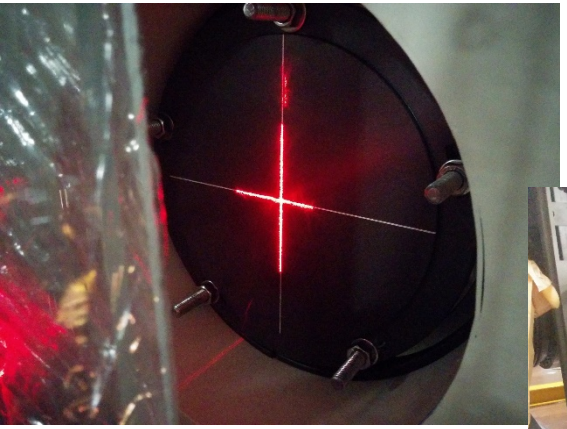


- Actuators completely installed (CO_2 lasers, ring heaters)
- HWS benches assembled, final intergration almost completed.

TCS - CO_2 benches

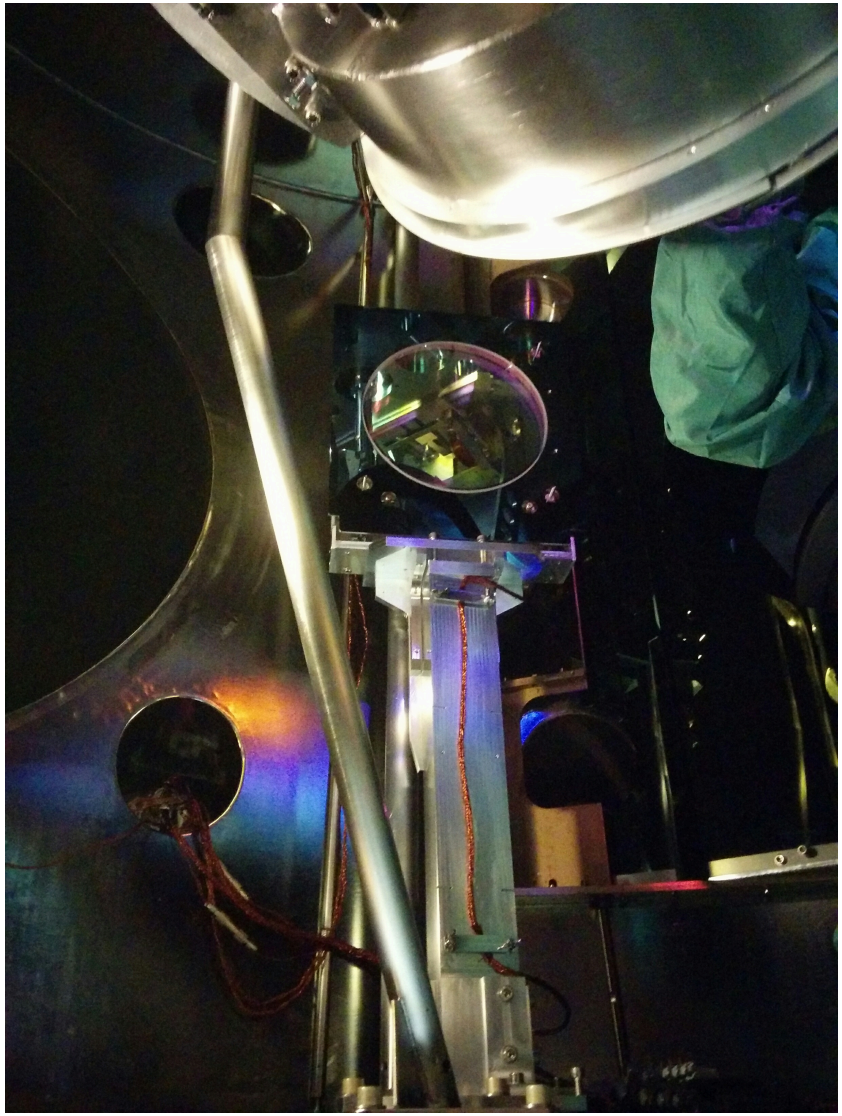


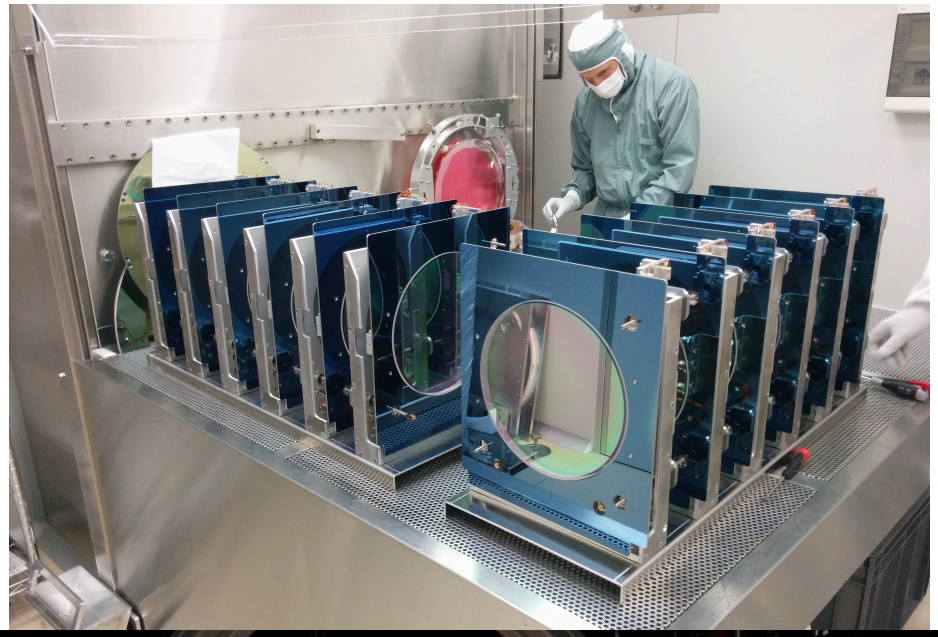


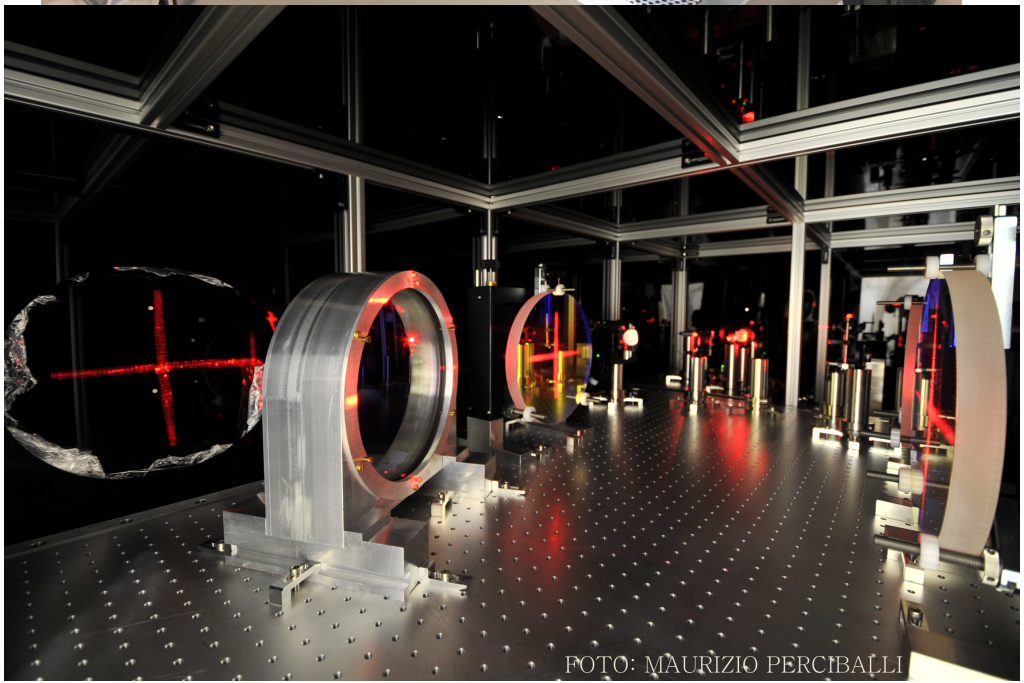


Fine alignment of visible aiming beam on CPs completed

TCS - HWS benches

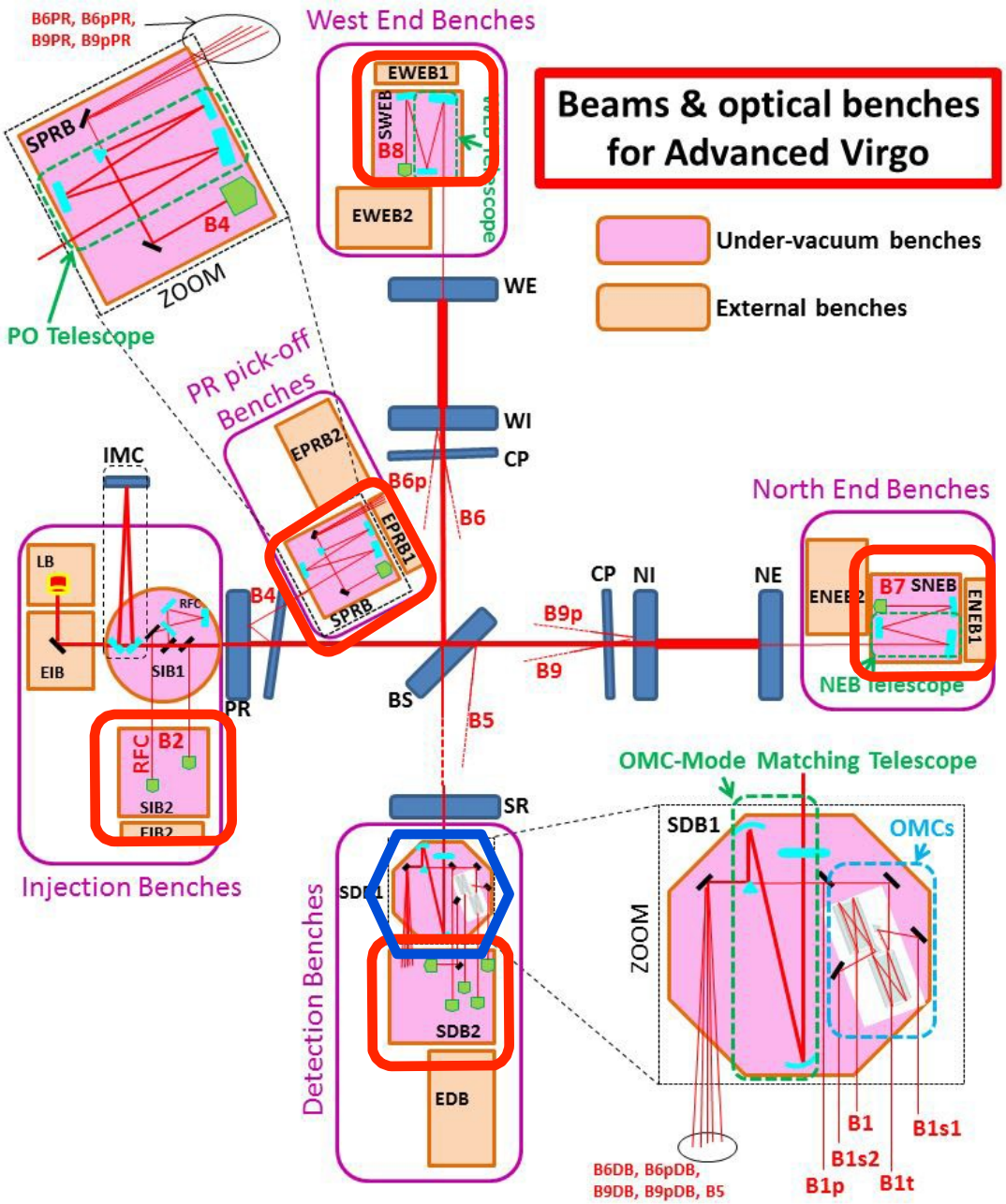


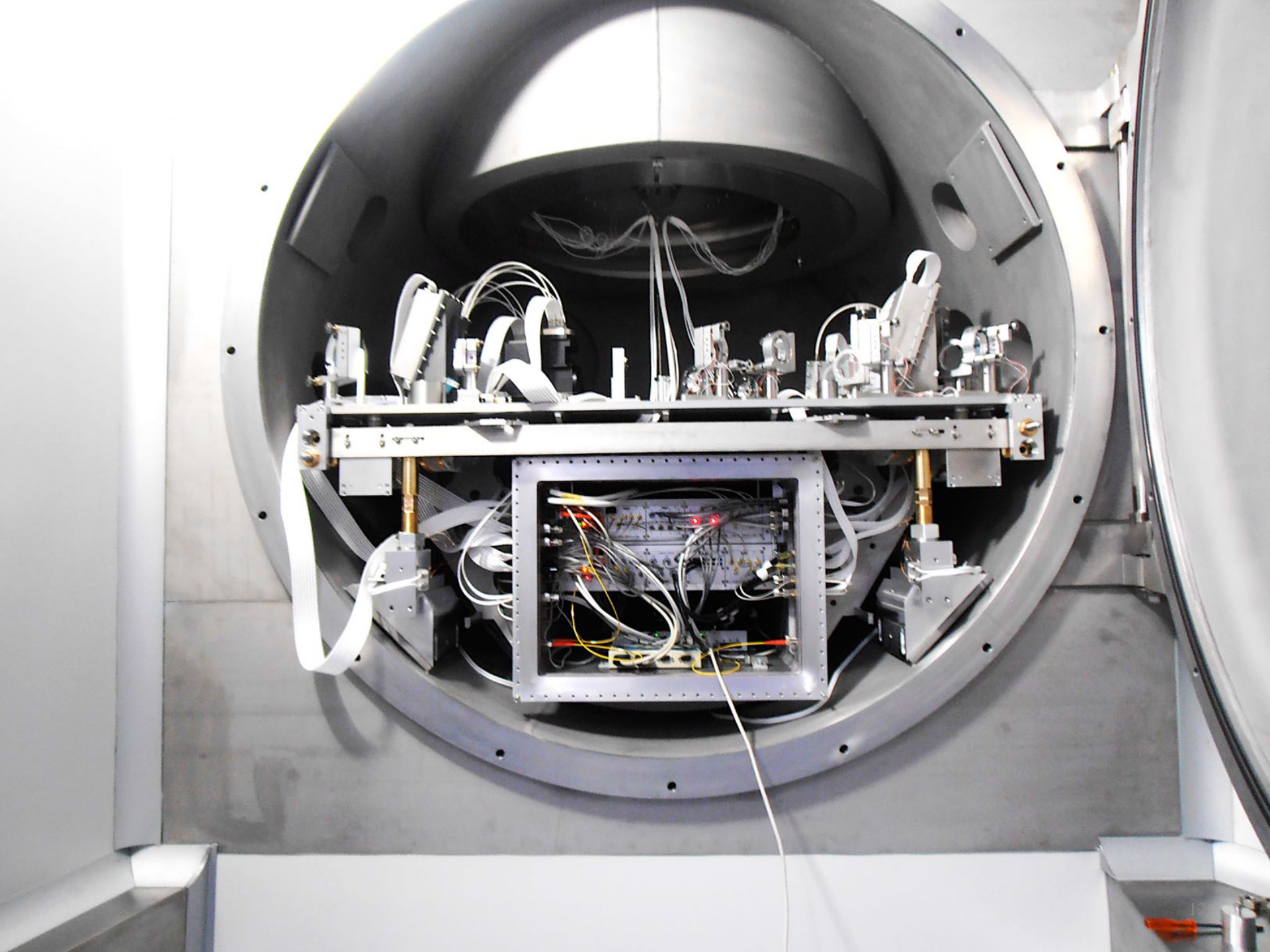




Detection System

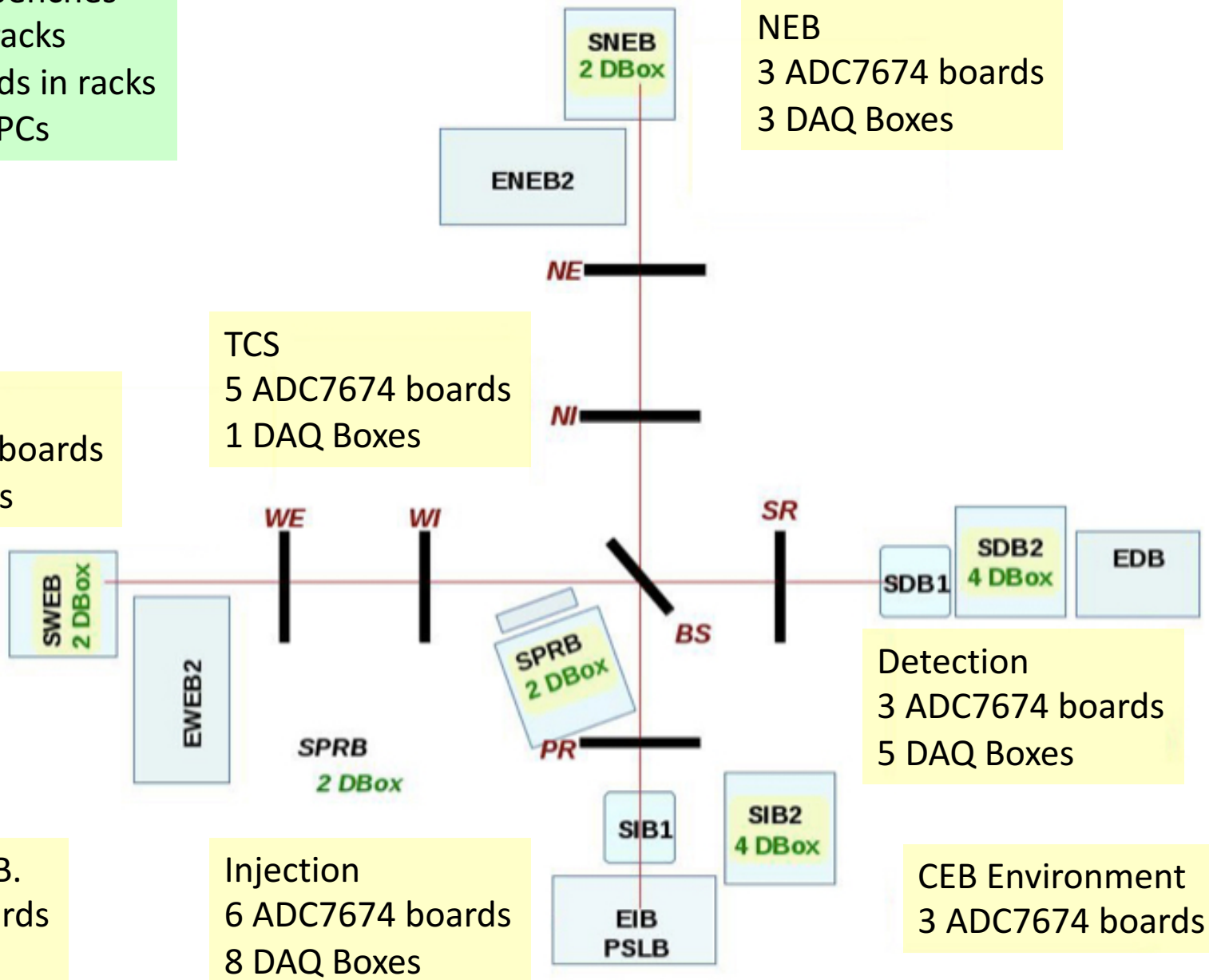
- 6 benches placed in vacuum chamber
- 2 (SDB1 and SNEB) suspended and controlled
- SNEB in vacuum





DATA ACQUISITION SYSTEM

14 DAQ Boxes in benches
25 DAQ Boxes in racks
25 ADC7674 boards in racks
12 new real time PCs



NEB
3 ADC7674 boards
3 DAQ Boxes

TCS
5 ADC7674 boards
1 DAQ Boxes

WEB
3 ADC7674 boards
3 DAQ Boxes

Detection
3 ADC7674 boards
5 DAQ Boxes

Control B.
16 RT PCs

Mode Cleaner B.
2 ADC7674 boards
1 DAQ Boxe

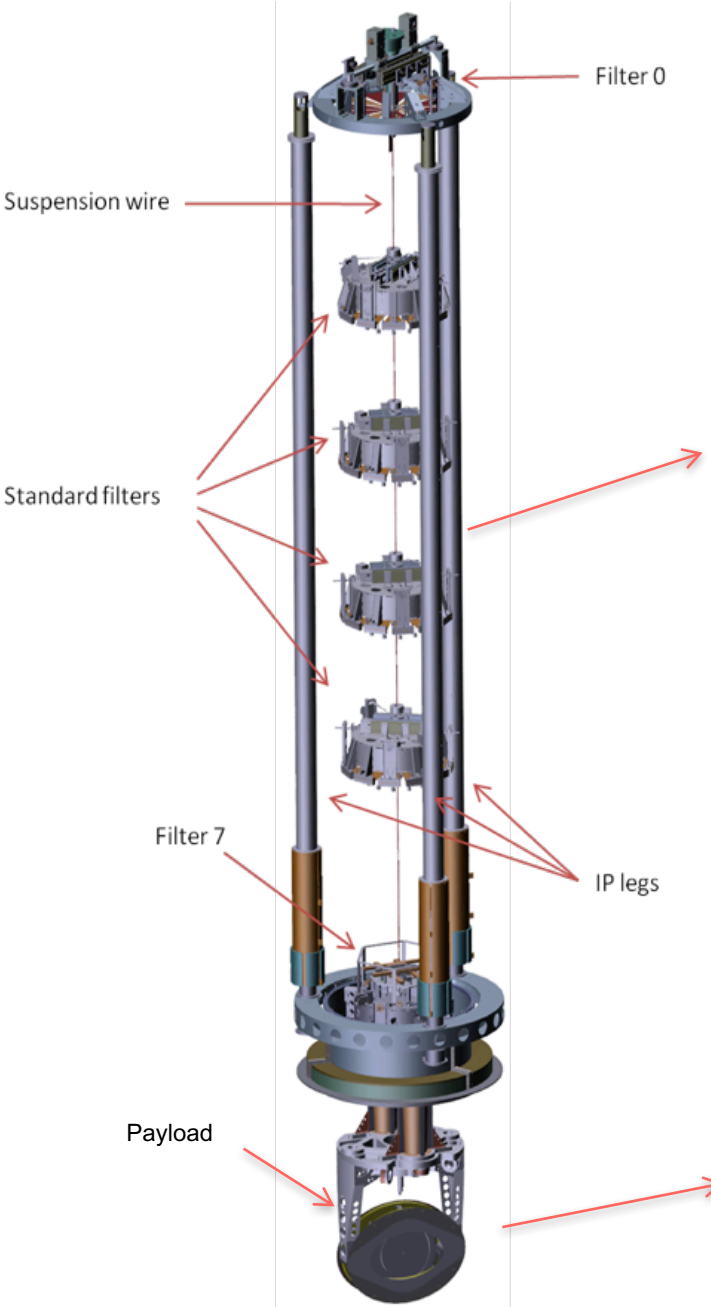
Injection
6 ADC7674 boards
8 DAQ Boxes

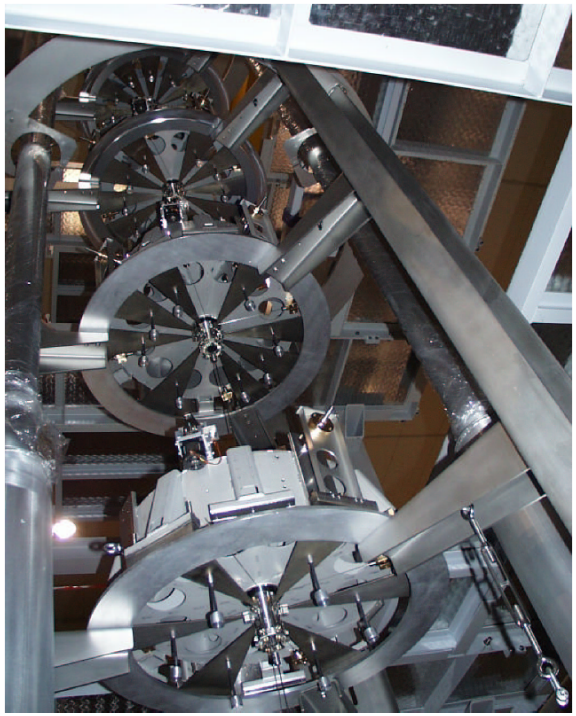
CEB Environment
3 ADC7674 boards

Suspensions of the optical elements

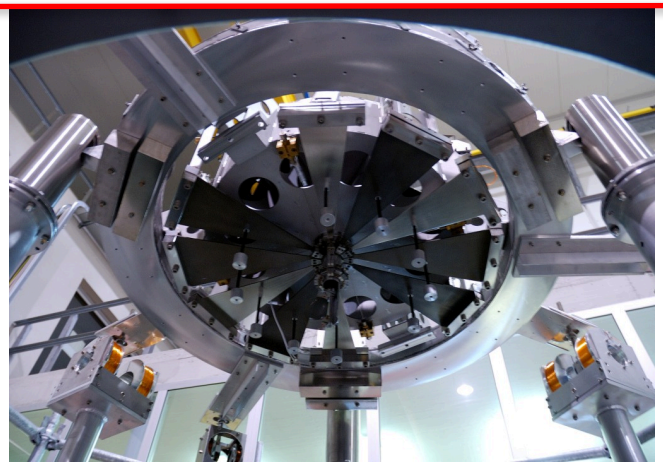
