Plans for Advanced Virgo

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On behalf of the Virgo-IN2P3 groups (APC, LAL, LAPP, LMA)

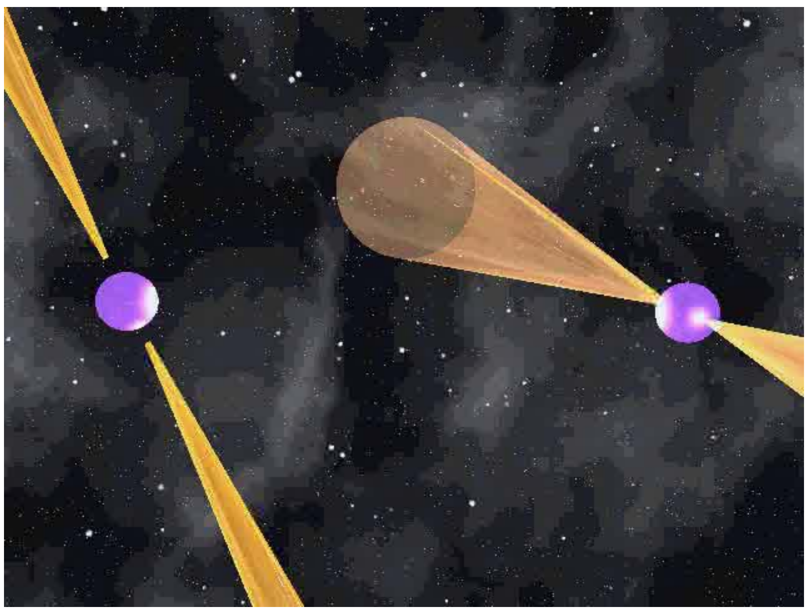
SUMMARY

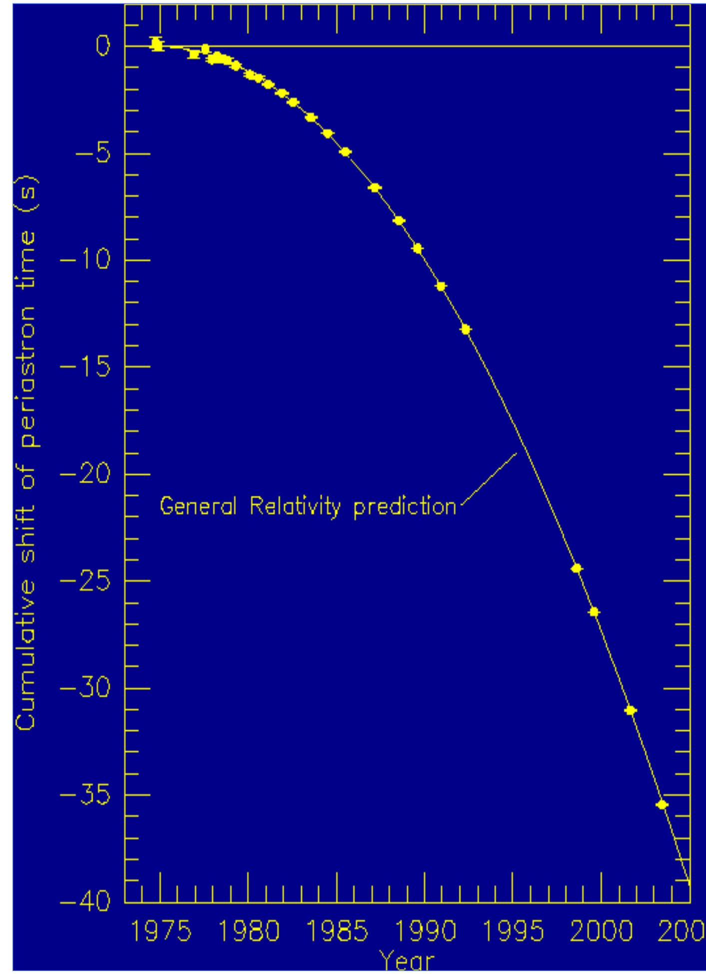
- Scientific case
- Detector design
- The IN2P3 contribution
- Status and timeline

