Status of Advanced Virgo project

PNHE – 3rd April 2014

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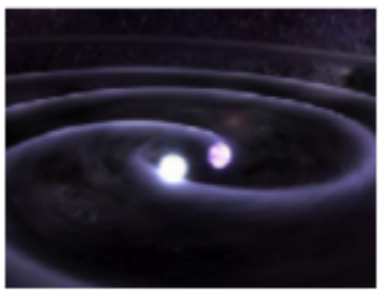
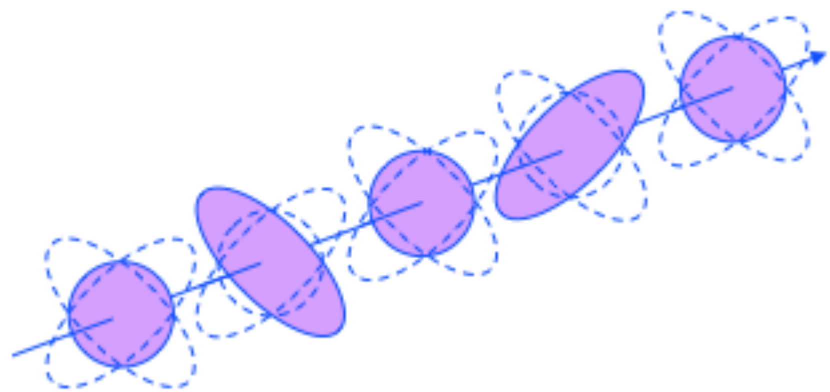
GW in a nutshell

- Gravitational waves are propagating solutions to Einstein equation in GR ('ripples in space-time')
  - Emission from rapidly accelerating mass distributions (quadrupolar momentum)
  - Need relativistic objects to maximize emission strength
- Propagation at speed of light with 2 polarizations





- Physically, gravitational waves are strains : $h = \partial L / 2L$
  - Kilometric interferometers are the most sensitive device so far (between 10 – 10^3 Hz)
  - Measurement "h" scales with the amplitude (not energy)
  - Sense of scale : neutron stars merging at 15 Mpc

$$h \approx \frac{4\pi^2 G M R^2 f_{orb}^2}{c^4 r} \quad \Rightarrow \quad h \sim 10^{-21}$$

f_{orb} = 400 Hz
M = 1.4 $M_\odot$
R =20 km
r = 15 Mpc

Virgo science case

- First direct detection of a gravitational wave from coalescing binaries, core collapse supernovae, gamma-ray burst, pulsars, ….
- Test general relativity in strong field regime
- Direct detection of black hole
- Test equation of state of neutron stars
- Provide constraints on stellar population
- Cosmology
- …..

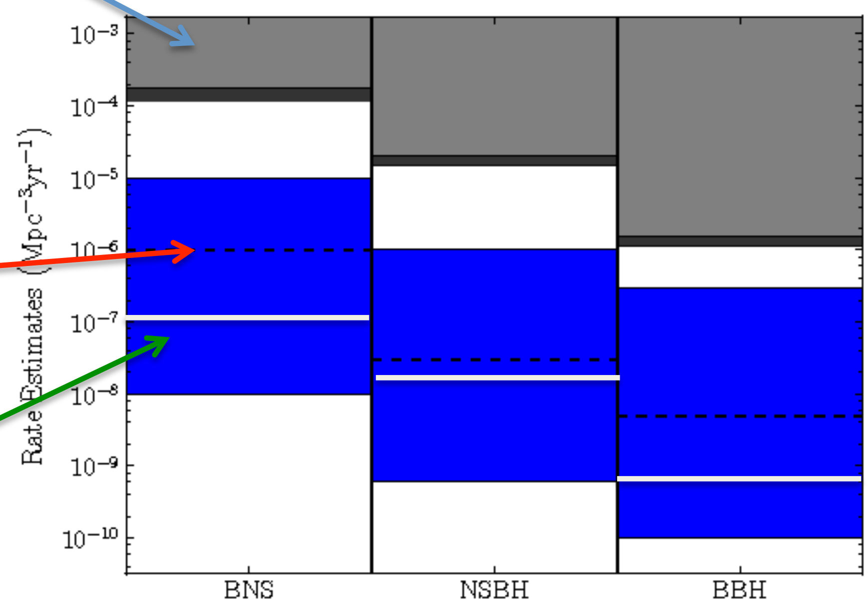
Virgo performed several scientific runs between 2007 and 2010 cumulating 384 days in coincidence with LIGO/GEO

LIGO-Virgo results - 1

- Search for 2-25 $M_\odot$ total mass inspiral system
- Post Newtonian restricted waveforms
- No evidence for a GW signal
- 90% upper limits on the events rate

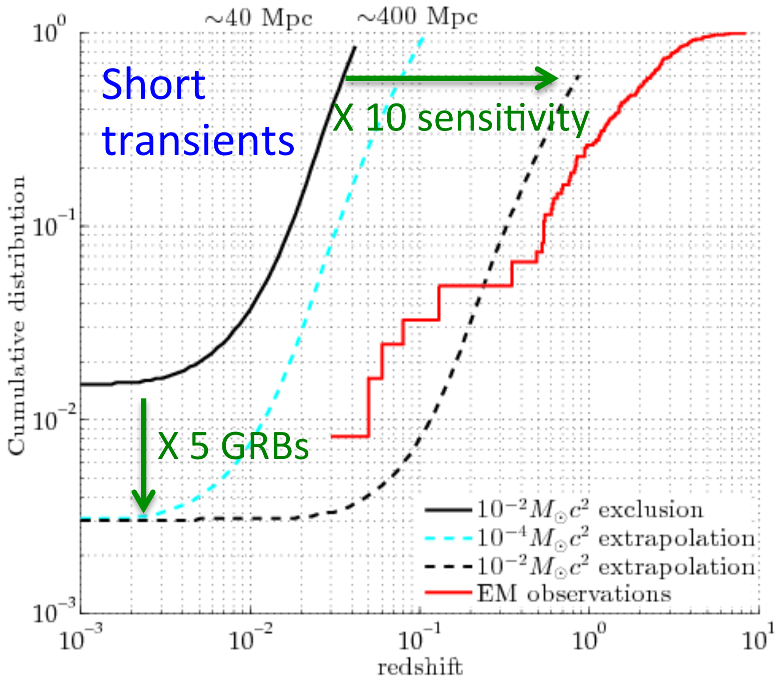
Still 2 orders of magnitude above realistic rate

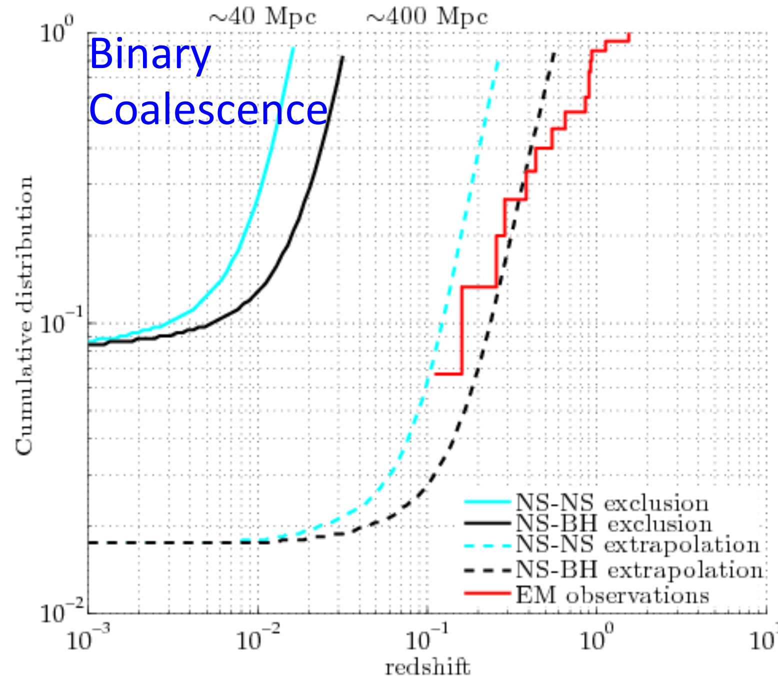
With Advanced detectors at design sensitivity