Suspensions of the mirror test masses: Super attenuator + Payload

Optical Benches: Short length Super attenuators





Elastic blades Issue



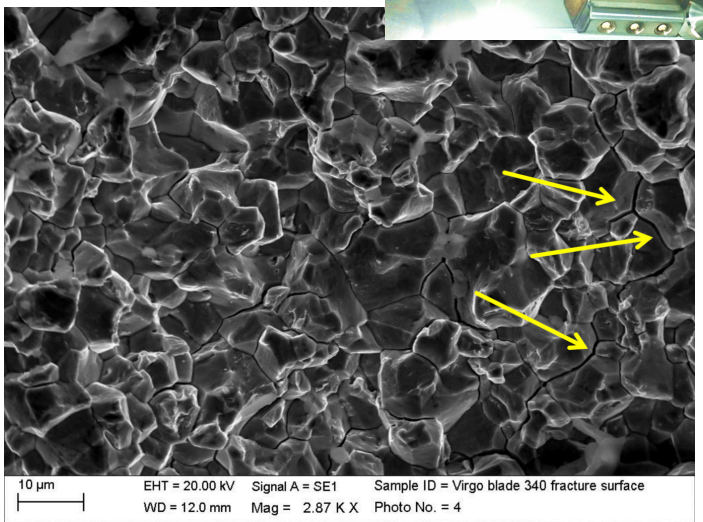
- 13 broken blades of the seismic filters of the mirror suspensions

- 1 broken blade of the seismic filters (G.A.S.) to suspend optical benches

- Cause identified: *Hydrogen embrittlement of the Maraging steel.*

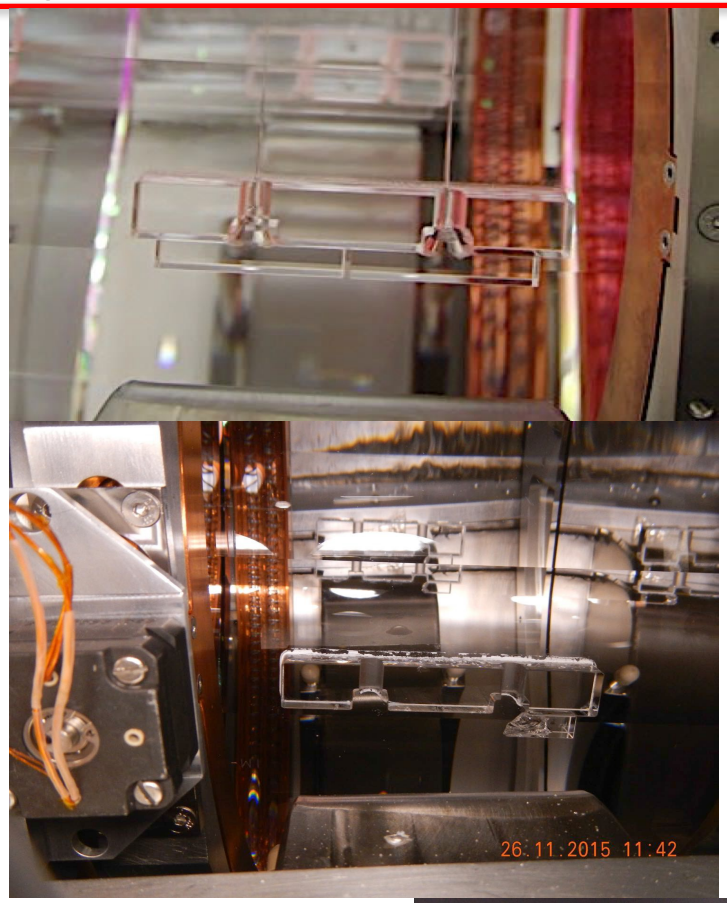
- Substitution of the broken and suspected blades: 161/260

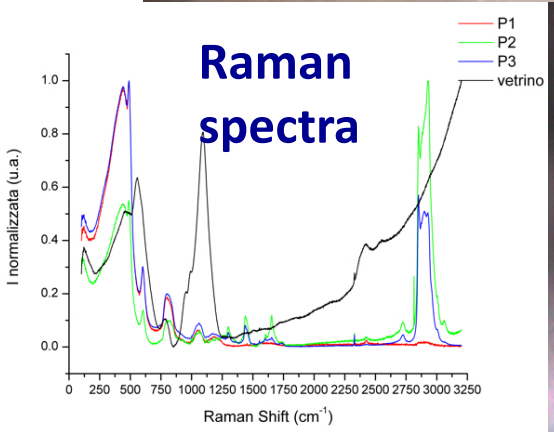
- 120 extra blades built and characterized

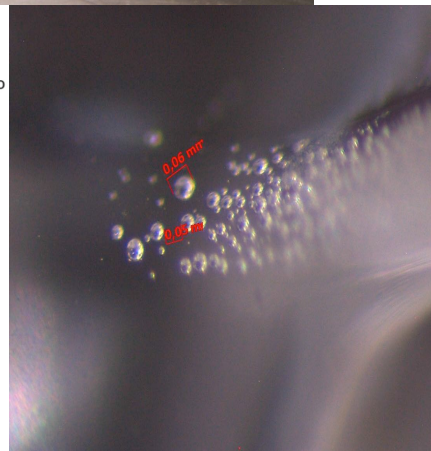


Monolithic suspension failure

- With the mirrors suspended under vacuum, we experienced failures of the monolithic suspensions
- In order to do not stop the commissioning we implemented a steel wire suspension to replace the broken ones.
- At present all mirrors suspended in vacuum and the commissioning activity is progressing
- *Investigation on the failure cause continue (Micro bubbles in the suspension? Material default?)*







The present configuration of AdV

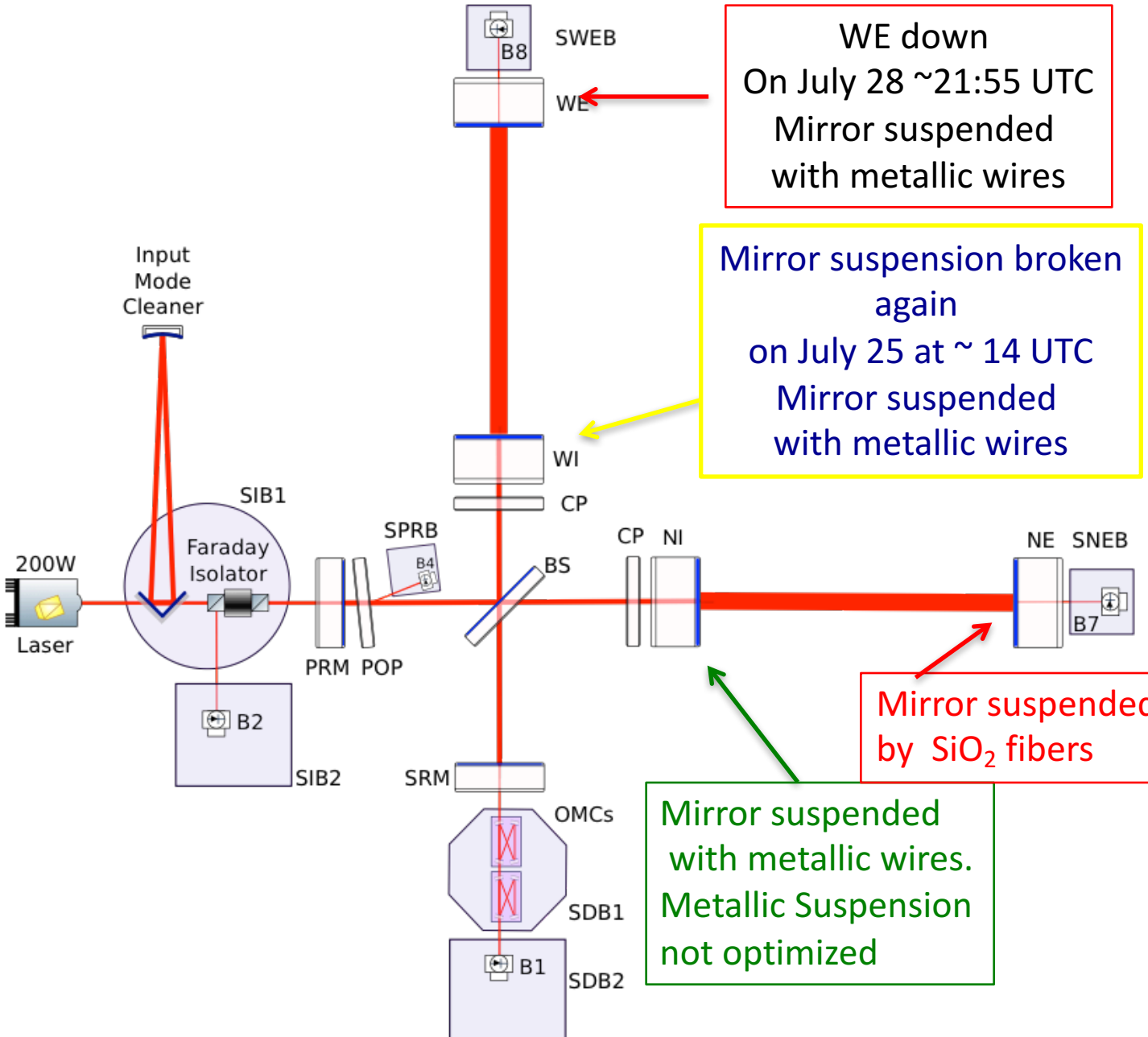
All the main parts of hardware are on-site and are installed