Scientific case:
from Virgo to Adv Virgo

Gravitational waves are there

- Binary pulsar 1913+16
  - Binary pulsar with short period ~8h
  - Period decreasing with time due to GW emission
  - Decrease in agreement with GR
  - Physics Nobel prize to Taylor and Hulse (1993)
- Compact binaries are a unique tool to study the gravitational force





Coalescing binaries

- Four (five) pulsars binaries known in the Milky Way
  - Deduce rate of coalescence in the Milky Way
  - Deduce rate of expected events
- Other predictions based on stars population models
  - Only method available for black holes binaries
  - Use population models to deduce rate of events
- Small probability for a detection in Initial Virgo

Observed properties of tight DNS systems

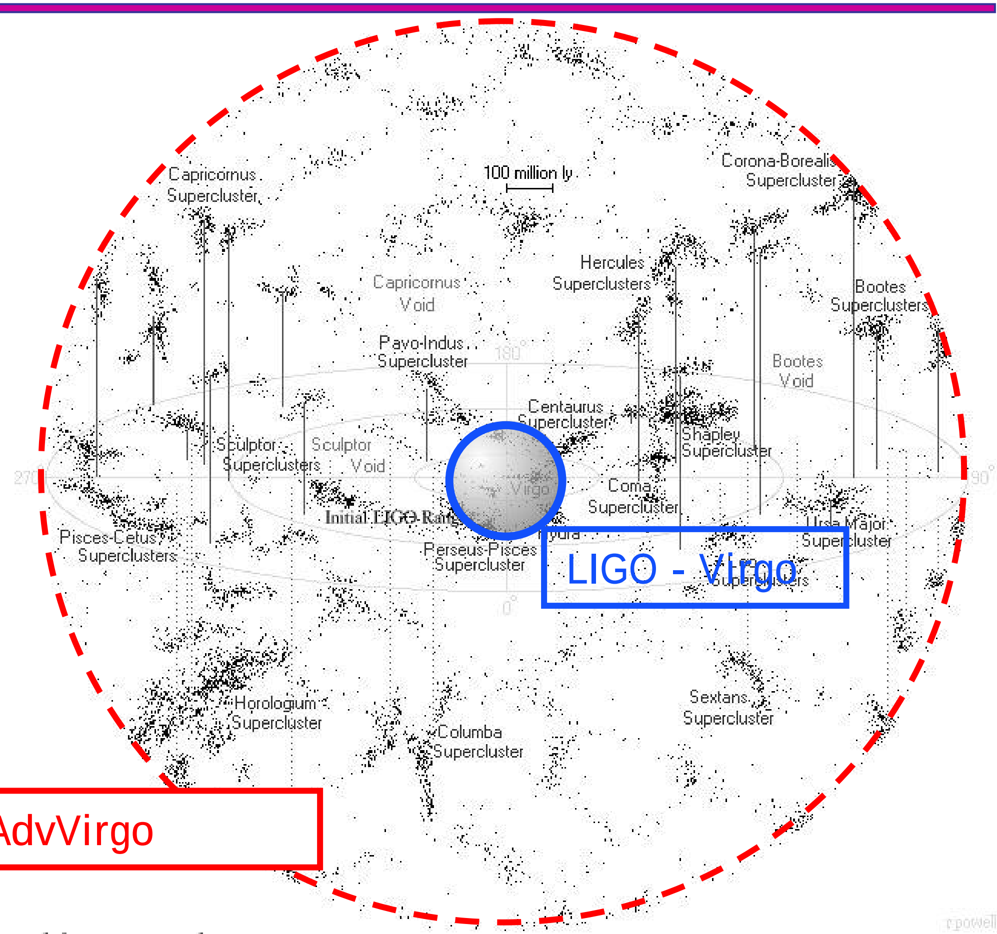
PSR name	P_s^a (ms)	P_b^b (hr)	e^c	τ_{life}^d (Gyr)	N_{PSR}^e
B1913+16	59.03	7.75	0.617	0.37	680
B1534+12	37.90	10.10	0.274	2.93	480
J0737-3039A	22.70	2.45	0.088	0.23	1680
J1756-2251	28.46	7.67	0.181	2.03	$400-600^f$
J1906+0746[g]	144.14	3.98	0.085	0.082^h	300

Table 5. Detection rates for compact binary coalescence sources.