LIGO-Virgo results - 2

GRB-GW searches – results & prospectives





With a factor 10 in sensitivity we will be sensitive to short-hard GRBs

ADVANCED VIRGO

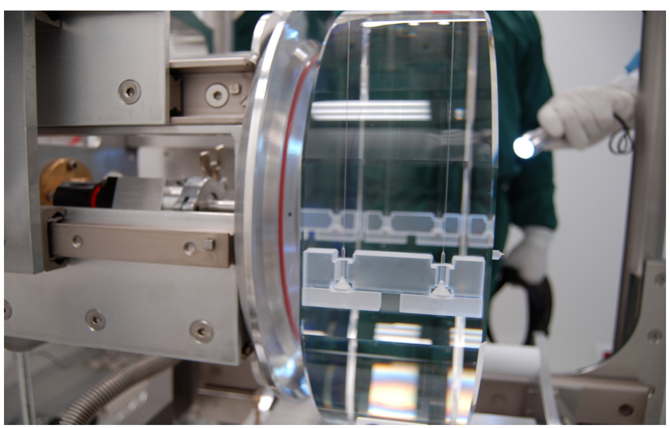
- Advanced Virgo (AdV): major upgrade of the Virgo interferometric detector of gravitational waves
- Participated by scientists from Italy and France (former founders of Virgo), The Netherlands, Poland and Hungary
- Funding fo rAdvanced Virgo investments approved in Dec 2009
  - from INFN, CNRS : 10 ME each
  - from Nikhef : 2ME
- Construction in progress. End of installation: fall 2015
- Goal: first science data in 2016

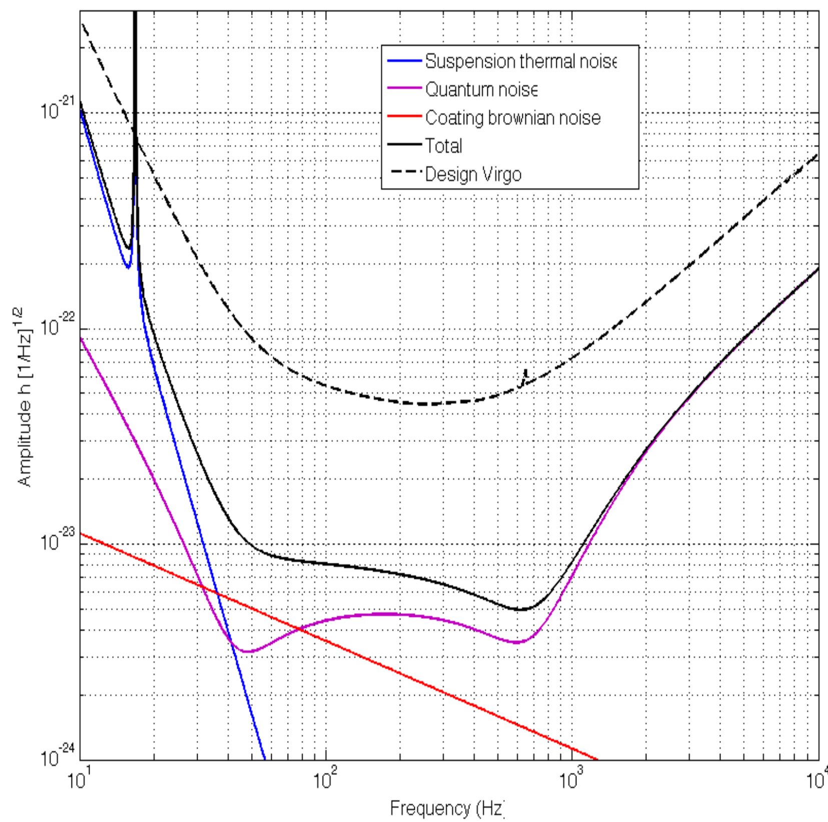
5 European countries
19 labs, ~200 authors

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

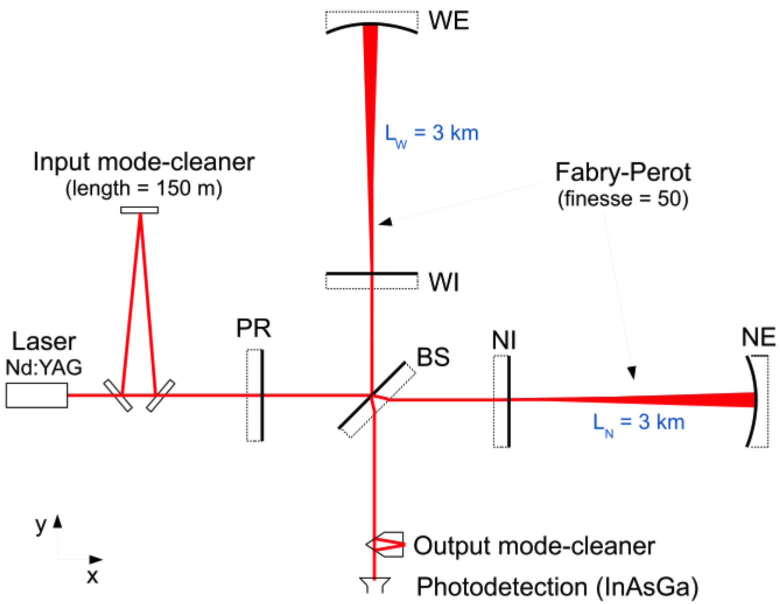
Towards Advanced Virgo

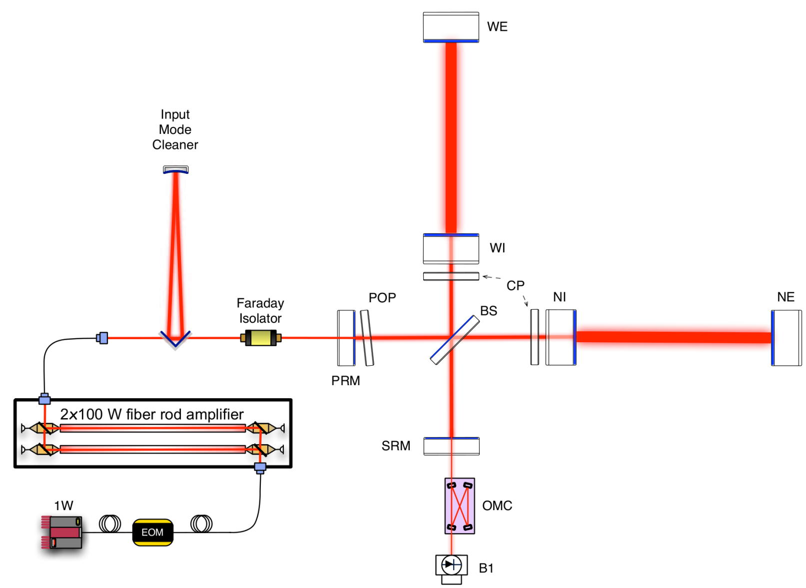
- Main goal is to gain a factor 10 in sensitivity to gain a factor 1000 in volume (and so in detection)
- Strong impact on the machine
- Some upgrades already tested like the monolithic suspension to gain in thermal noise