Final NI payload installation TBD soon

Failure of a NIKHEF blade solved promptly

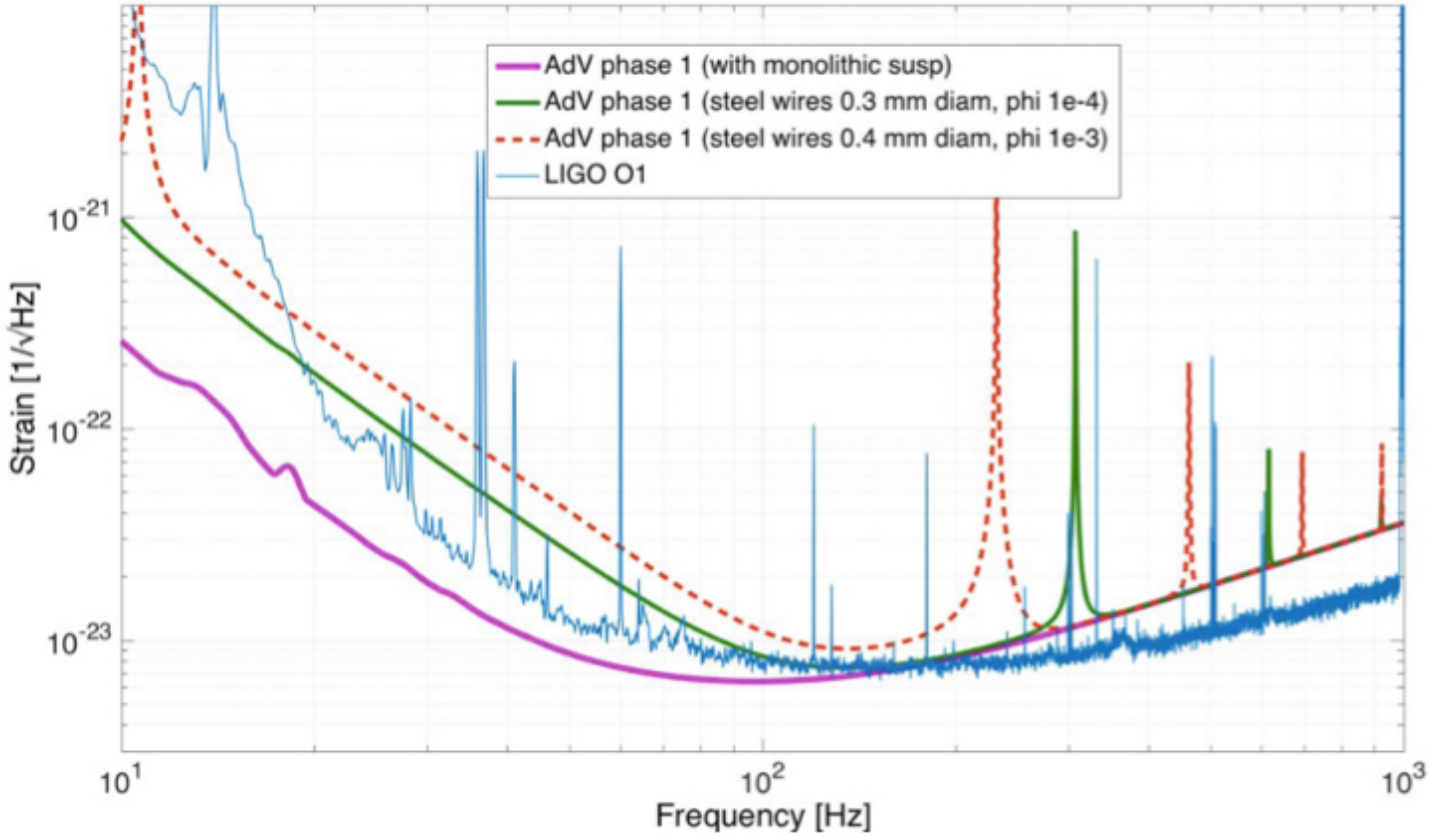
Commissioning of the North arm done. Arm locked. Light circulating also on CITF

West Input down again: action lan TBD



New target based on the present config.

- *We feel strongly that it must be maintained the prime goal of participating meaningfully in O_2 and this is still possible with mirror suspensions of steel wires*



	Steel 300 μm ϕ=10^{-4} (ϕ=10^{-3})
BNS Horizon [Mpc]	60 (45)
BBH Horizon [Mpc]	**313 (202)**

AdV Project Readiness

SubSystems	Status
INJ	
MIR	
PSL	Laser for phase 2 not available
SAT	
SBE	
INF	
SLC	
VAC	
PAY	2+1 payloads of the test masses with metallic wires + 1 monolithic
DAQ	
DET	
TCS	Almost Completed--- completed the sensing system
ISC	Hardware for phase 2 under study
OSD C	

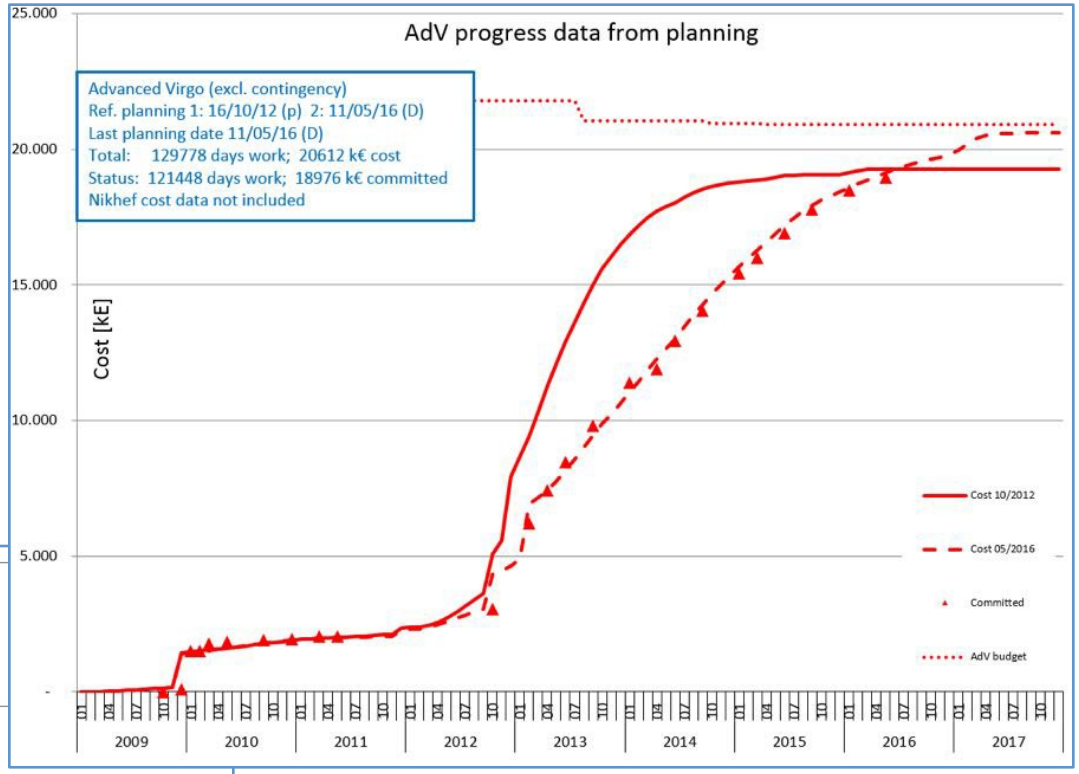

June 10, 2016
LAST TOWER
CLOSED

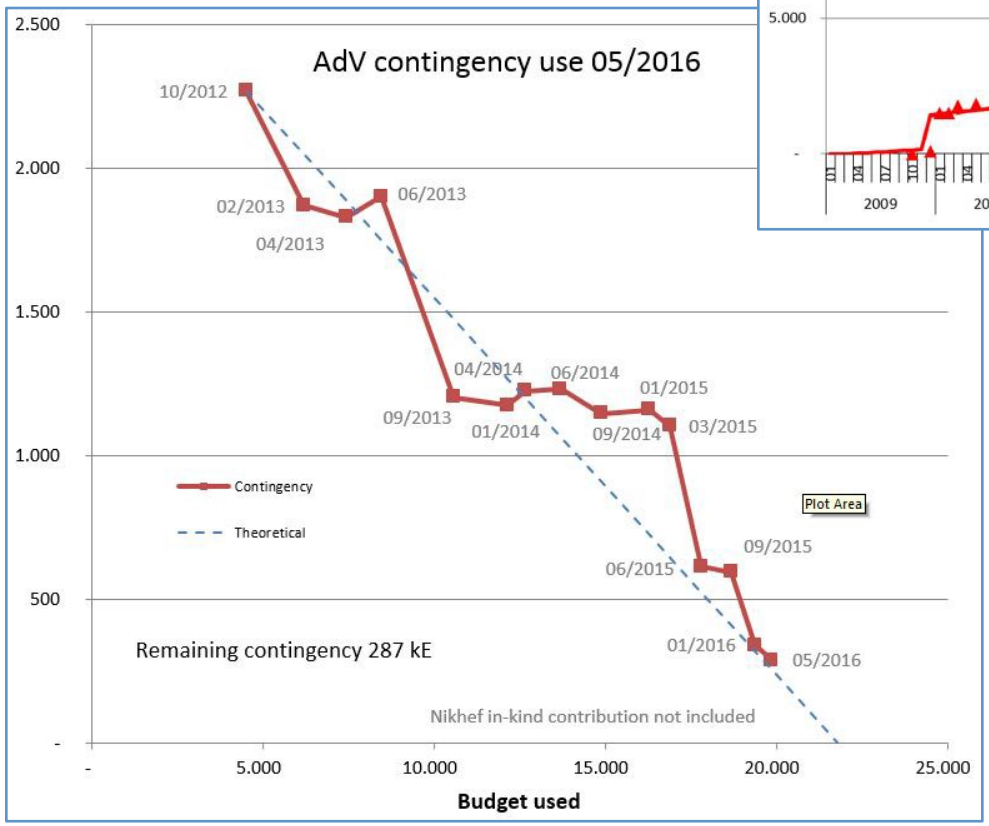
Virgo central hall
APRIL 2016


3000N CC
---
mBar
TCM_3000N_Valve
Turbo speed
600
Hz
2400N CC
5.328e-08
mBar
TCM_2400N_Valve
Turbo speed
600
Hz
1800N CC
8.56e-09
mBar
TCM_1800N_Valve
Turbo speed

Hz
1200N CC
6.237e-09
mBar
TCM_1200N_Valve
Turbo speed
600
Hz
600N CC
3.585e-09
mBar
TCM_600N_Valve
Turbo speed
600
Hz
NORTH ARM ready for commisioning on May: largevacuum valves opende and laser light at 3 km!
~2e-7 mbar
~2e-8 mbar
(it was ~5e-9 before the valve opening)
~4e-7 mbar

AdV Budget





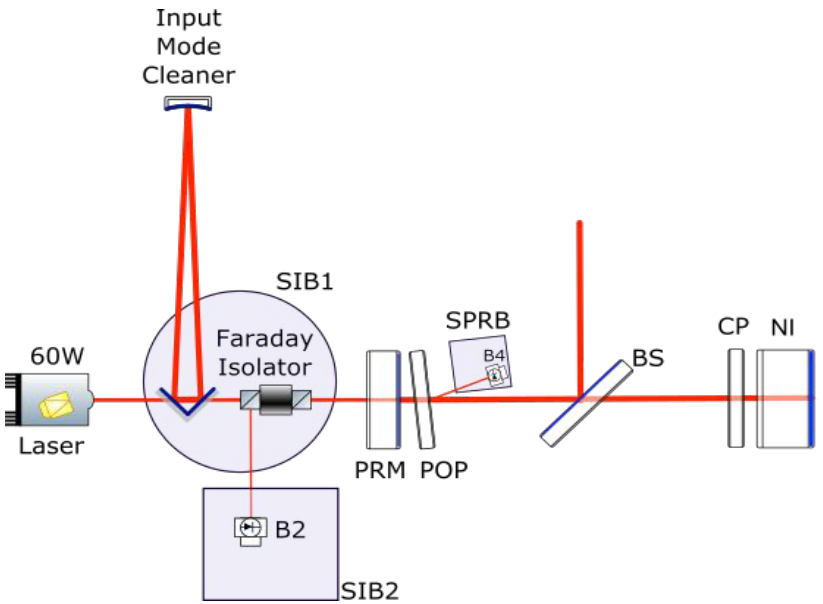
- Total cost 21.1 M€ (+2 M€ of Nikhef nominal contribution)
- Comm. Budget ~ 92%
- Contingency residual ~10%

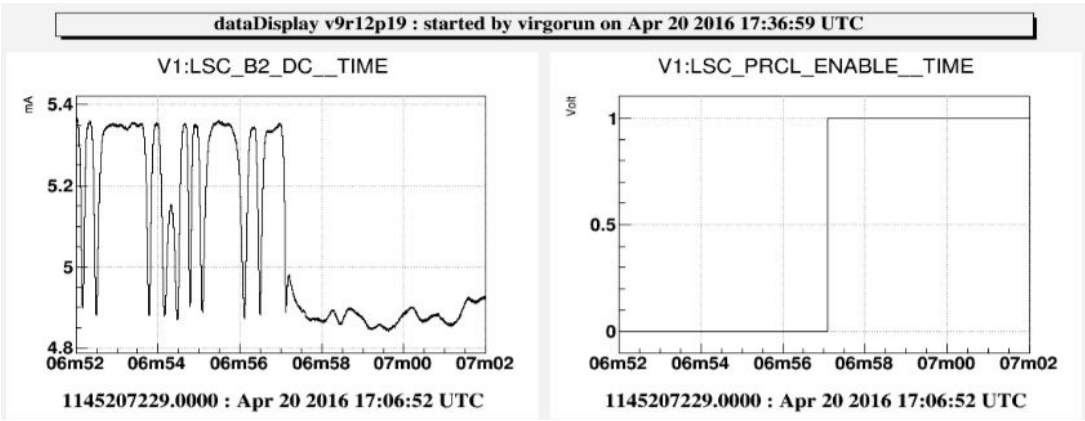
AdV Commissioning

First milestone:
the lock of PR-NI Cavity

A good integrated test for the
- upgraded super attenuators,
- new payload design,
- new control electronics,
- - digital demodulation,
- -new acquisition/locking software,
- - use of ring heater of the TCS system