IFO	Source[a]	$\dot{N}_{low}$ yr^{-1}	$\dot{N}_{re}$ yr^{-1}	$\dot{N}_{high}$ yr^{-1}	$\dot{N}_{max}$ yr^{-1}
	NS–NS	2×10^{-4}	0.02	0.2	0.6
	NS–BH	7×10^{-5}	0.004	0.1	
Initial	BH–BH	2×10^{-4}	0.007	0.5	

Coalescing binaries

- Advanced Virgo
  - Sensitivity x 10
  - Volume explored x 1000
- Tens of coalescing binaries expected per year
- Sources visible up to large distances
  - NS-NS ~150 Mpc
  - BH-BH > 1 Gpc
- Sources are standard candles
  - Cosmology
- Likely to be visible with other instruments
  - Multi-messenger approach



AdvLIGO – AdvVirgo

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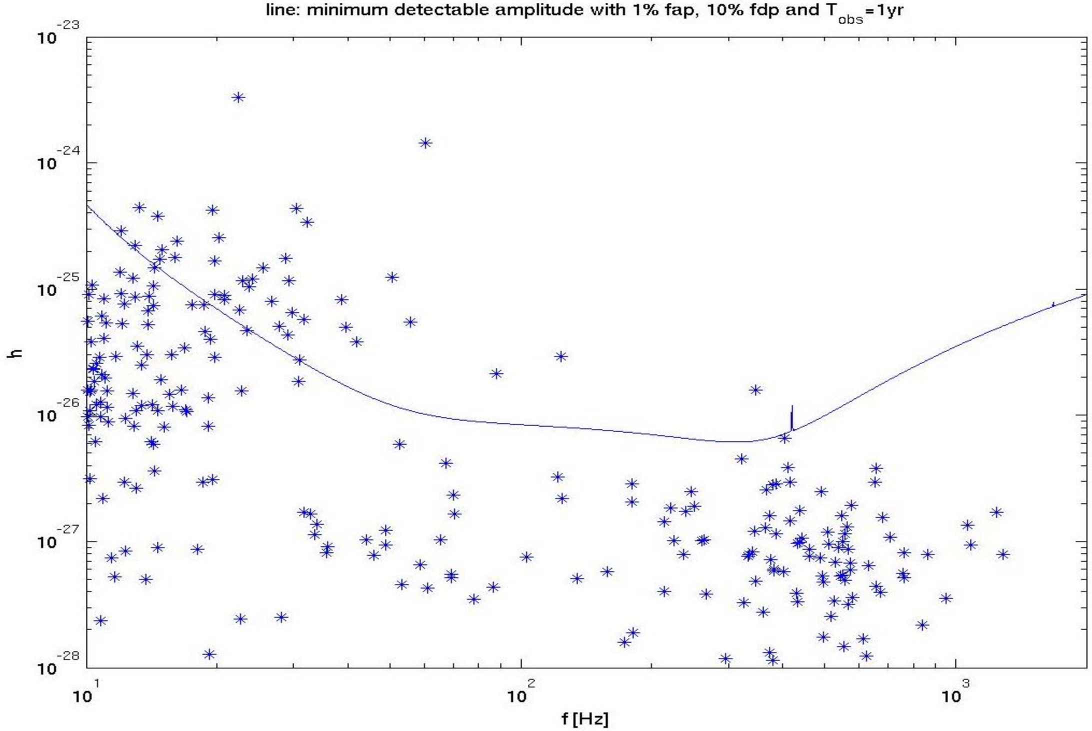
	NS–NS	0.4	40	400	1000
	NS–BH	0.2	10	300	
Advanced	BH–BH	0.4	20	1000	

Binary black holes

- Two interesting X-binaries known
  - IC10 X-1 and NGC300 X-1
  - Formed by a 20-30 black hole and a massive Wolf-Rayet (W-R) star
  - Should evolve into a binary black hole with Mchirp~15 Mo
  - Both within 2 Mpc
- Advanced Virgo can see these systems up to distances > 1 Gpc
  - Several hundreds of events each year
- Advanced Virgo/LIGO can provide unique information on the behavior of gravity when two black holes merge