From Virgo to Advanced Virgo

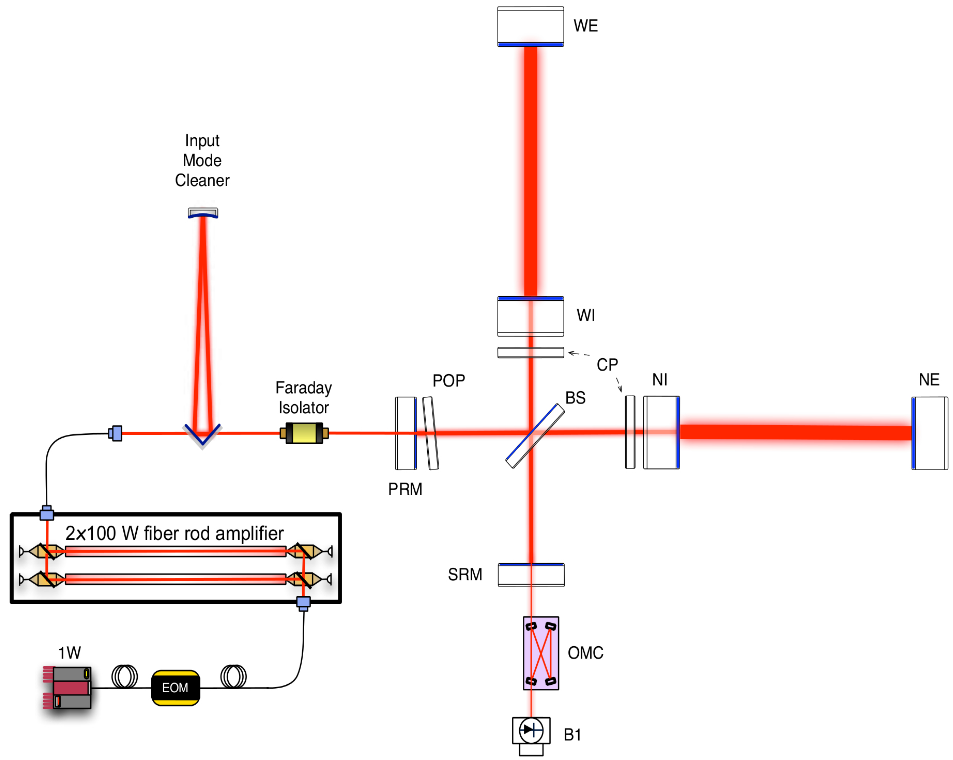




- Increase laser power from 20 W to 200 W
- Increase finesse of the cavities – up to 650 kW stored in the long ones (x65)
- Add one new mirror : signal recycling
- Change size of the beam in the cavities
- Add some suspended optics (CP and POP)
- All photodiodes will be under vacuum
- Keeps the same suspensions

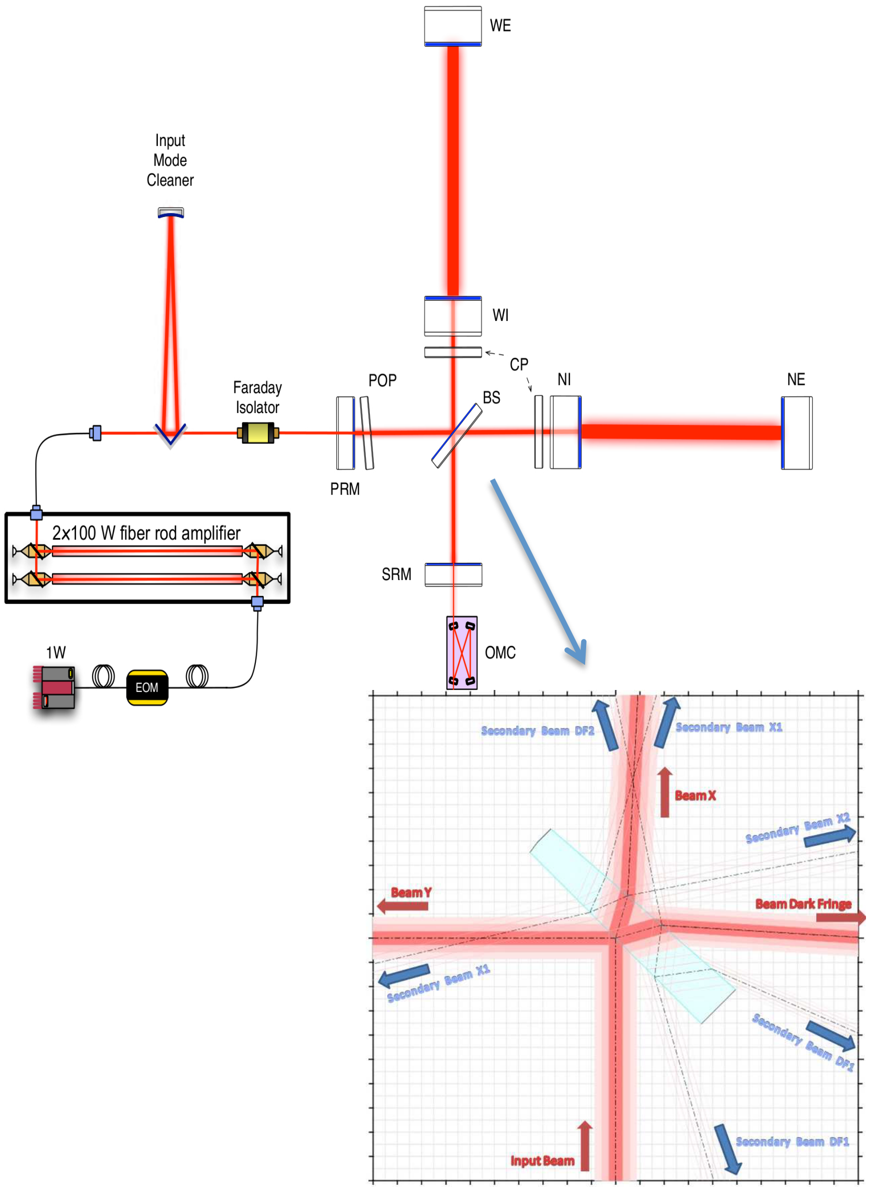
French contributions

- Contributions from the detectors to the scientific exploitation
- Many responsabilities both in construction, management and data analysis effort



Optical design

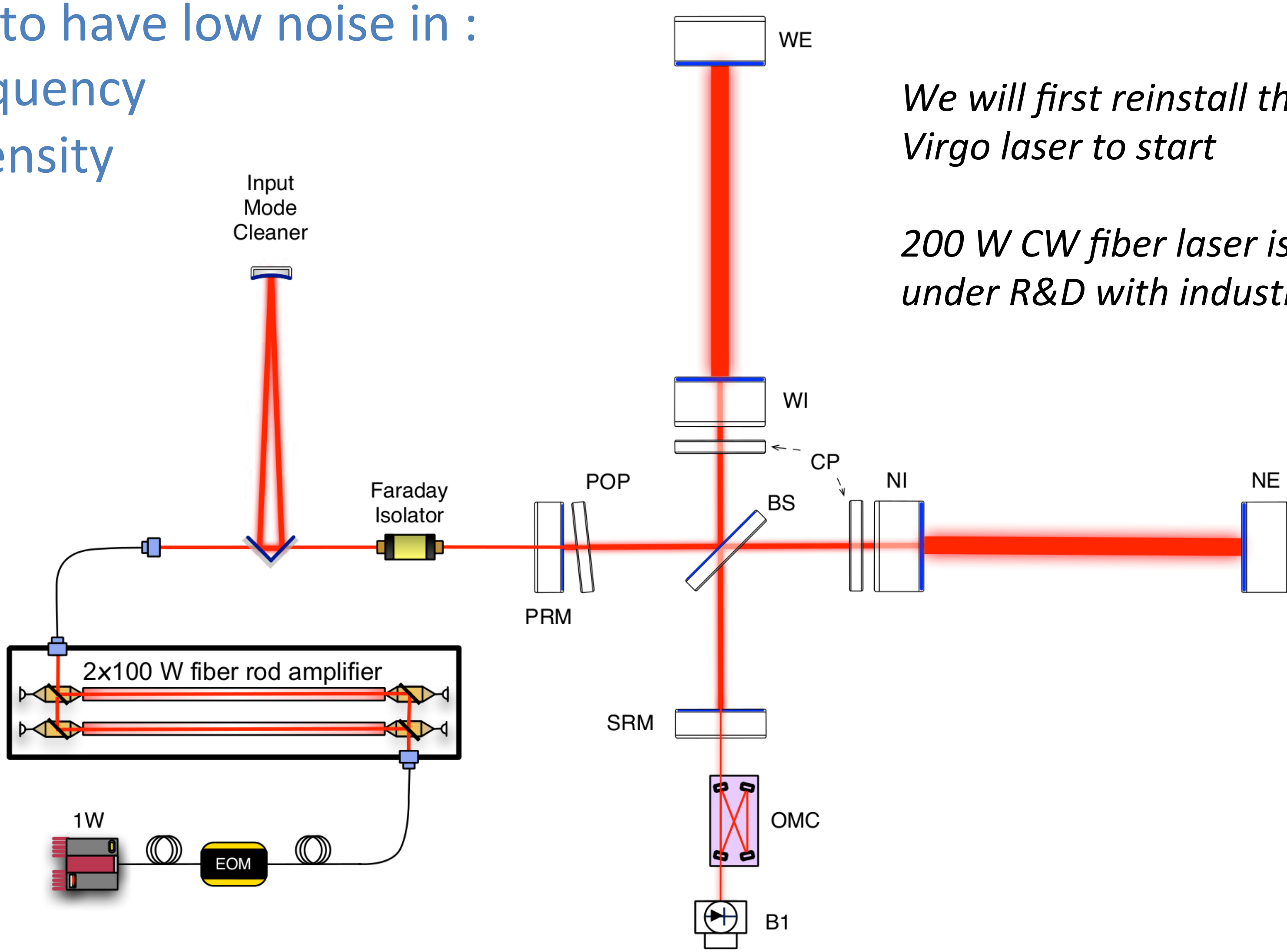
APC
LAPP
LMA



- Define the different optical parameters:
  - Reflectivities
  - Radius of curvature
  - Length of the different cavities
- Maintain and develop simulations tools
- Define modulation frequencies needed to control the ITF
- Compute and check beam size on the full system
- Design of optical benches