Achieved on March, after the decision to suspend the NI mirror with steel wires

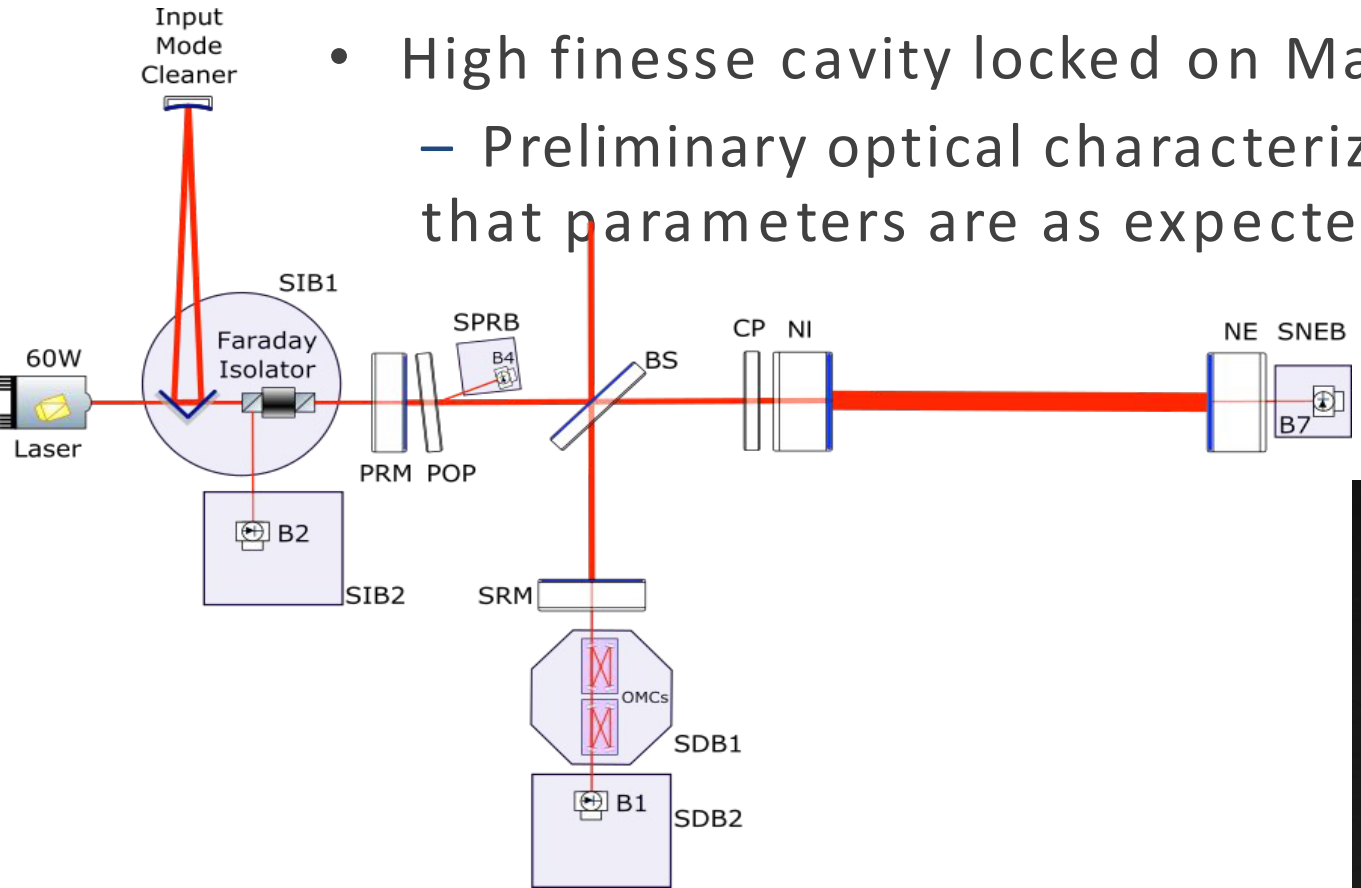




Second milestone: the lock of North Arm Cavity

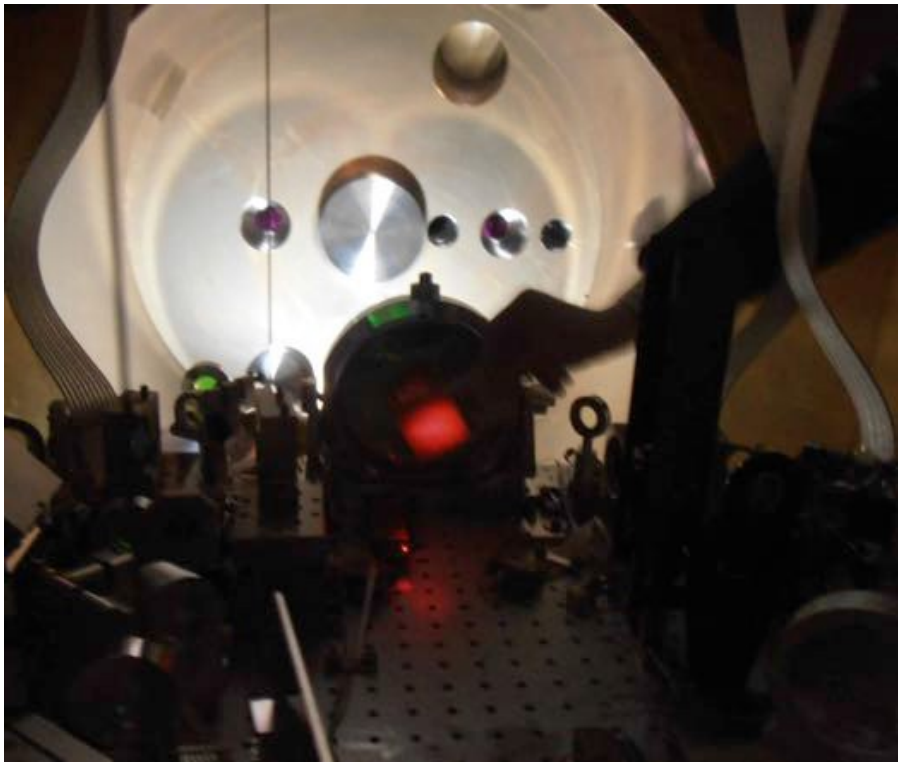
- Light sent at the end of the North arm on May 4 and the beam found shortly afterwards at 3 km of distance

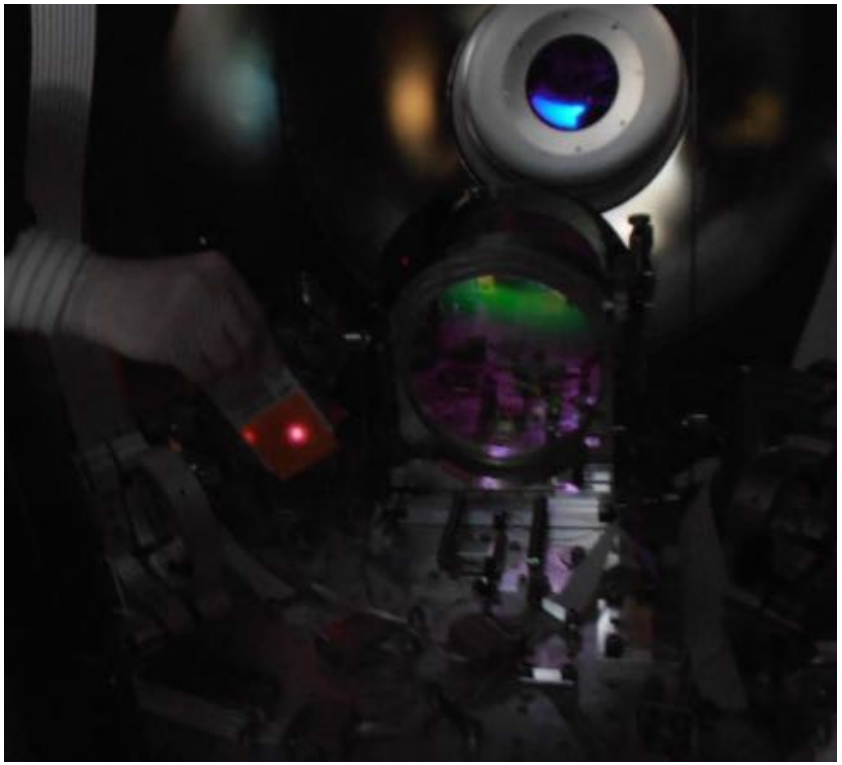
- High finesse cavity locked on May 22
  - Preliminary optical characterization shows that parameters are as expected



After a recent optimization lock duration record: well over 1.5 day!

Light on the Detection Bench





- Signals now available on most of the photodiodes
- The two short output mode cleaners are in operation

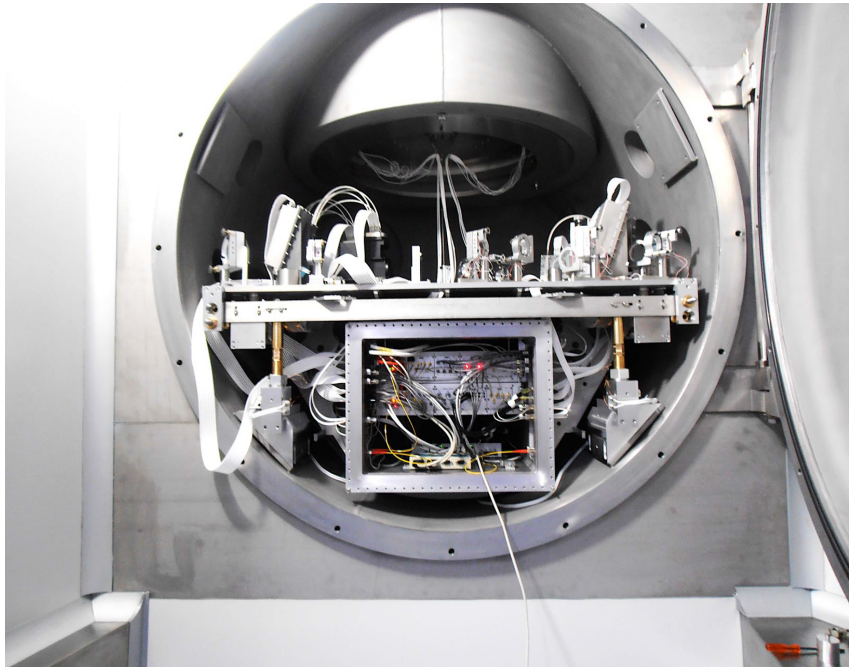
End Benches Suspended and Vacuum Test started

Crucial test of the system with the photodiodes and the related electronic under vacuum

Test started on August 18 on the Suspended North End external Bench (SNEB)

2 photodiodes on under vacuum ➔Power increase 10 W (up to a total of 120 W)

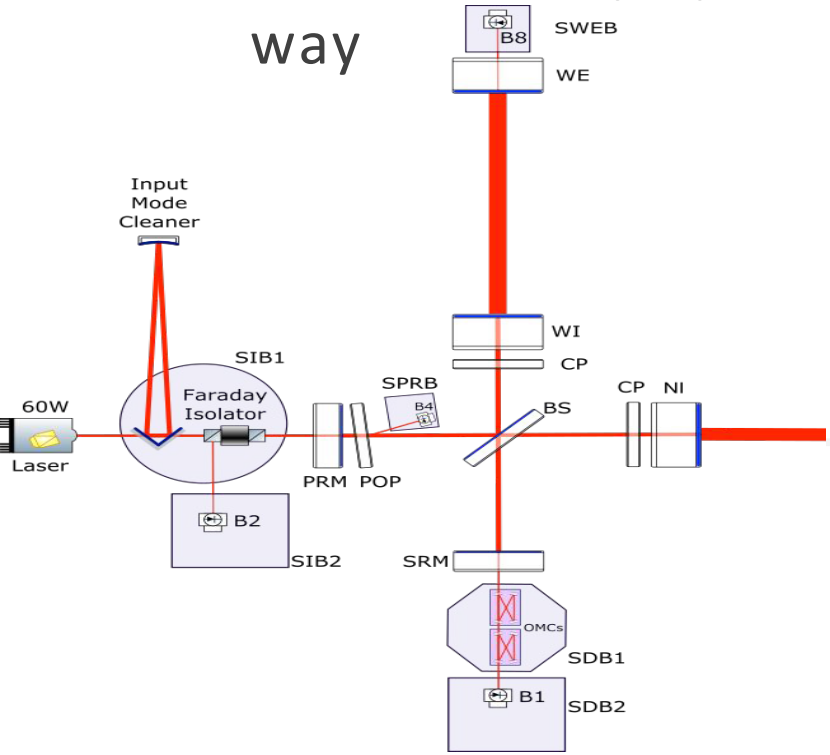
Thermal transient few hours

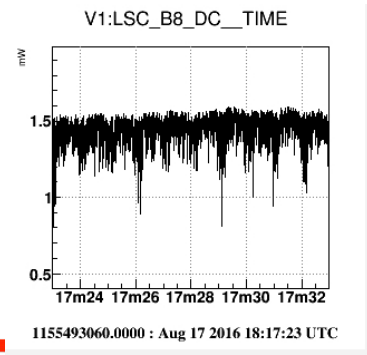


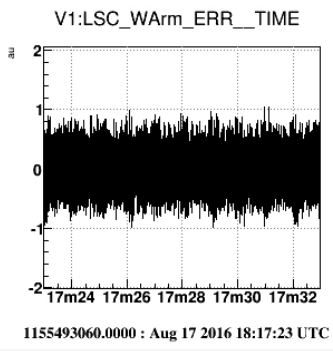
Third milestone: the lock of West Arm Cavity

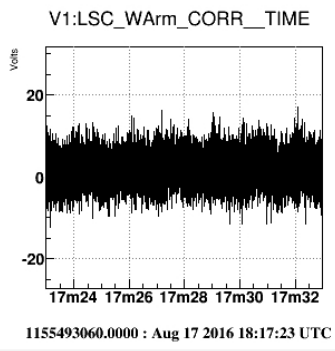
- Light sent at the end of the North arm on July 28 and the beam found shortly at 3 km of distance

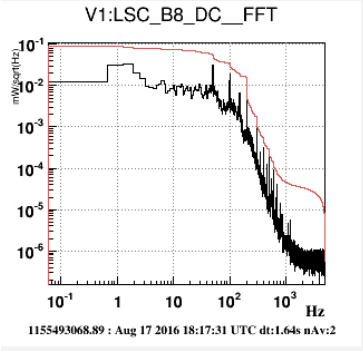
- High finesse cavity locked on August 17
  - Preliminary optical characterization on the way

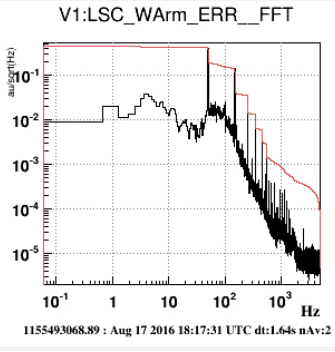


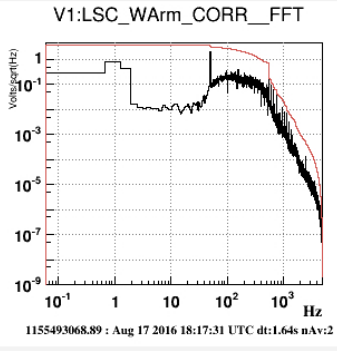






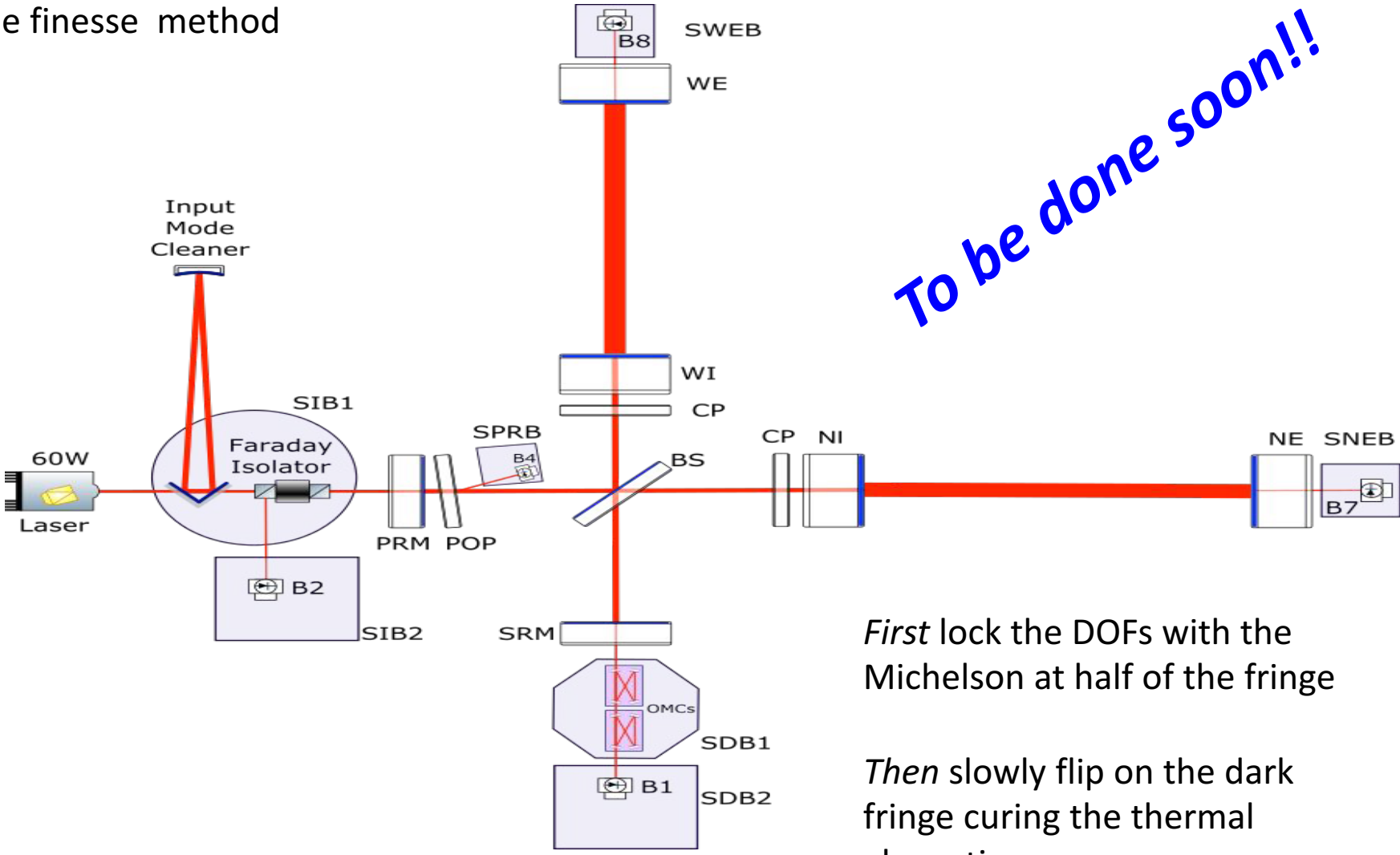






Fourth milestone: the lock of the full Interferometer

Strategy based on the use of the variable finesse method



To be done soon!!