Pulsars

- Rotating neutron stars
  - ~2000 pulsars known in the Milky Way
  - 10^9 neutron stars expected in the Milky Way
- LIGO and Virgo testing upper limits for a few pulsars
- Adv Virgo/LIGO will test current upper limits for more than fifty known pulsars

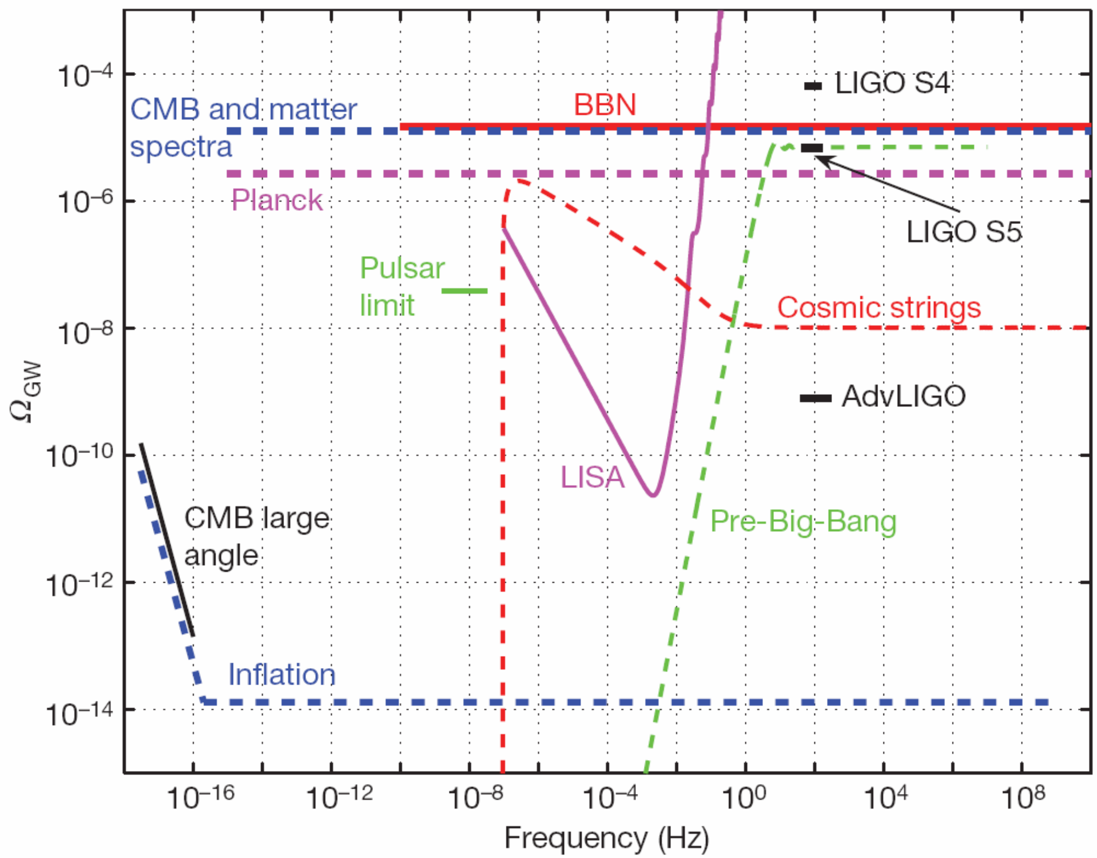


GW stochastic background

- GW background described by a spectrum of GW density energy
  - Amount of GW energy per frequency interval
  - Critical energy