Laser – from 35 W to 200 W

Need to have low noise in :
- frequency
- intensity

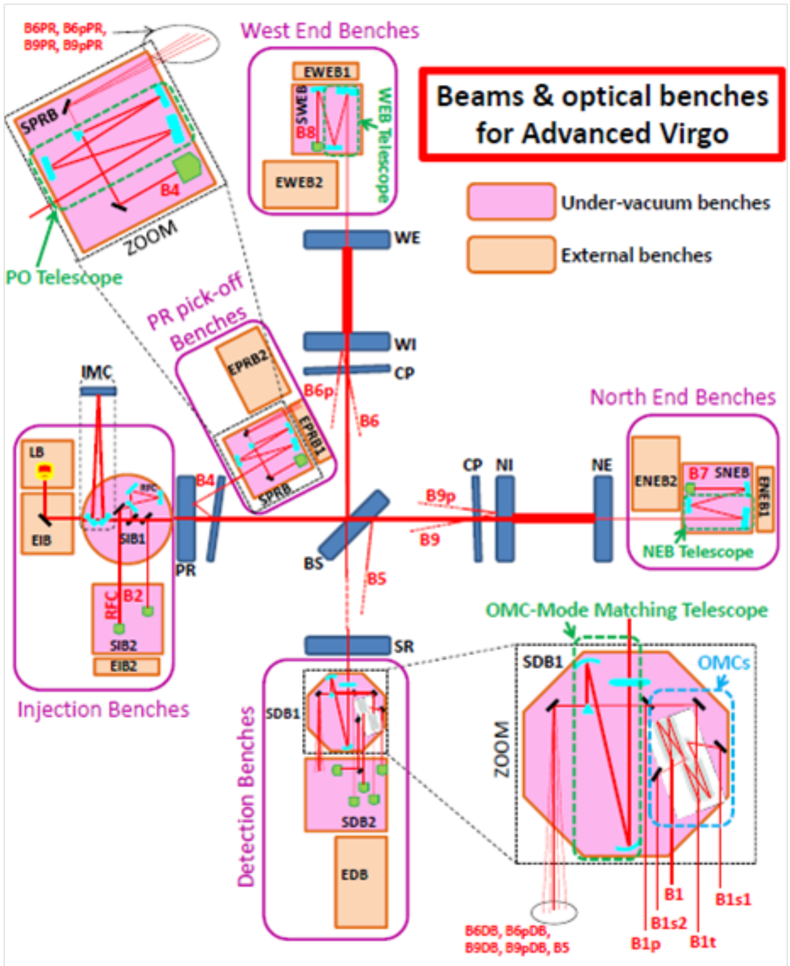


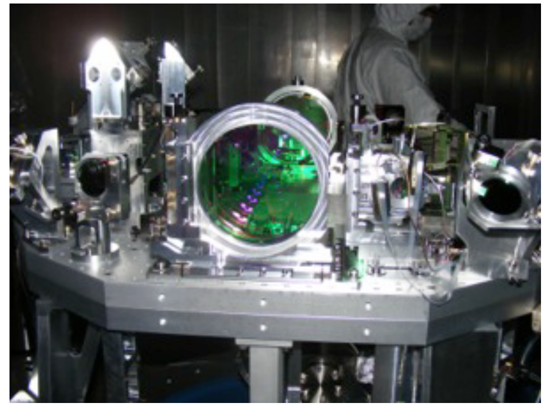
We will first reinstall the Virgo laser to start

200 W CW fiber laser is under R&D with industrials

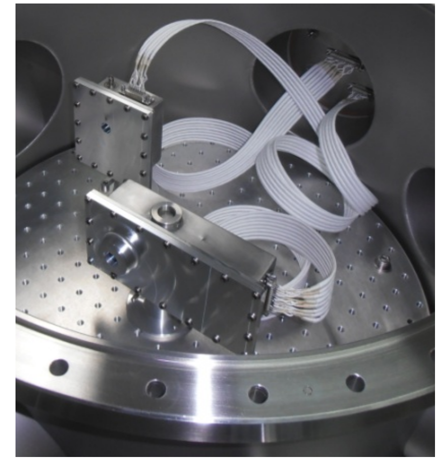
Optical benches

APC
LAPP

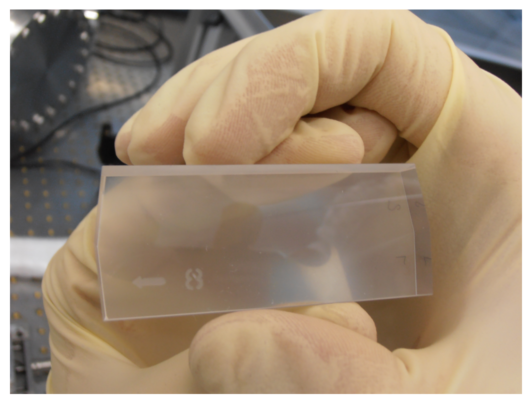




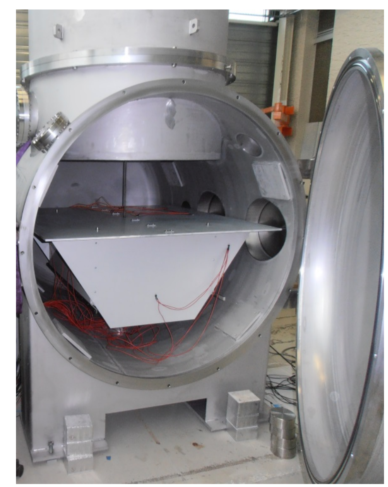
Telescope for beam size matching



Vacuum compatible photodiode



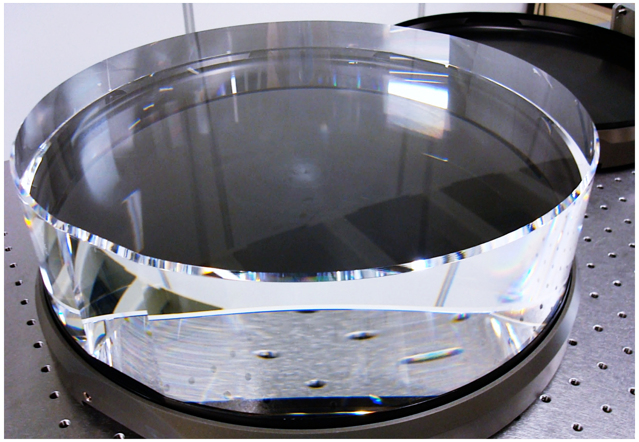
Prototype for OMC



Suspended bench and vacuum tank

Mirrors

- Mirror diameter : 35 or 55 cm , thickness between 6.5 and 20 cm, 40 kg for the heavier ones
- Substrat
  - Absorbtion as low as 0.2 ppm/cm
  - Flatness < 0.15 nm RMS
  - Roughness < 0.1 nm RMS
- Coating:
  - Reflectivity defined at 1 ppm level
  - Low absorption < 0.5 ppm
- Metrology is a key point
- Coating can also be used to correct defect on the substrat