First lock the DOFs with the Michelson at half of the fringe

Then slowly flip on the dark fringe curing the thermal aberrations

Path toward the Science Run

Achieve stable 1st lock

Address issues to to MSRC configuration (thermal aberrations). Requires smart use of TCS

Improve the stability and reliability of the lock

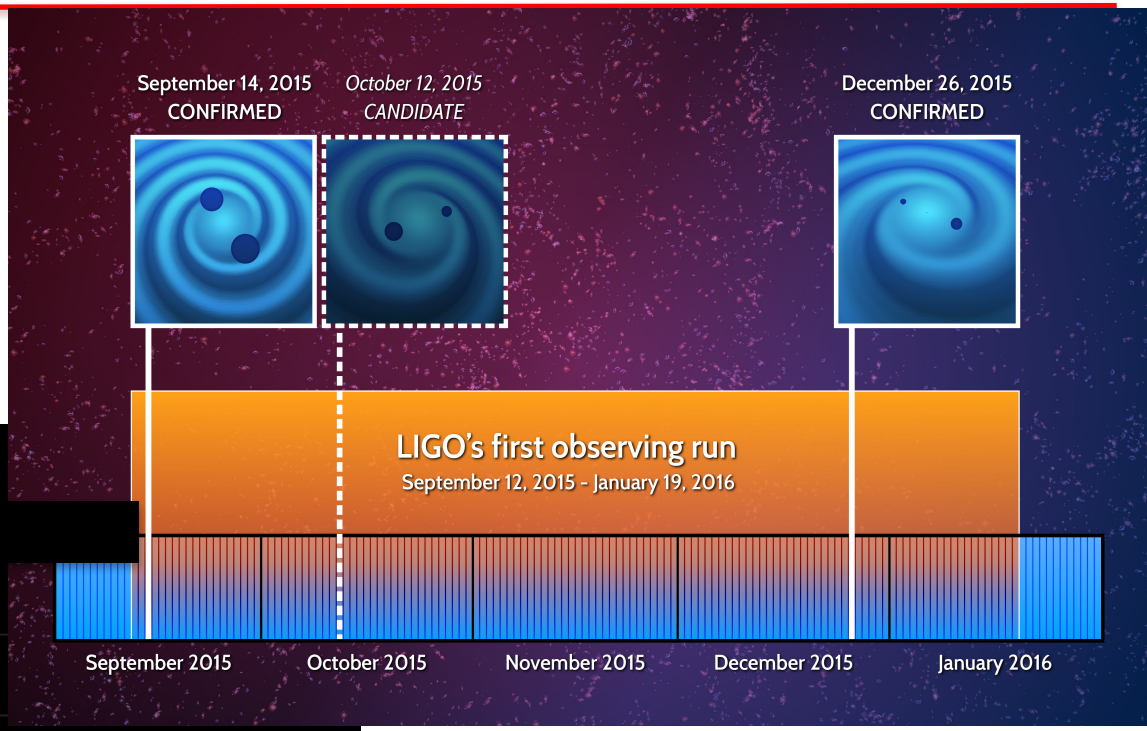
Noise hunting and reduction

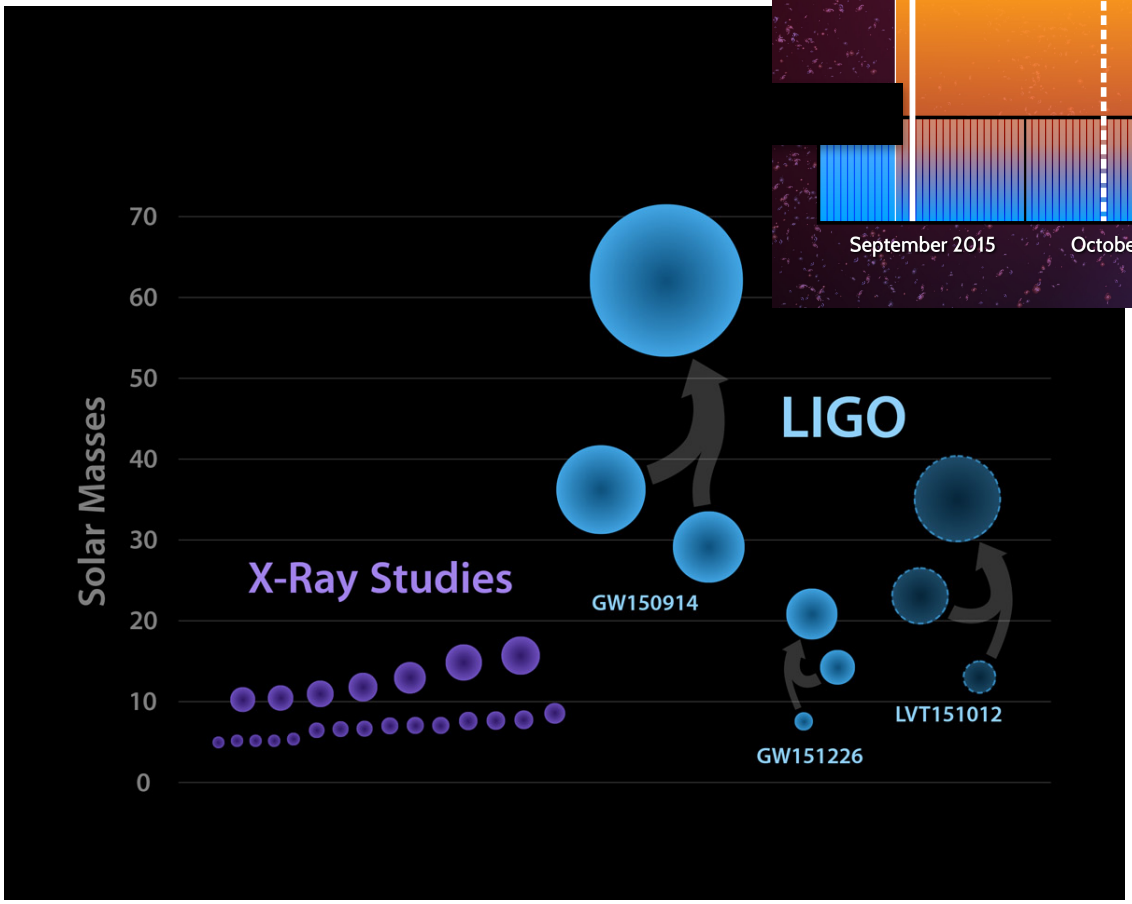
Optimize the sensitivity curve

Join O2 to detect GW signals

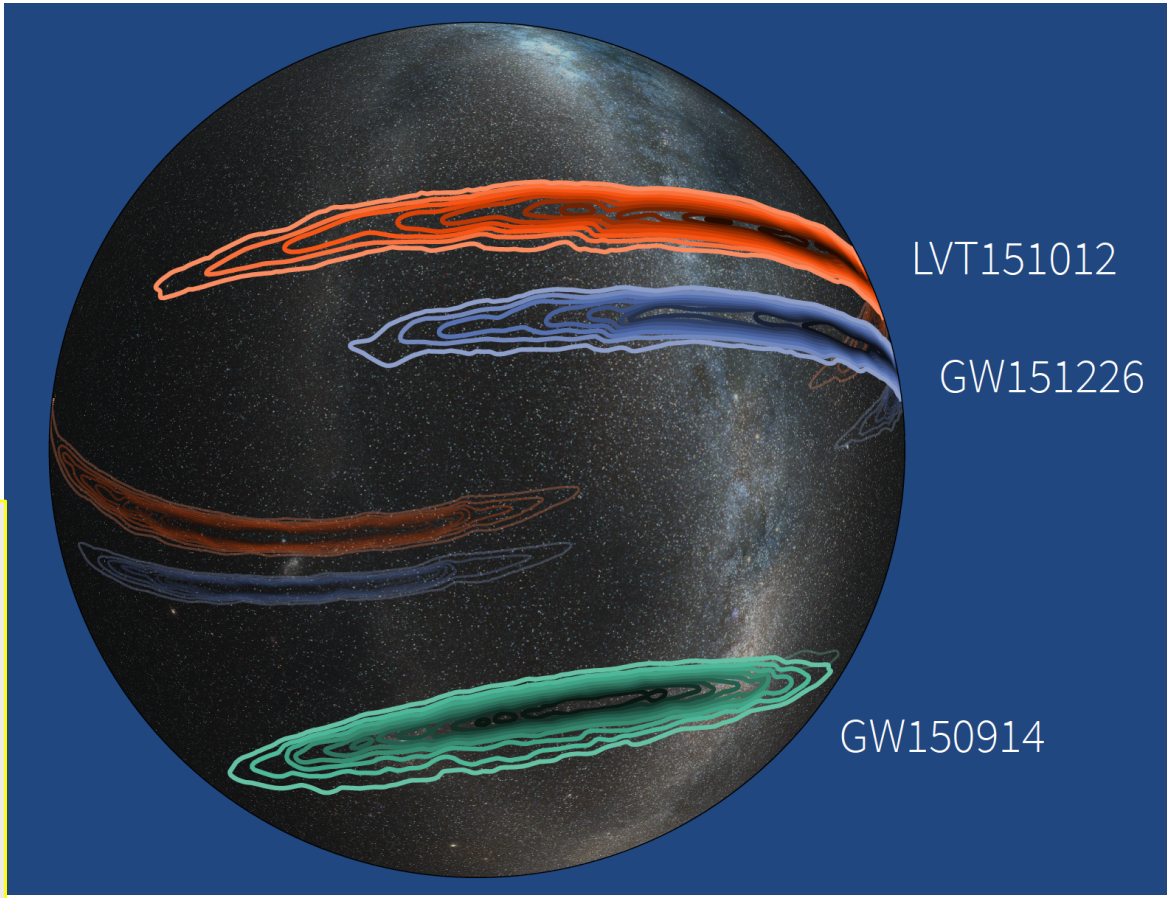
Preparing O2 for new discoveries: EM follow up & Computing effort

Starting point of O2: the O1 detections





Sky Locations of Gravitational-wave Events GW150914, GW151226 and Candidate LVT151012



Sky localizations
90% credible areas of about

620 deg^2 GW150914

1600 deg^2 LVT15012

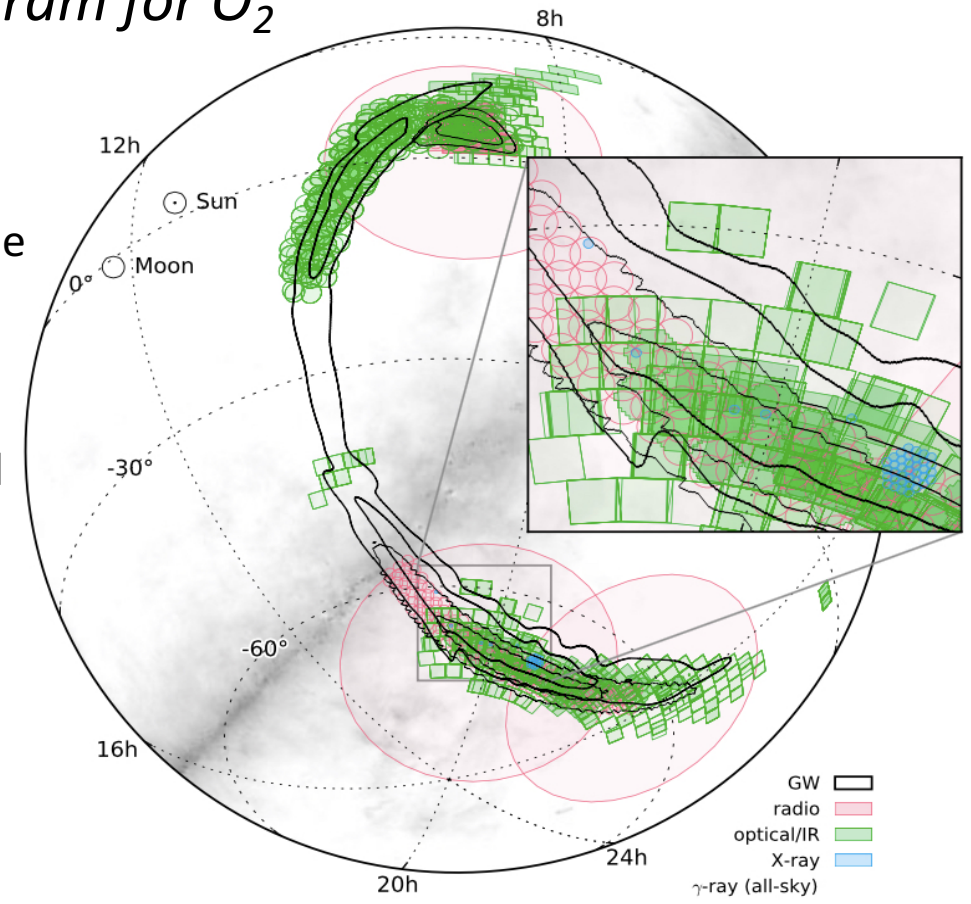
1000 deg^2 GW151226

EM follow up for GW150914 and …….

Great success of the e.m. follow up program.
20 groups reacted to the circular sent to astronomy community

New groups admitted to the program for O_2

- AGILE, (X-ray and Gamma ray astronomical **satellite)**
- DWF, (Deep-Wide-Fast program to survey the sky with LSST)
- DLT40, (Frequent survey of galaxies closer than 40 Mpc)
- GROND, (GROND 7-channel imager mounted at the 2.2 m telescope at La Silla-ESO)
- HUNTSMAN, (8 Cannon telephoto lenses used to rapidly scan the GW error box)
- IKI (Gamma-ray burst follow-up capabilities of Russian Space Research Ins8tute -IKI)
- COSI (Compton Spectrometer and Imager , balloon-borne wide-area gamma-ray survey)



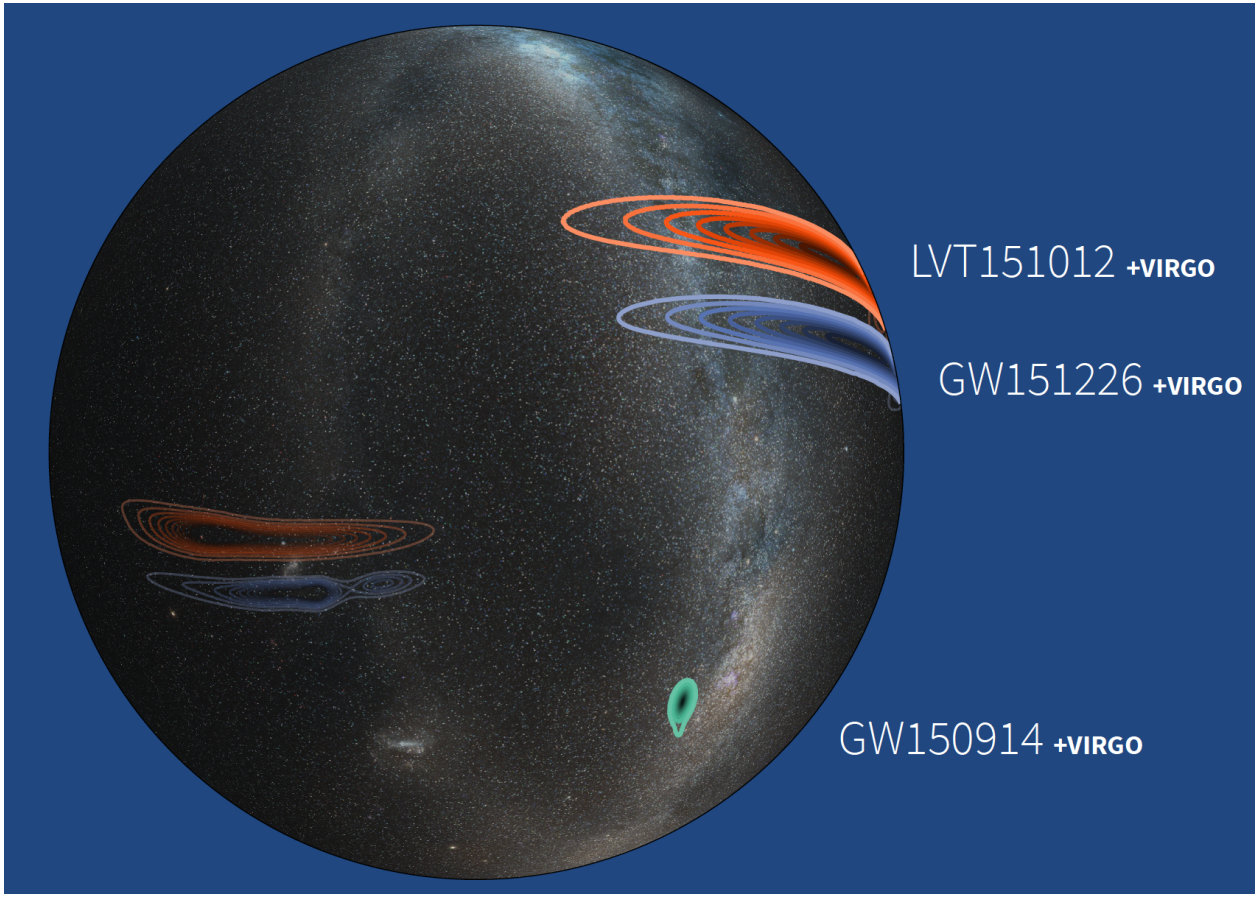
Simulated Sky Locations of O1 Events and Candidate Including the Virgo Interferometer

Sky localizations
90% credible areas of about

10-20 deg^2 GW150914

1000 deg^2 LVT15012

600 deg^2 GW151226



Effort to increase the Virgo off-line Computing for O_2

- ✓ Successful effort to harmonize the CNAF software environment with the LIGO one
- ✓ Virgo able to provide already off-line computational power of 25 kHS06_ per _year* (via CC-CNAF) ➔ 6% of the total computational power (~420 kHS06_ per _year)
- ✓ Effort to increase our contribution
  - Wigner: 2Mhours of CPU, no GRID compliant –difficult to be used,
  - Polgrav: 3Mhours of CPU, GRID compliant , high performance
  - Nikhef: 25kHS06 (as CNAF), GRID compliant, Test to be done

** 1 kHS06 ➔ 1 Tflop (double-precision peak) ➔100 CPU cores as of 2012*

New Discovery in O2 ?