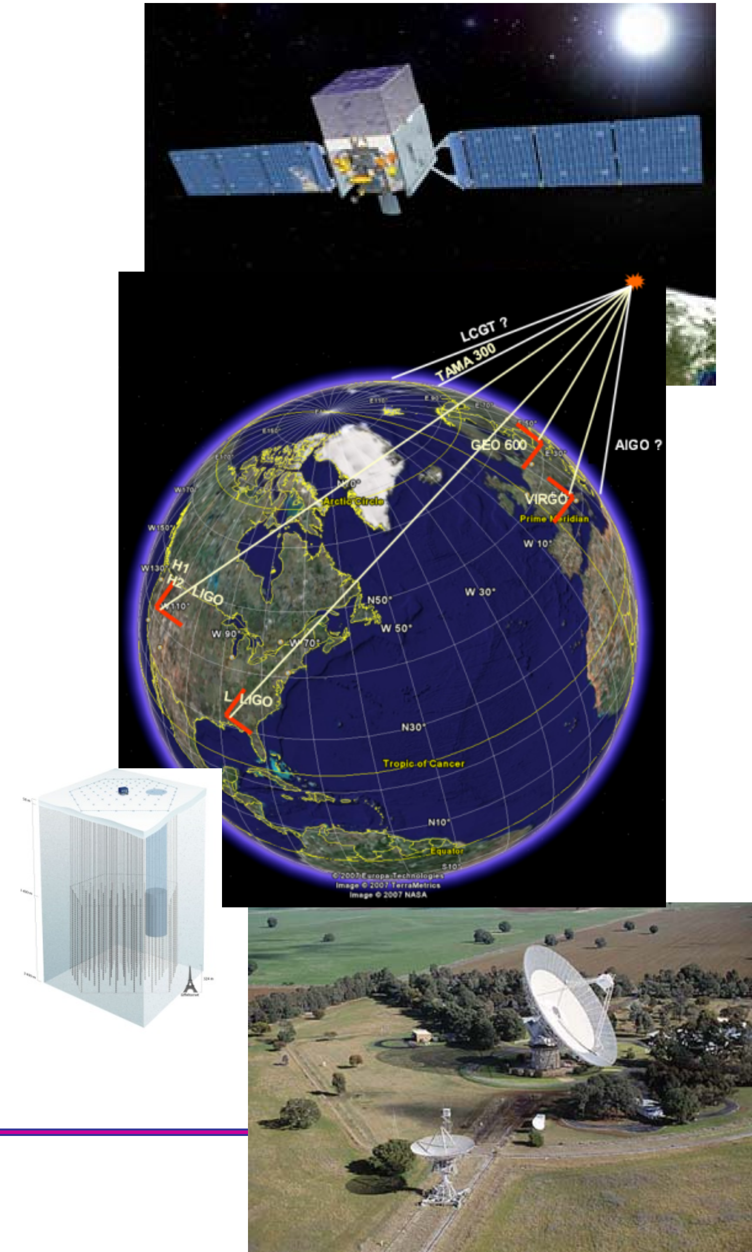
$$\Omega_{GW}(f) = \frac{f}{\rho_c}\frac{d\rho_{GW}}{df}$$

- LIGO beat the Big Bang Nucleosynthesis UL
- Advanced detectors will test different models