One of the Advanced Virgo mirror

Robot for the corrective coating

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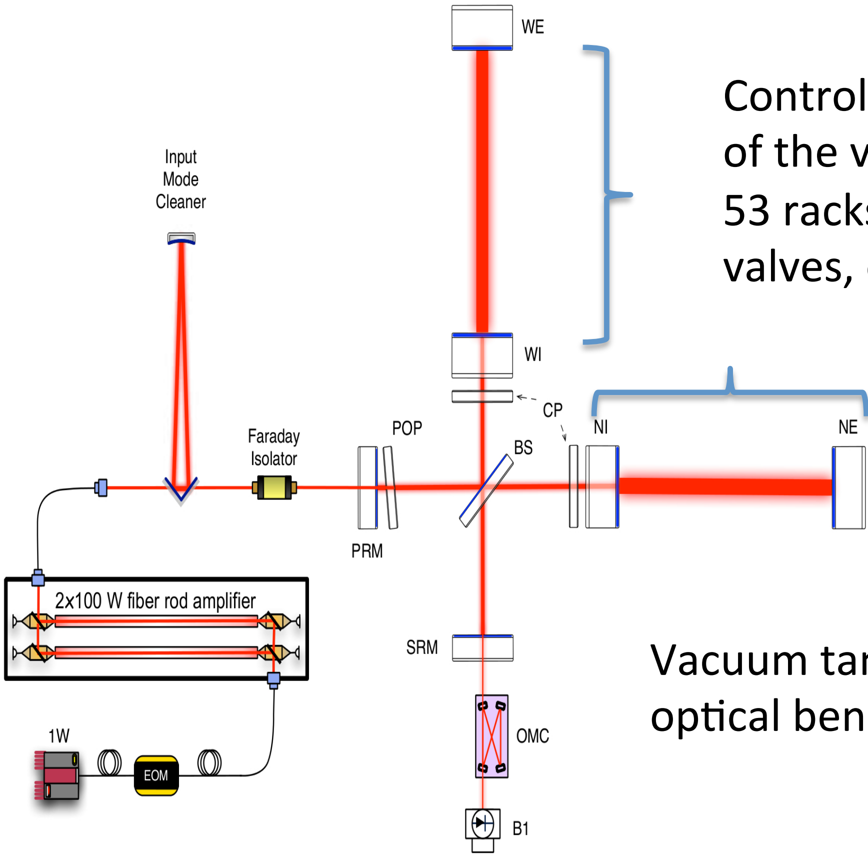
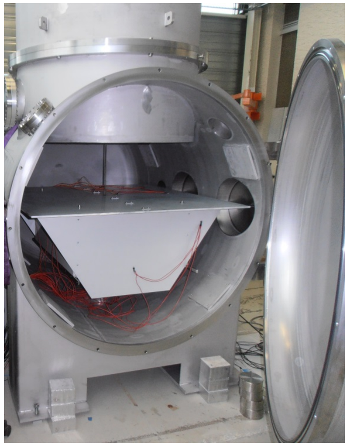
Vacuum systems



Control-command
of the vacuum system
53 racks to control pumps,
valves, cryogenic traps, …

Vacuum tanks to host
optical benches



Cavities controls

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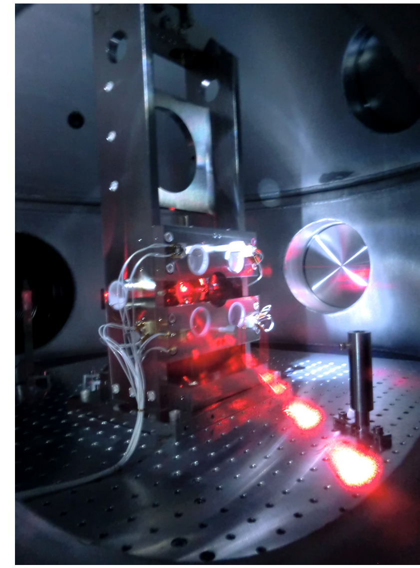
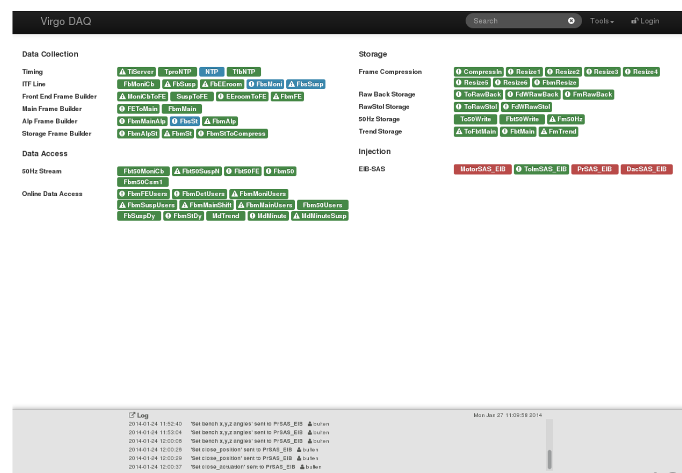
LKB



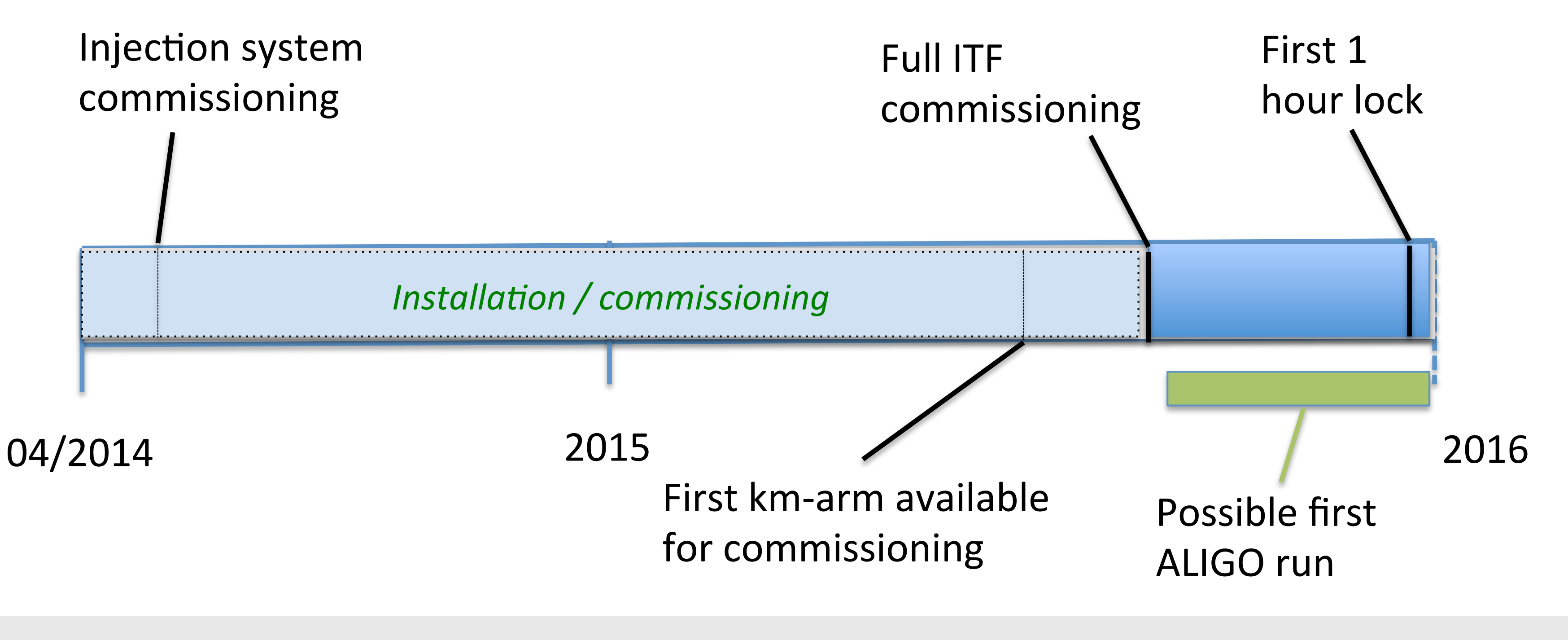
- Control all the different lengths within 10^{-16} m RMS
- Deal with the coupling between the different optical cavities (1 more with SR)
- Prepare new strategies to cope with new problems
- Install and use a 50+5m long suspended coupled cavities in Orsay – CALVA setup - to test new ideas
- Take into account parametric instabilities
- Control the output mode cleaner

Electronic and software

- Digital conversion of all analogic signals and propagate them almost everywhere on the setup
- Analog conversion to use different actuators
- Feedback loops performed with real time PCs
- DAQ (>1000 channels), 20 Mb/s
- Interfaces to interact with all subsystems and processes running on the interferometer