- ✓ During the conferences of the summer season, we collected a lot of different predictions and beats for a new discovery. Apparently the winner seems to be:

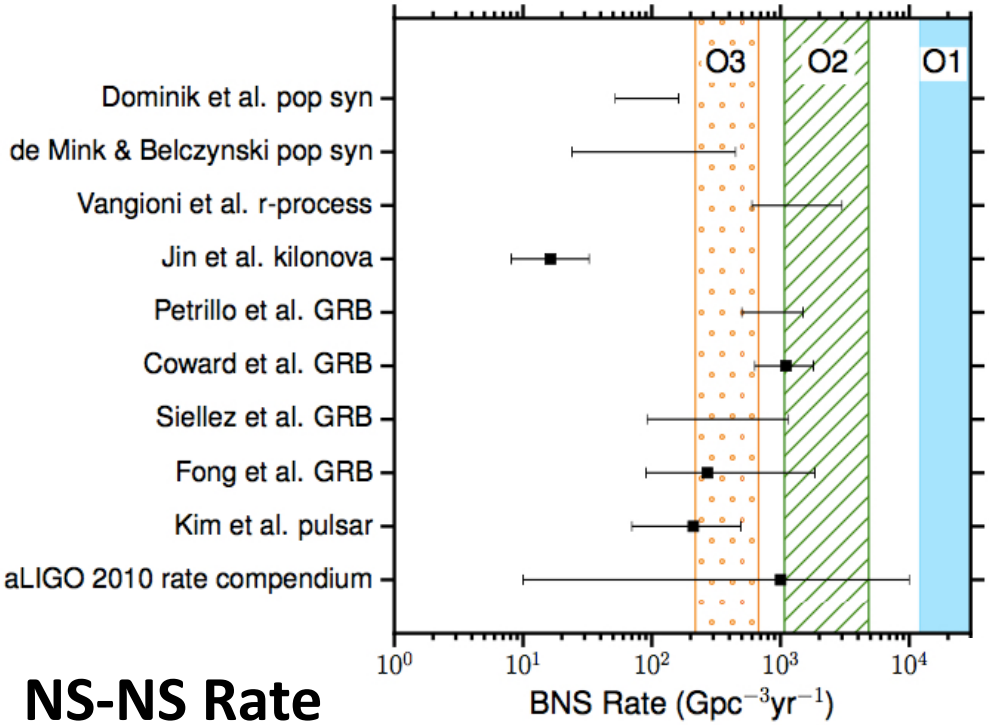
NS-BH!

Just one citation: Nakamura summary talk @ GWPAW2016 in Boston.

<< *Now as for chirp mass , BBH >> NS-BH >> NS-NS*

- *The detectable range is proporTonal to 5/6 power of the chirp mass and the volume is 5/2*
- *So that BBH is the easiest detectable source.*
- *Following this tendency in O2, I predict*
- *NS-BH will be observed !!* >>

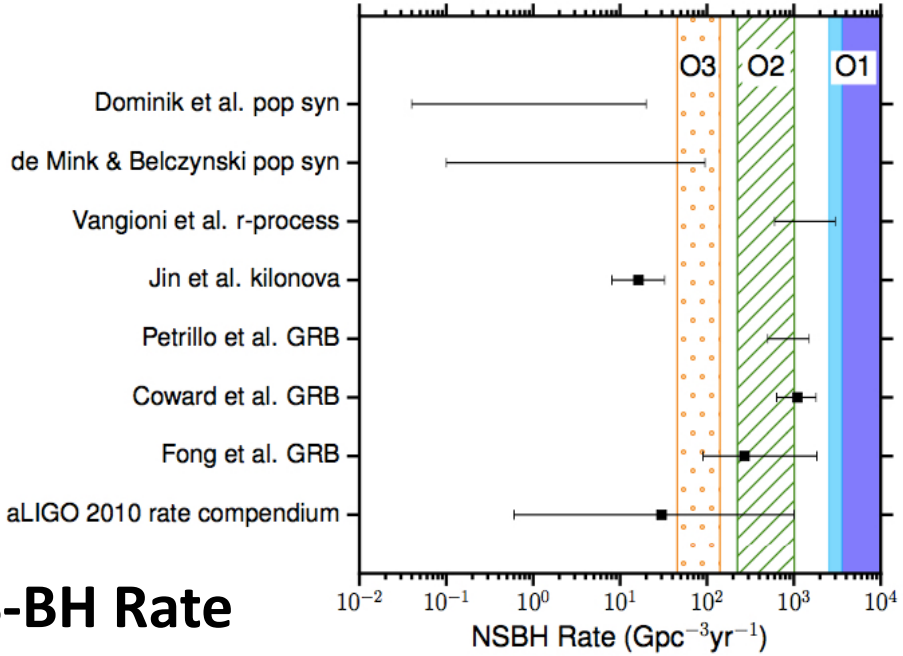
Upper Limits Rates of BNS and NSBH Mergers from O1



NS-NS Rate

(Abadie *et al.* 2010 Class. Quant. Grav. 27, 173001 ; Fong *et al.* 2015 , Astrophys. J. 815, 102; Coward *et al.* 2012 Mon. Not. Roy. Astron. Soc. 425, 1365 ; Petrillo *et al.* 2013 , Astrophys. J. 767, 140 ; Jin *et al.* 2015 Astrophys. J. 811, L22 ; Vangioni *et al.* 2016 Mon. Not. Roy. Astron. Soc. 455, 17 ; de Mink and Belczynski 2015Astrophys. J. 814, 58; Dominik *et al.* 2015, Astrophys. J. 806, 263)

(Abadie *et al.* 2010-Class. Quant. Grav. 27, 173001 ; Kim *et al.* 2015 Mon. Not. Roy. Astron. Soc. 448, 928; Fong *et al.* 2015 , Astrophys. J. 815, 102 ; Siellez *et al.* 2014 , Mon. Not. Roy. Astron. Soc. 437, 649 ; Coward *et al.* 2012 , Mon. Not. Roy. Astron. Soc. 425, 1365 ; Petrillo *et al.* 2013 , Astrophys. J. 767, 140 ; Jin *et al.* 2015 , Astrophys. J. 811, L22 ; Vangioni *et al.* 2016 , Mon. Not. Roy. Astron. Soc. 455, 17 ; de Mink and Belczynski 2015 Astrophys. J. 814, 58 ; Dominik *et al.* 2015 , Astrophys. J. 806, 263).



NS-BH Rate

A vision of the AdVirgo future

A vision of the Virgo future

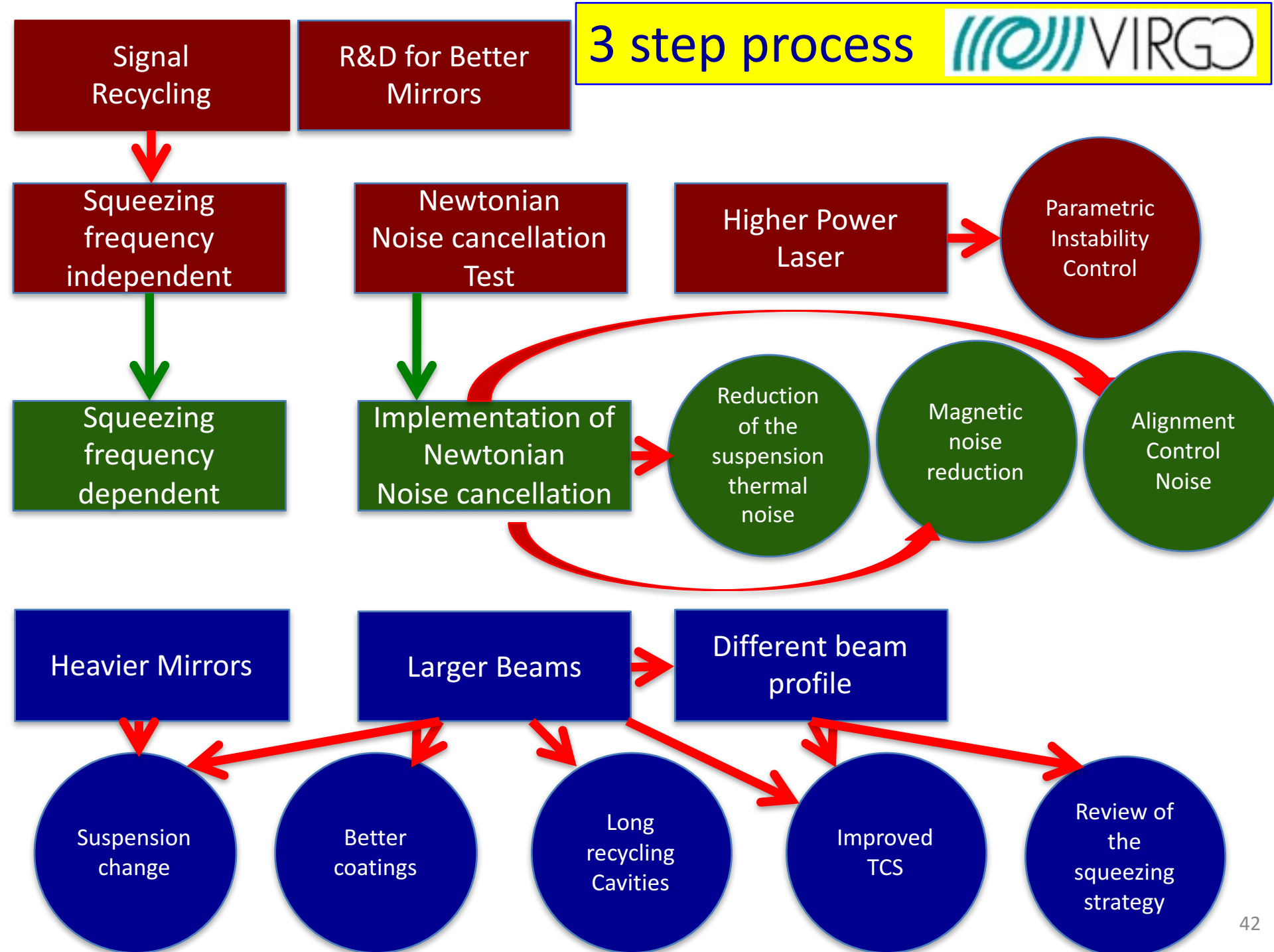
- Goal for the next decade: maximize the scientific output of AdV
  - Maximize data taking
  - Minimize downtime

- Phase 1 (2017):
  short term actions to prepare new implementation between O2 and O3

- Phase 2 (2018-2021):
  pushing toward the nominal sensitivity of AdV

- The far future (>2021)
  attempts for a further increase of the AdV sensitivity, useful also in view of a new infrastructure

3 step process



Preparing a new powerful laser

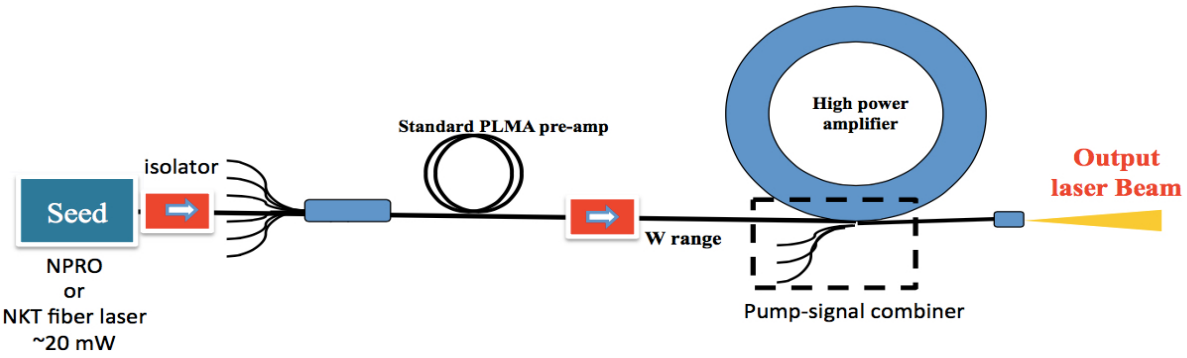
Test of an ALS system based on the fiber technology :

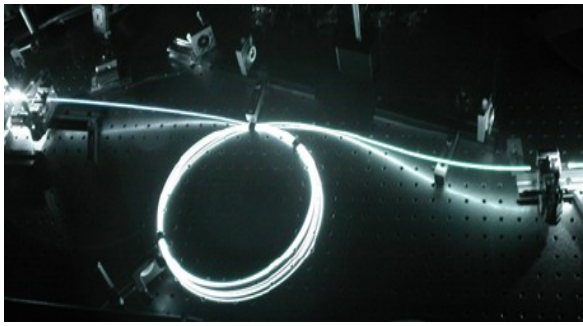
-Output power : 43 W

ALS1 tested for 2400 h, ALS2 tested for 3900 h

-Tested with respect to noise issue and found to be compliant with the AdV specifications

-- Effort on the way to go up to 100 W





Test of the new NeoLAS Solid State Laser:

- NEO Lase (Germany) has designed a 100W based on a 4 stages solid Nd-YVO4 rods Seeded by a 20W
- 100 W module is an upgrade of the 60 W amplifier used now for Adv Virgo
- Contact among NEO Lase, Virgo group in Nice and AEI -Hannover for testing this solution

Whatever the system will choose, we are targeting a coherent combination → 2x100W based on medium power amplifiers

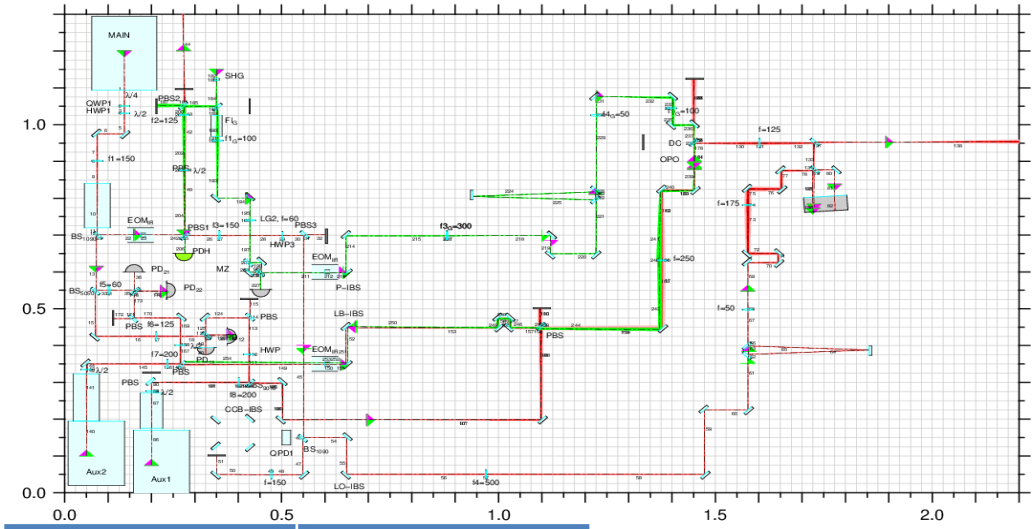
Squeezing activity in Cascina

Green Line SHG+MZ+MC532

OPO Line OPO cavity

Homodyne line MC1064+ homodyne

Other OPLL, electronics



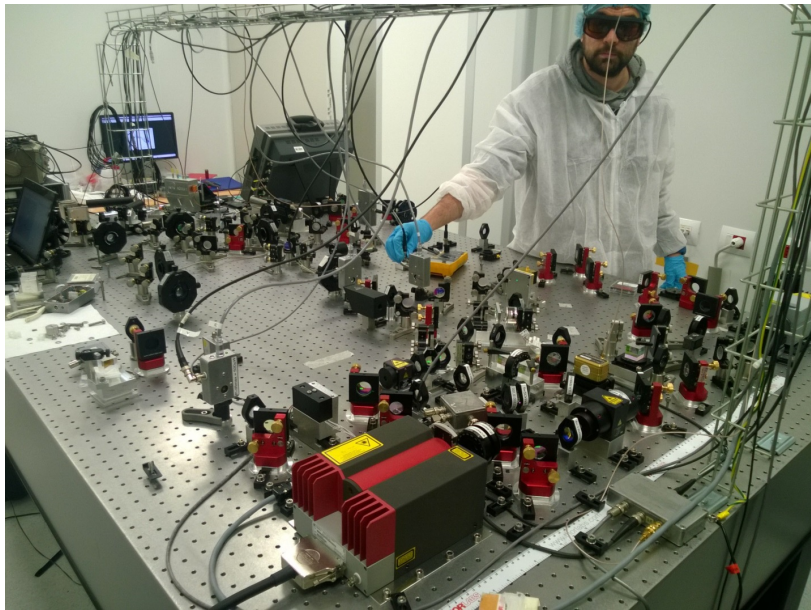
- SHG - Second Harmonic Generation
- MZ - Mach Zender for power stabilization
- MC532- Green light mode cleaner
- MC1031- Infrared light mode cleaner
- OPO - Optical Parametric Oscillator
- OPLL – Optical Phase Locked Loop

Green Line	
SHG	Installed
MZ	Installed
MC532	Installed

Homodyne Line	
MC1064	Installed
Homodyne	Installed

OPO line	
OPO	Installed and test started

OPL and electronic	
OPLL PCB	Ready
DCC	Ready
Main Controls	Work in progress



Test on New. Noise cancellation

Modelling NN for Virgo is not simple: we need to understand

- Seismic correlation
- Seismometer placement
- Structural response to seismic sources at various locations

- Nikhef developed a dedicated sensor in the context of a large project supported by Shell.