Advanced Virgo Science Case

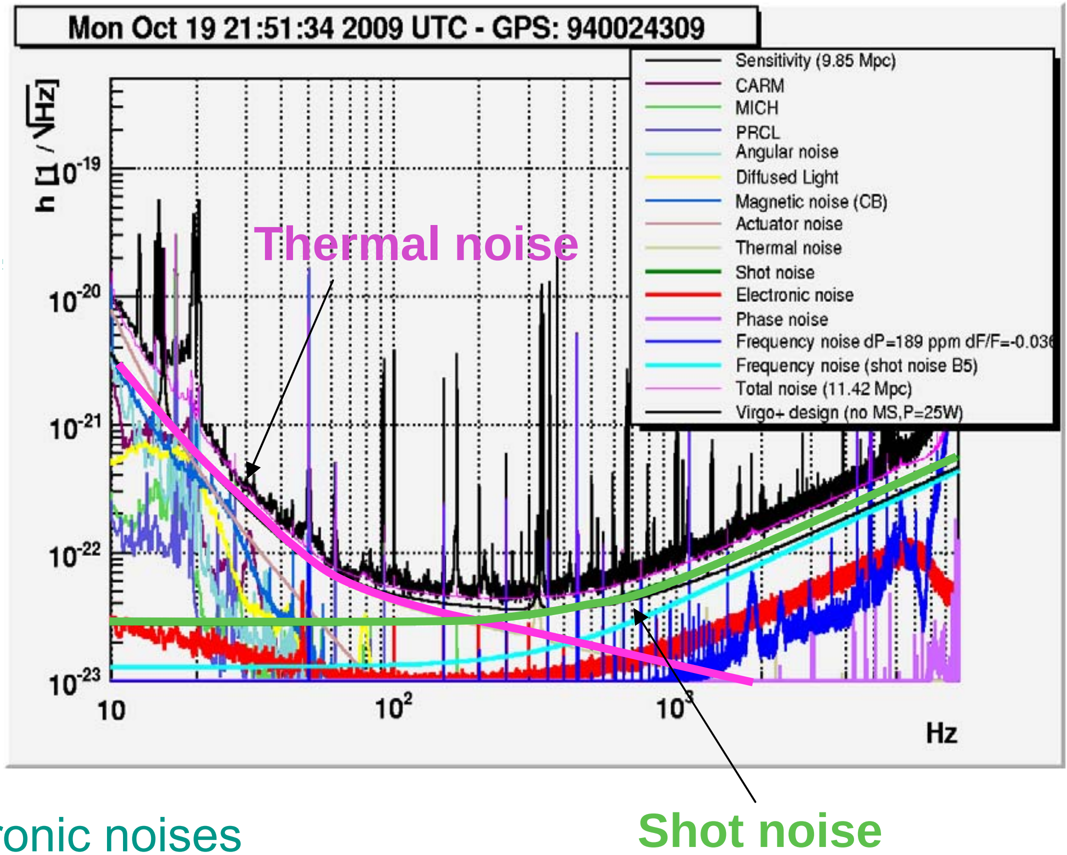
- 1 day of AdVirgo data ~ 3 years of Virgo data
- Coalescing binaries detection rates
  - BNS ~ 20/yr (AdV Virgo only)
  - BBH ~ 0.3 - 100/yr (model dependent)
- Advanced Virgo in the network:
  - Much better event reconstruction
    - » Source location in the sky
    - » Reconstruction of polarization components
    - » Reconstruction of amplitude at source and determination of source distance (BNS)
  - Detection probability increases: 40% more events than Advanced LIGO only
  - Detection confidence increase (coincidence techniques)
- Multi-messenger opportunities
  - Collaboration with E.M. and ν detectors will increase the search sensitivity or equivalently detection confidence
  - Advanced GW network opens new perspectives for Astroparticle Physics
- The experimentalists view
  - After ten years of R&D, technology for a major improvement has been demonstrated