Advanced Virgo installation



INSTALLATION COMPLETE BY FALL 2015

Detector characterization

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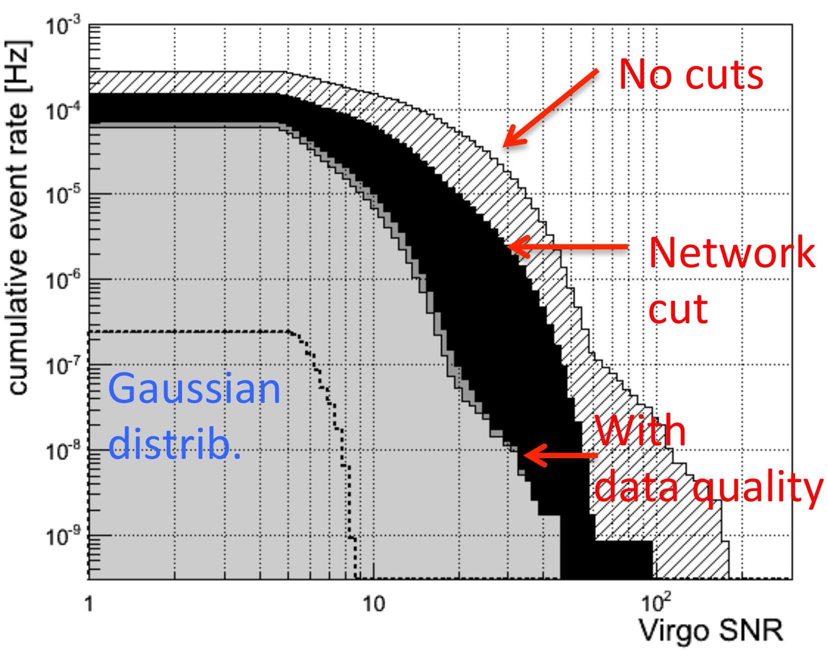
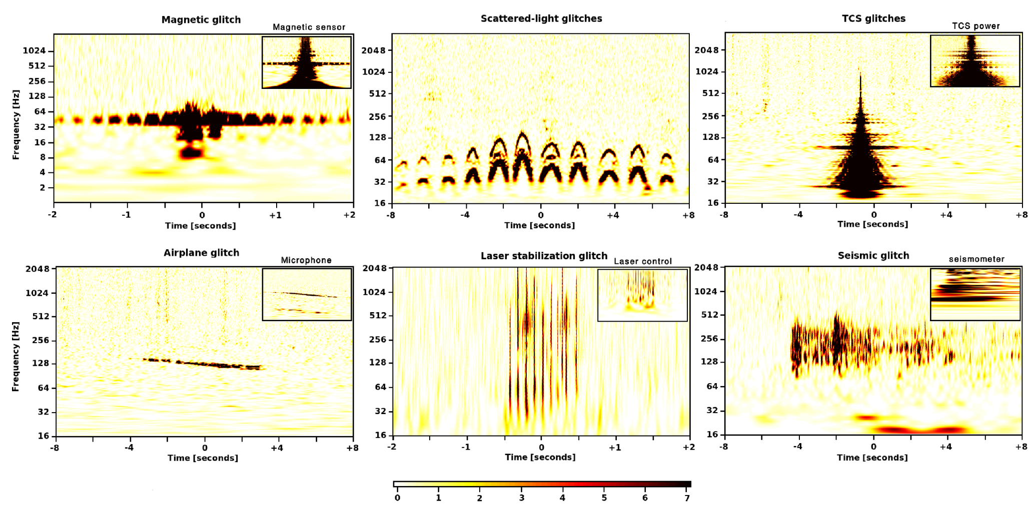
- Output of the interferometer is highly non gaussian using a generic event search
- Need to understand as much as possible the events distribution to reduce tail
- Detector characterization helps to understand problems
- It will also provide periods of time to be removed from the analysis





Calibration – reconstruction - computing

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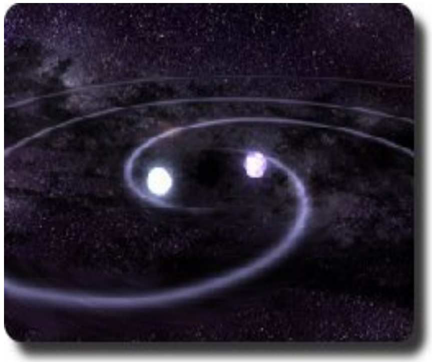
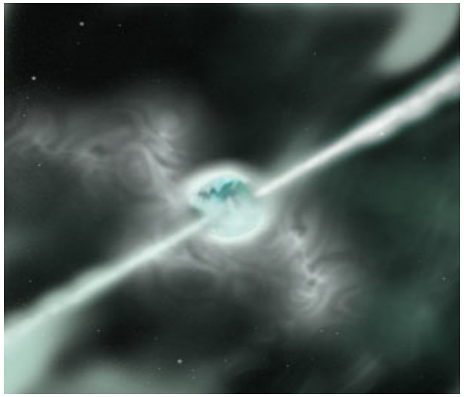
- We have the responsability for the calibration and the reconstruction of the GW signal from the output of the Virgo interferometer
  - Reconstruct the GW signal from the photodiodes signals and control channels
  - Performed consistency checks
- Distributed jobs workflow development (grid – DIRAC)