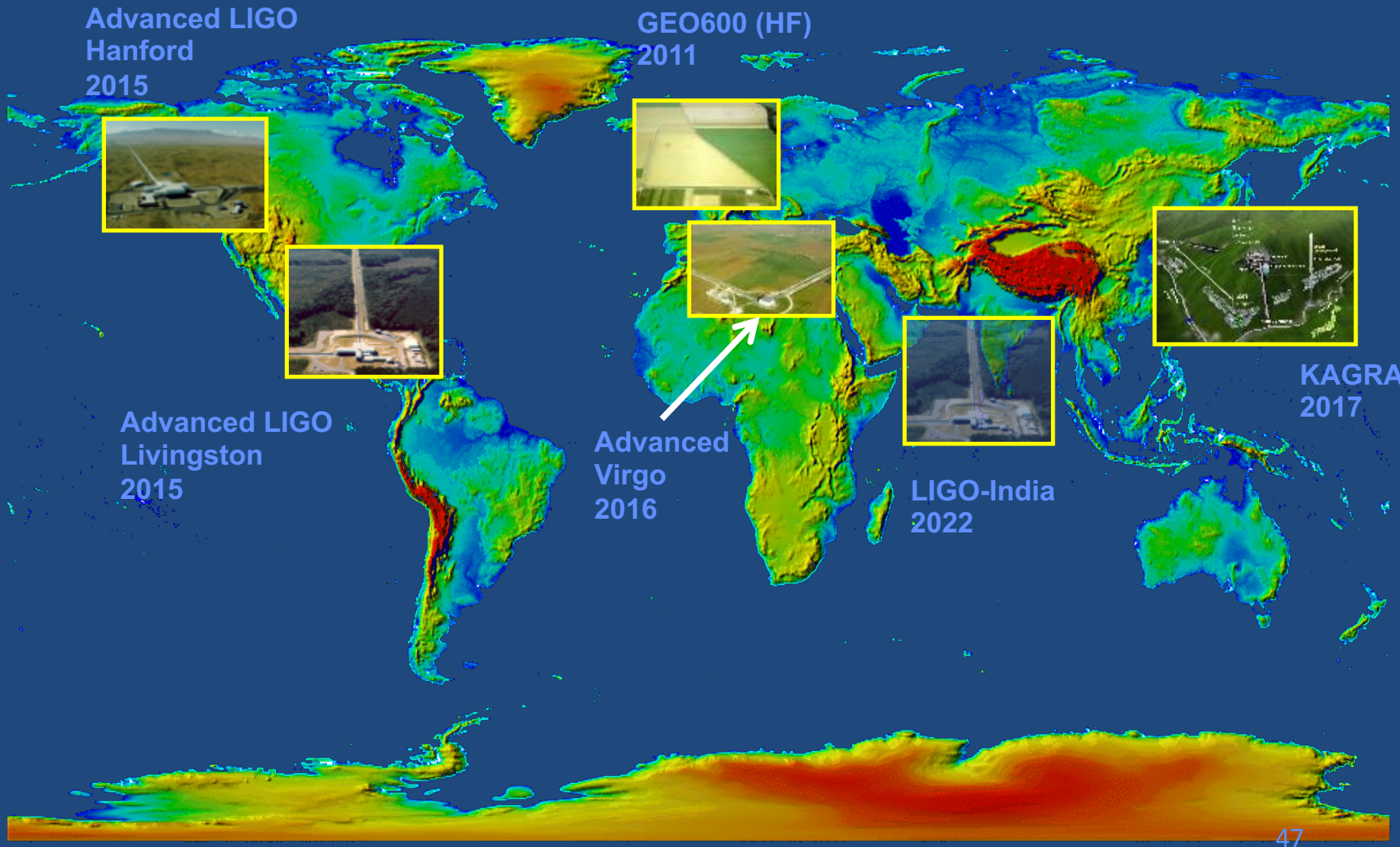
- The low cost sensors permits to deploy a lot of them to characterize the seismic properties of the location

- Plan is to bring them to the EGO site in the nearest future

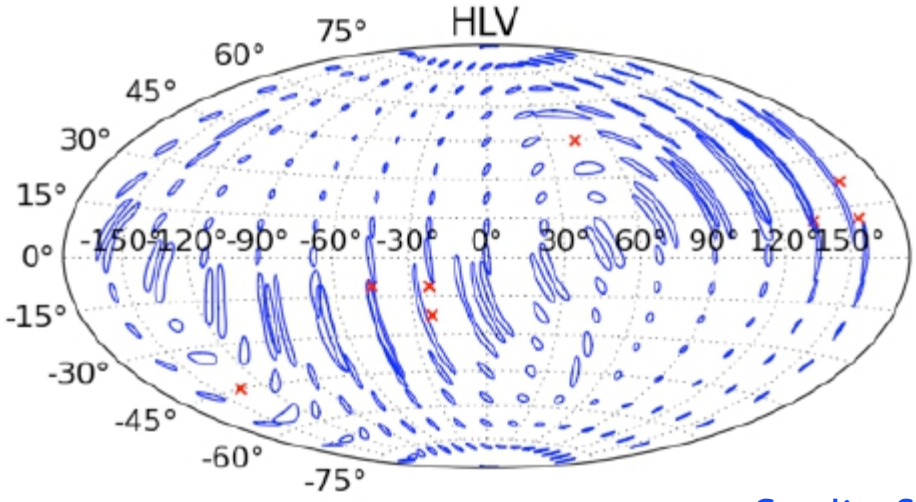
In addition INFN Naples built already a tilt meter in the specifications for NN cancellation.
We idea is to test a prototype at the Virgo site

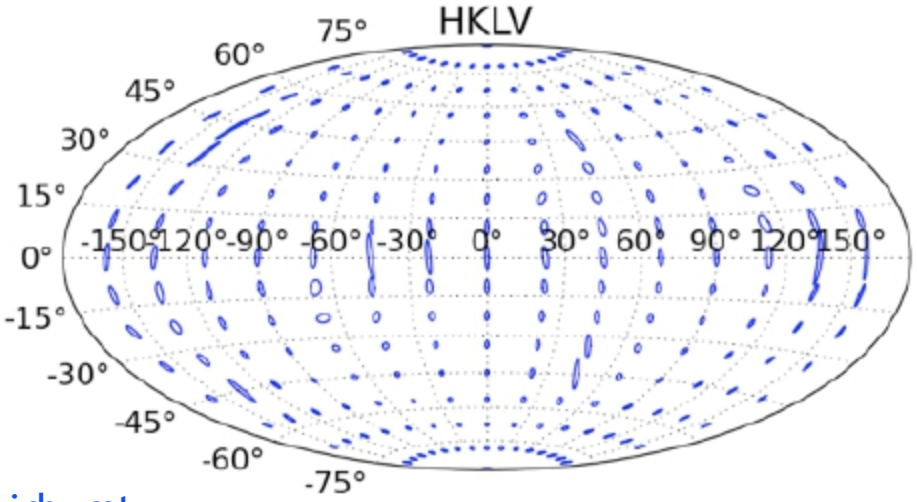
Conclusion

The advanced GW detector network: 2015-2025

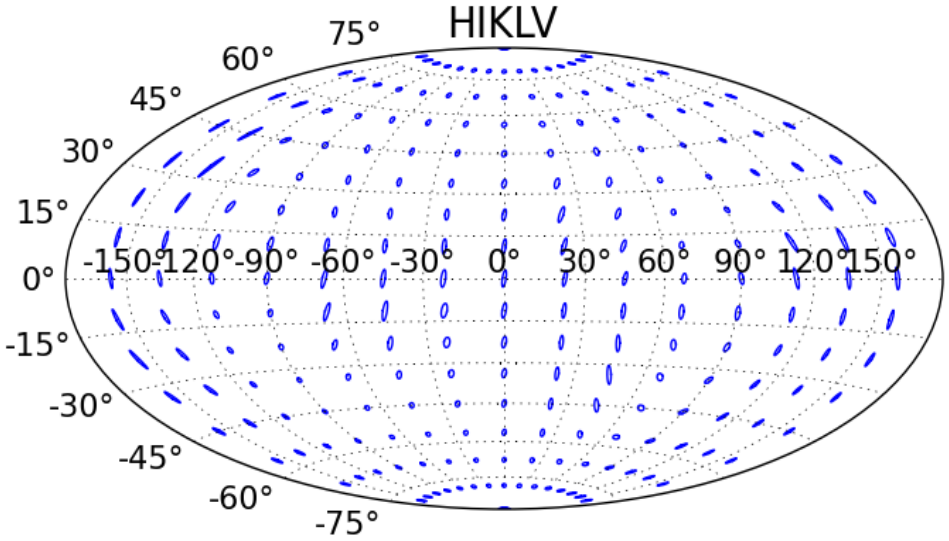


Source Localization of the Network: 3 , 4 , 5 detectors





Credit: S. Fairhurst

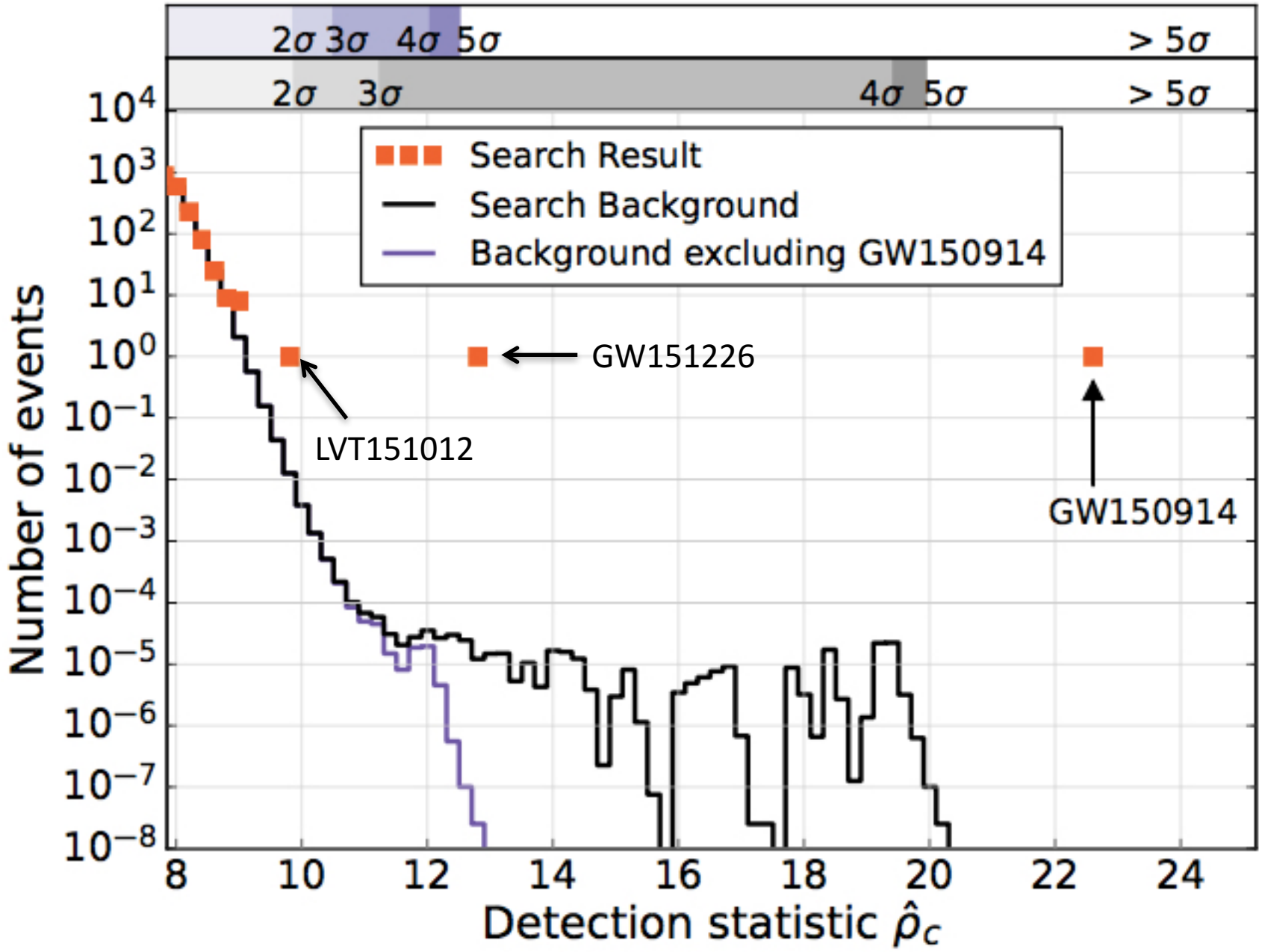


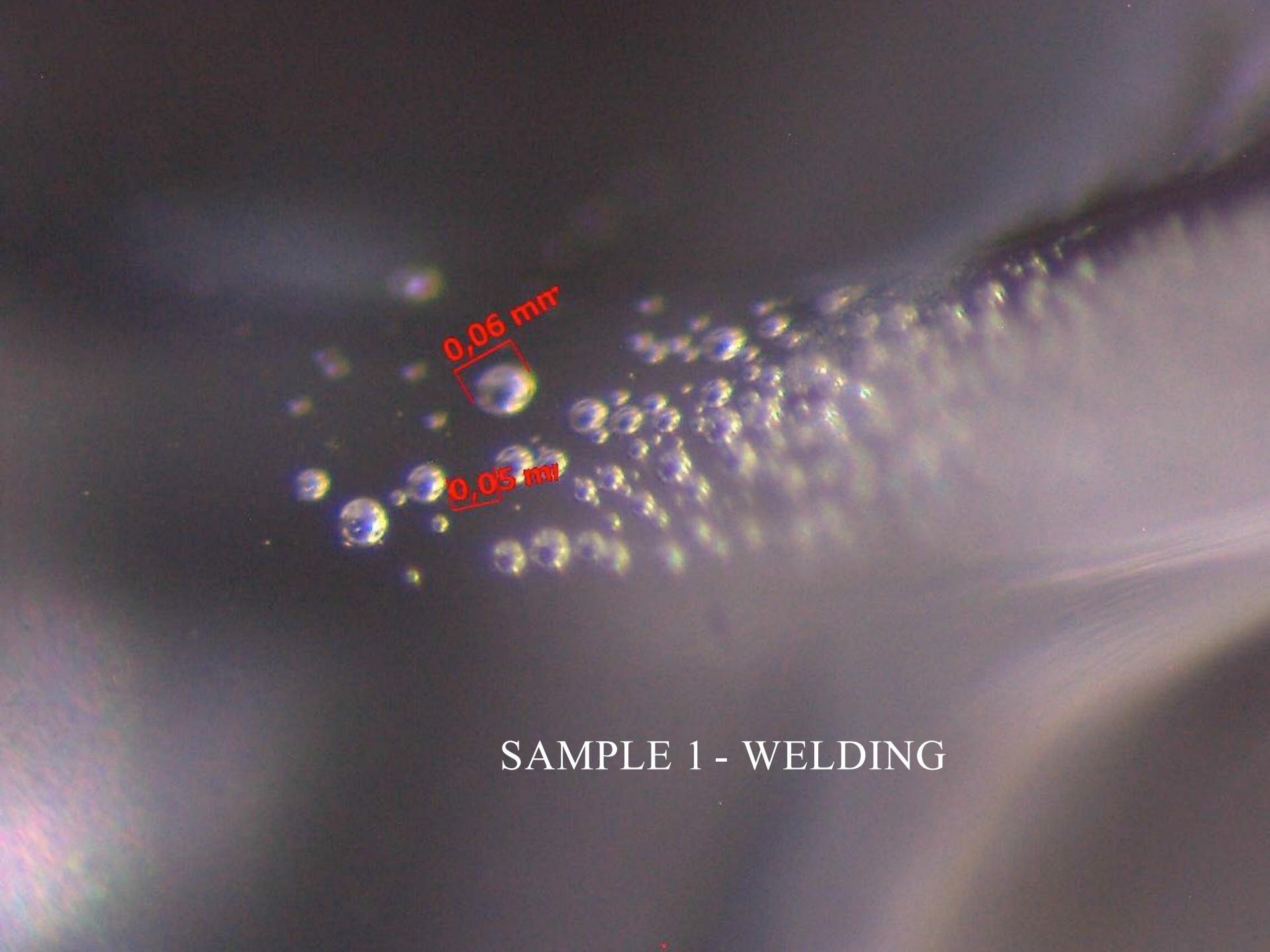
Conclusion

- Virgo is at the end of the integration phase and we are commissioning the interferometer in the new configuration.
- We faced few unexpected crisis and we reacted to preserve our main scientific target: to be online for O2
- We are preparing the near future of AdVirgo:
  - Choice of the new laser
  - Squeezing bench in preparation
- Discussion ongoing on the middle and far term plan

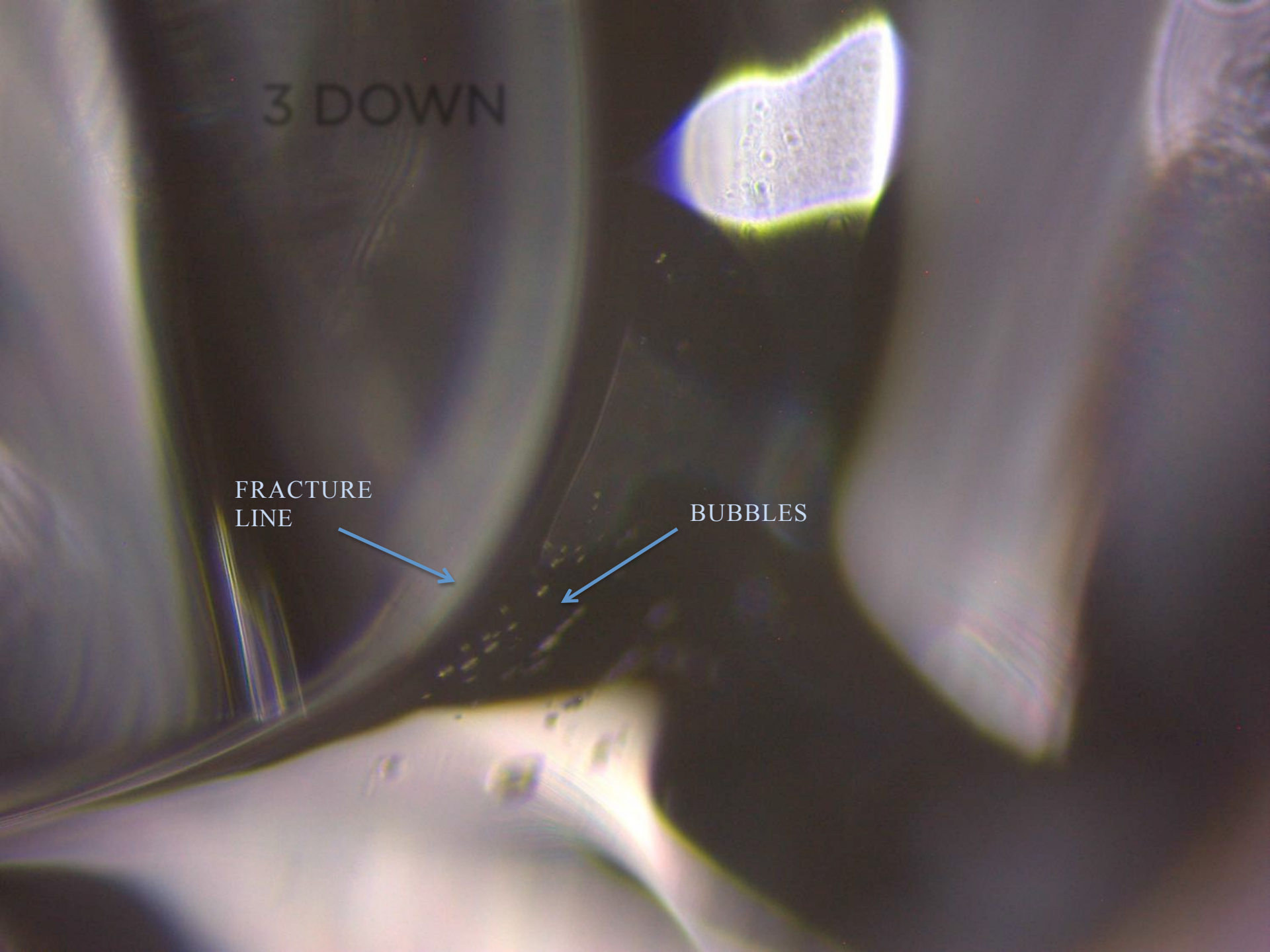

Thank you for the attention
The end....

Extra Slides


2σ 3σ 4σ 5σ > 5σ
2σ 3σ 4σ 5σ > 5σ
Search Result
Search Background
Background excluding GW150914
GW151226
LVT151012
GW150914
Number of events
Detection statistic $\hat{\rho}_c$



SAMPLE 1 - WELDING


3 DOWN
FRACTURE LINE
BUBBLES

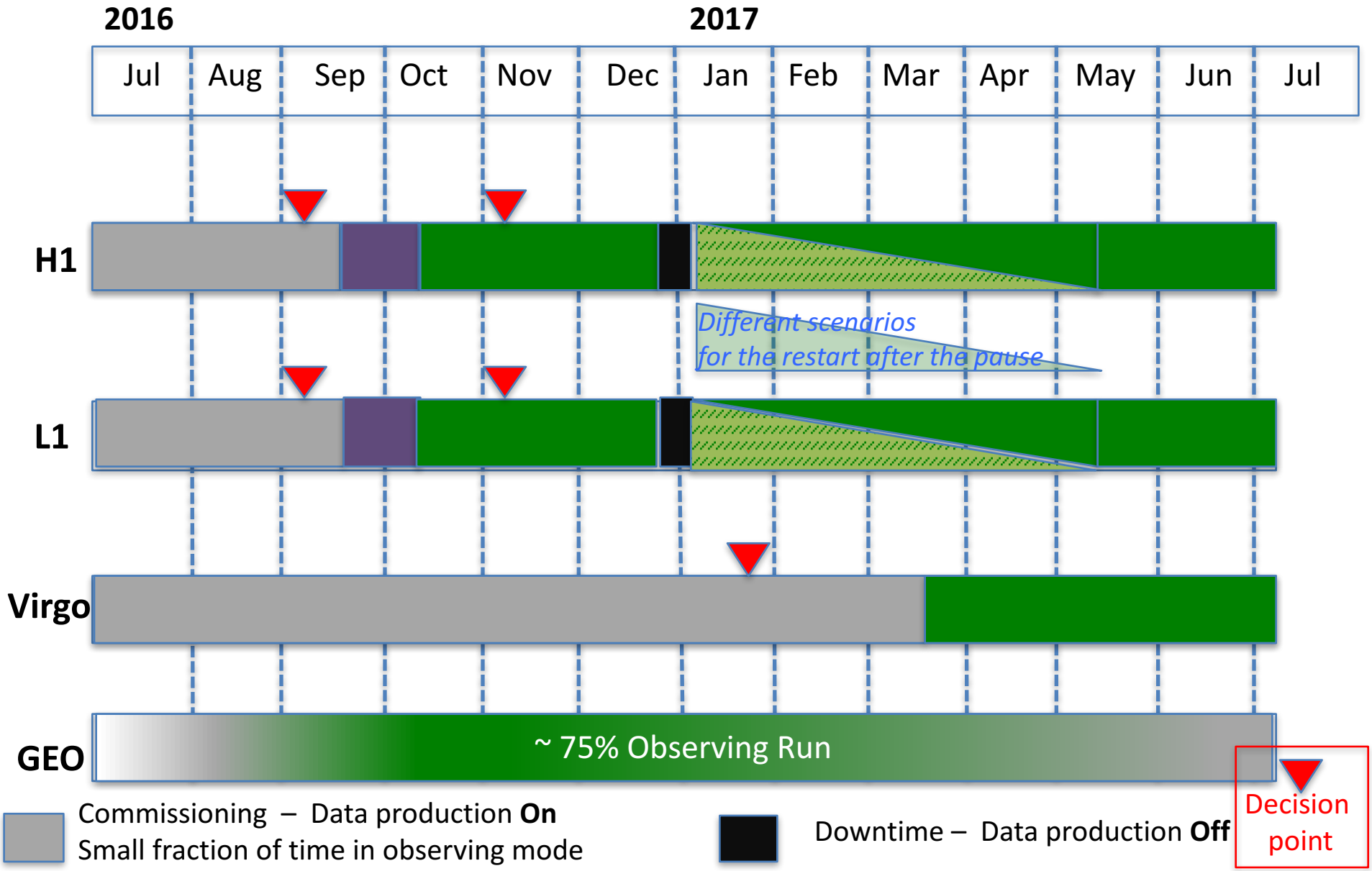

LIGO Livingston
USA


Virgo
Italy

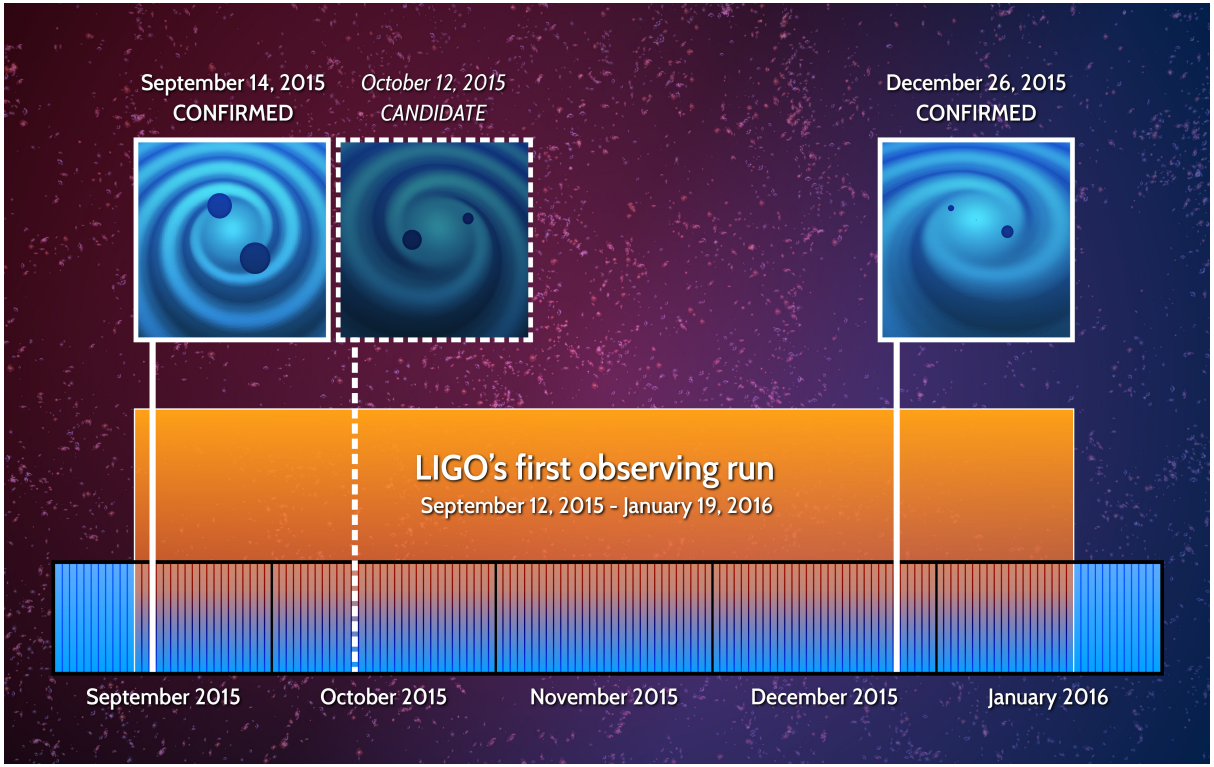

LIGO Hanford
USA


KAGRA
Japan

Preliminary *Joint* ***LVC*** *Plan for the Second Observation period O2*



Second detection announcements



AAS conference - June15th @ San Diego

LSC spokesperson

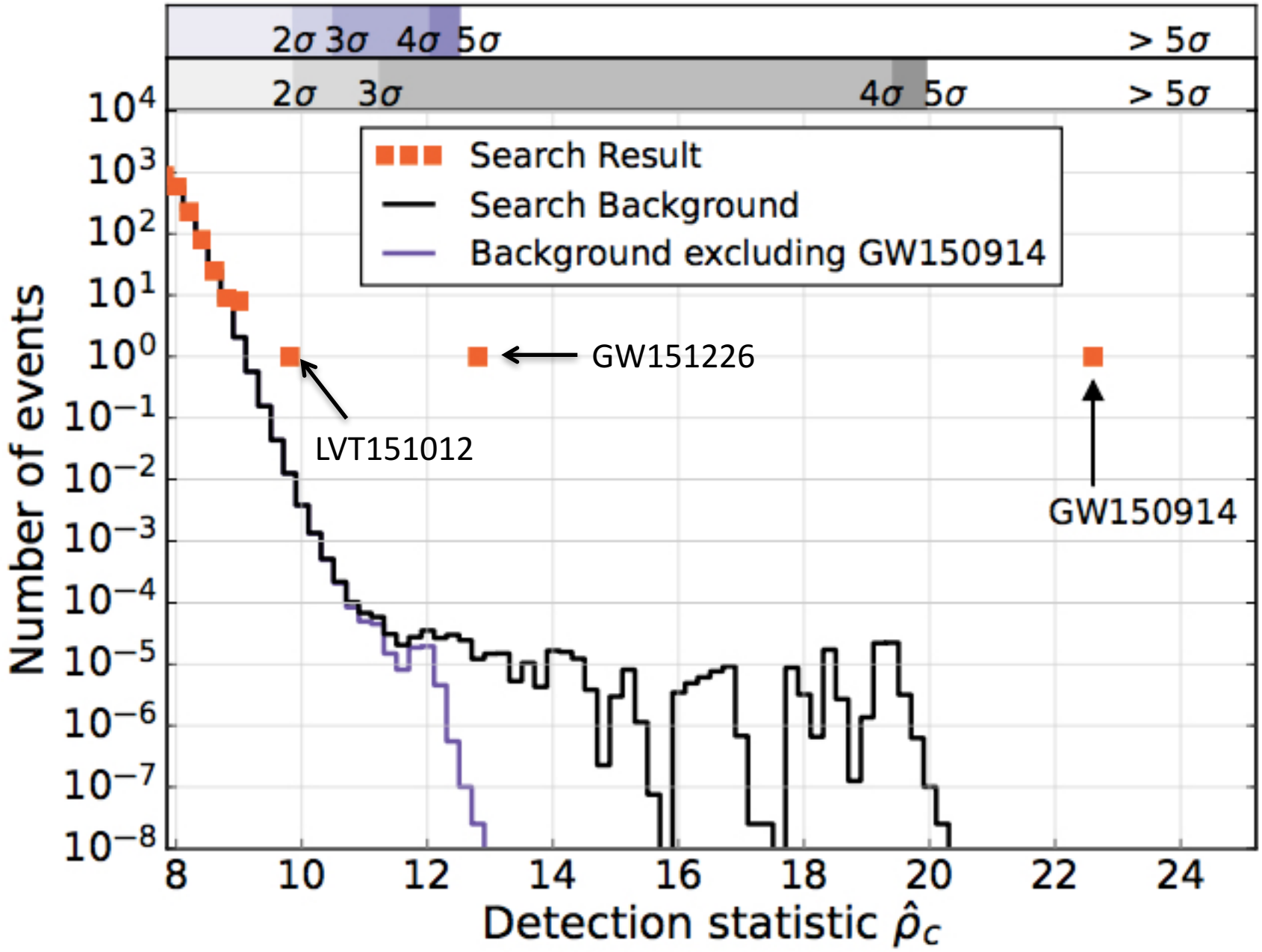
Virgo spokesperson

LIGO director

The Virgo collaboration congratulate the LISA team on the great success of the Pathfinder mission.

It paves the way for the future LISA mission that we wish to be approved as soon as possible.

Gravitational Wave detectors on the Earth and in the Space will be the main actors of the new era of astronomy and astrophysics.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Number of events
Detection statistic $\hat{\rho}_c$

Thank you for the attention!