Data analysis preparation

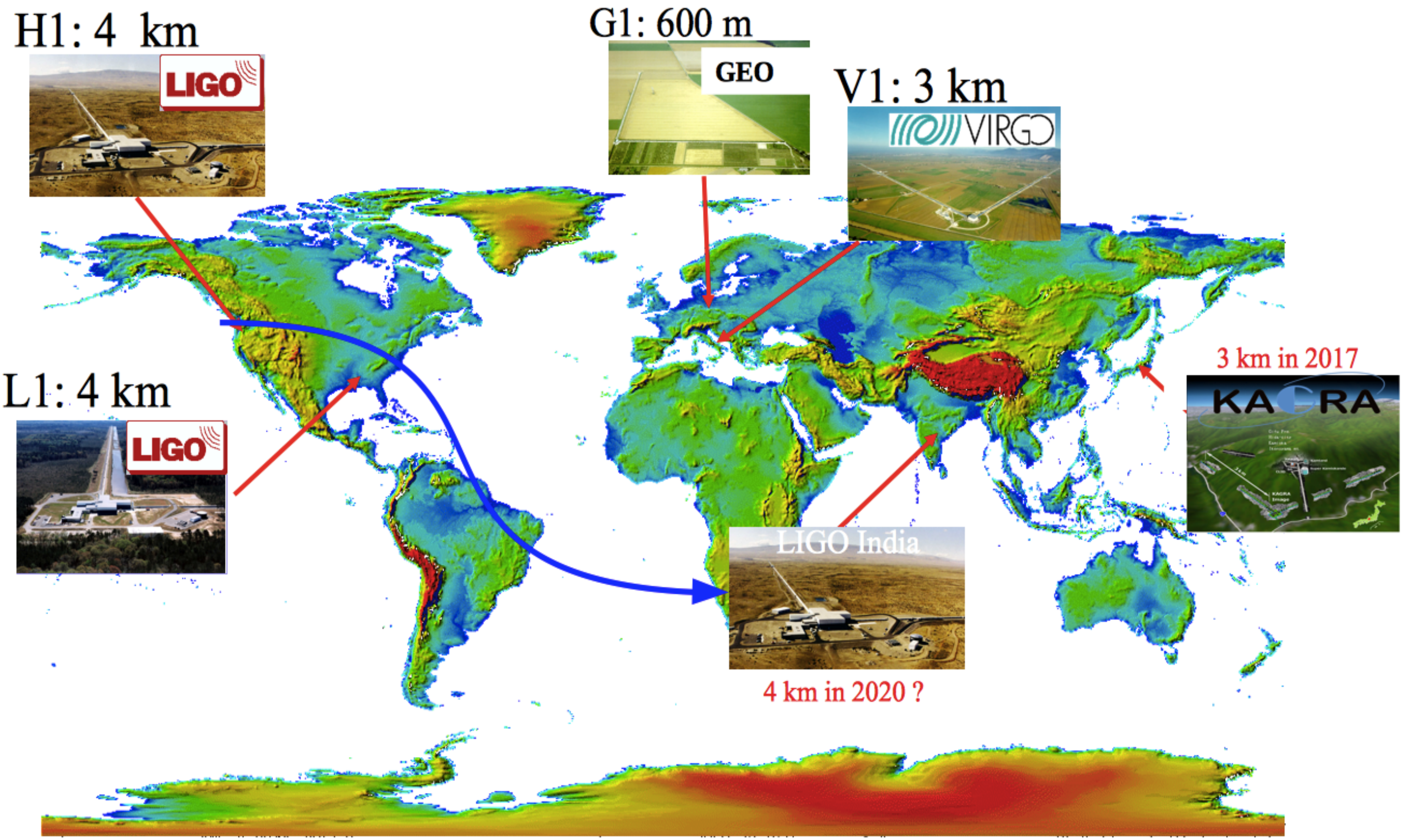
APC
ARTEMIS
LAL
LAPP



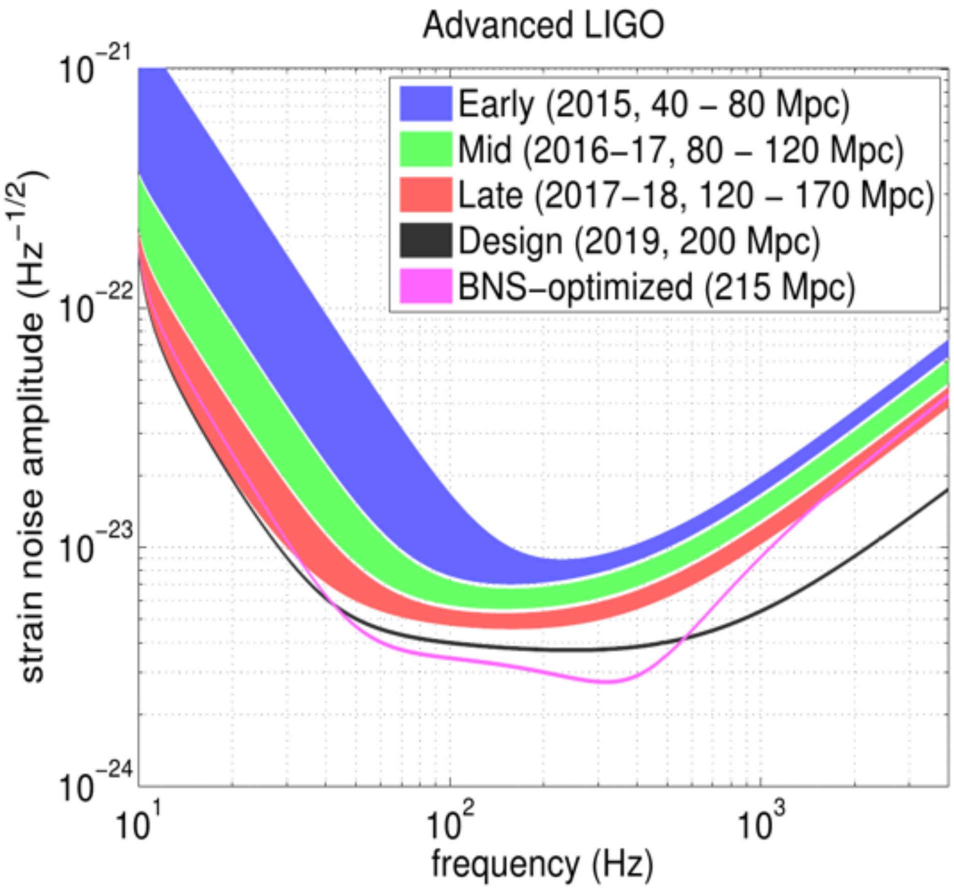
- We are involved in search for transient signals and stochastic backgrounds (phenomenology)
- On transient (short signals and coalescence binairies), three different strategies are followed :
  - Low latency for most significant events (coalescence like events)
    - Low latency data transfer between the different instruments
    - Low latency analysis for fast alerts towards EM telescopes
  - Triggered search on specific trigger like GRBs, supernovae, HE neutrinos, … : gain in sensitivity (short duration signals)
  - All-sky all-time for more exotic phenomena : cosmic strings, signals from accretion disks, …

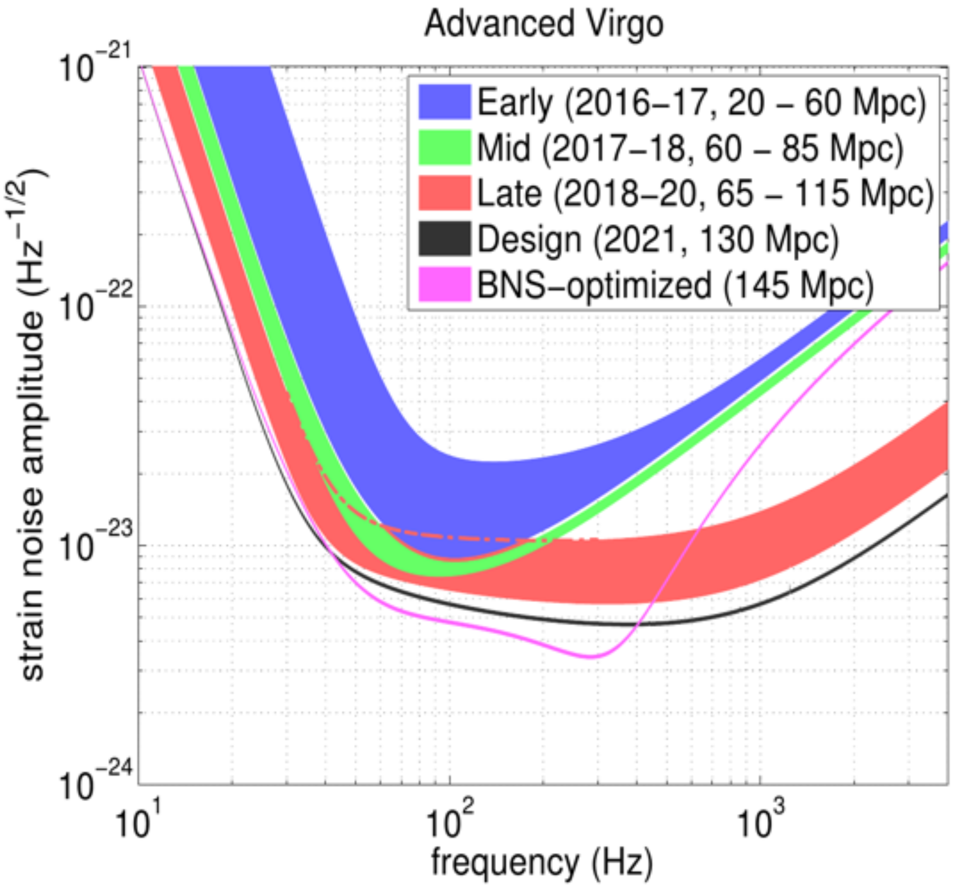


Future network

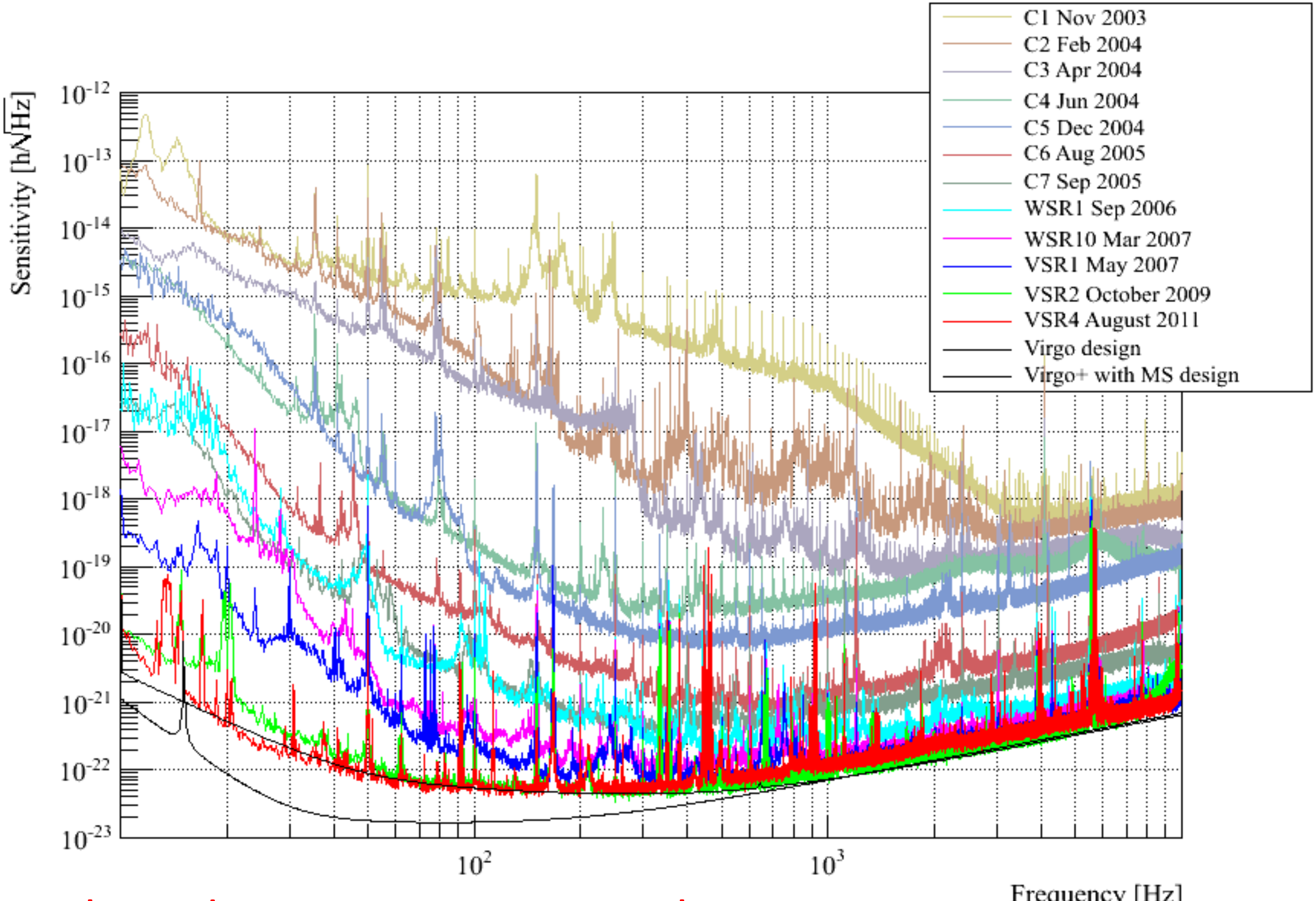


Probable path for LIGO-Virgo





Commissioning : a long story



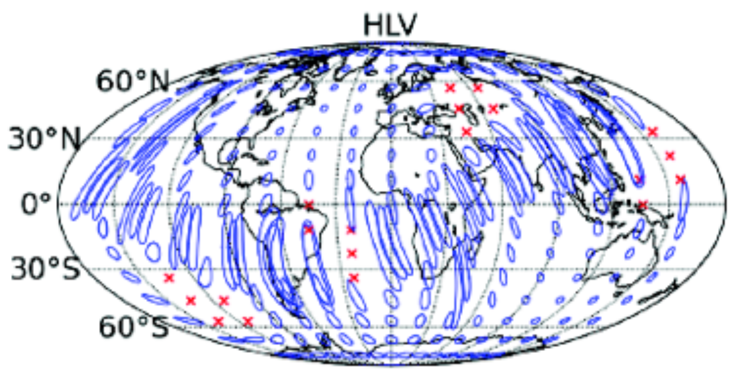
- Reaching design sentivity can take years

Position reconstruction

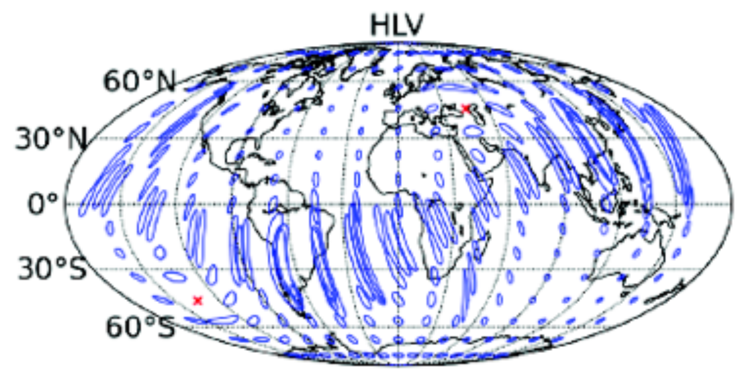
Depends on nb of sites and SNR of the detection

BNS source @ 80 Mpc

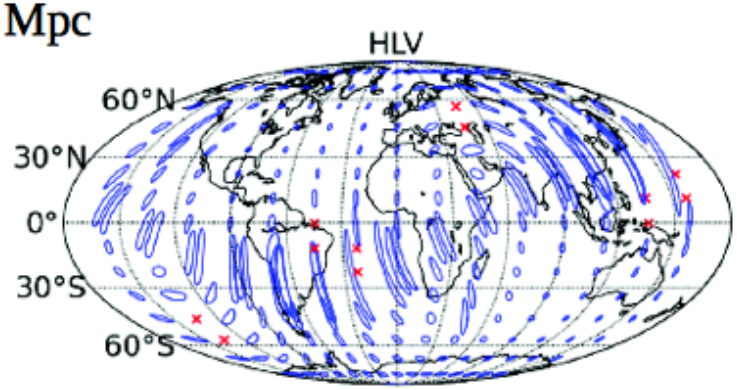
2016-2017 runs



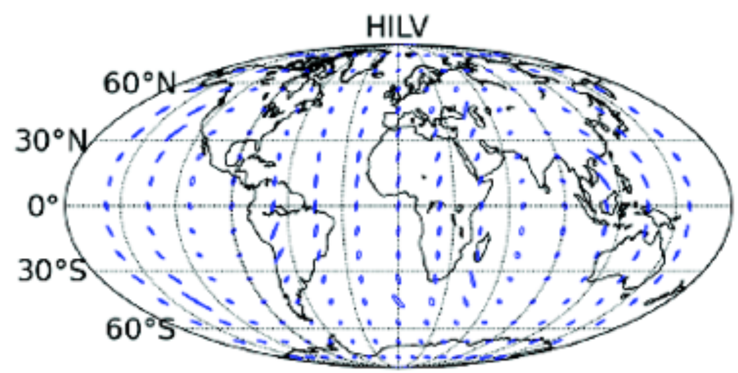
2018-2019 runs



BNS source @ 160 Mpc



2019+ runs

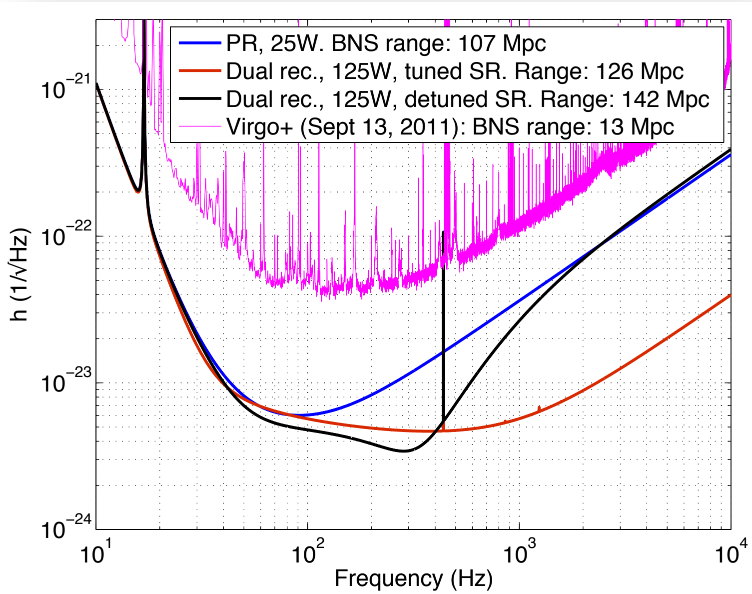


HLV + LIGO India 2022+

EM follow-up program

- A call for electromagnetic follow-up for GW alerts have been done beginning of 2014
  - Many groups show their interest
  - Large span from radio to TeV
- Creation of a private network is under construction to share information about our alerts
- First MoUs will be signed quite soon
- Confidentiality required up to the first detections
- We are planning to release public alerts after the first four detected events

Conclusions



- Advanced Virgo is currently under construction
- We plan to take scientific data in 2016 – LIGO schedule a run at the end of 2015
- Sensitivity and understanding of the instrument will improve with time
- We are also preparing the scientific exploitation :
  - Low latency to allow any possible follow-up with external observatories
  - Use all possible information to gain in sensitivity (like sky positions, time, …) and confidence level