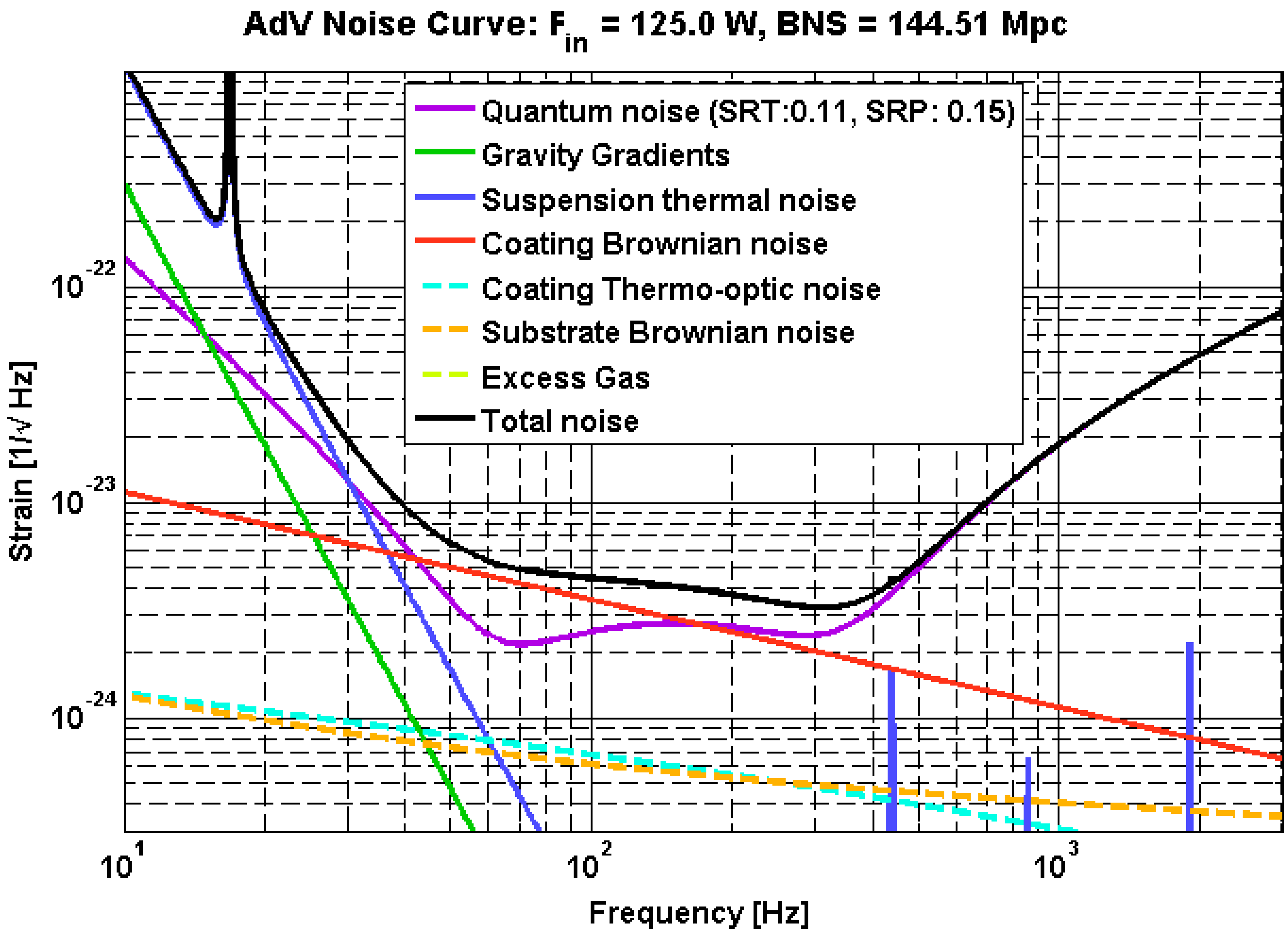
Advanced Virgo design

From Virgo to AdvVirgo in one slide

- Reduce thermal noise
  - Monolithic suspensions
  - Larger beam on mirrors
  - Better coatings
  - Heavier mirrors
- Reduce quantum noise ('shot noise')
  - Increase leaser power
    - Improve Thermal compensation
    - New injection optics
  - Improve mirrors flatness
  - Heavier mirrors
  - Use signal recycling
  - Use DC detection
- Reduce environmental noise
  - Reduce noise sources (air conditioning)
  - Move photodiodes under vacuum
- Improve reliability and control/electronic noises
  - Non degenerate recycling cavities
  - Better thermal compensation
  - Improve super-attenuator inertial damping
  - Use DC detection

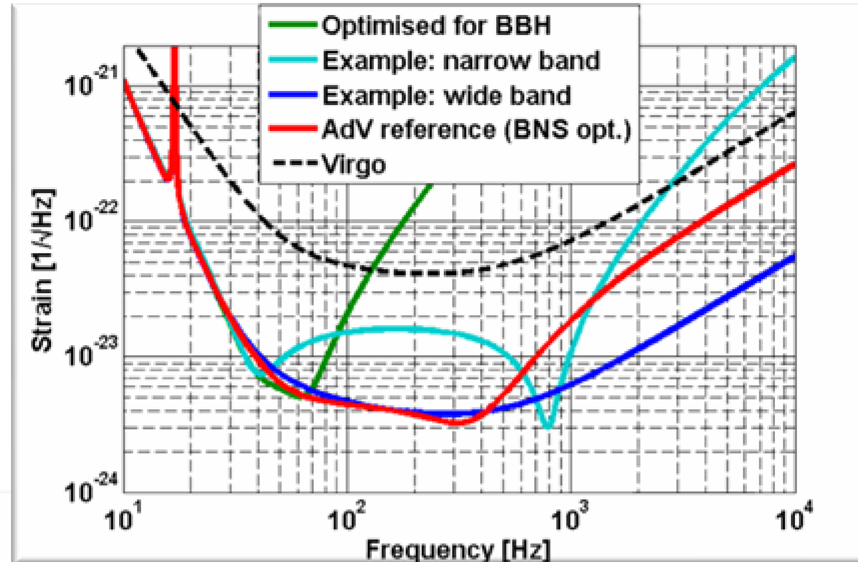


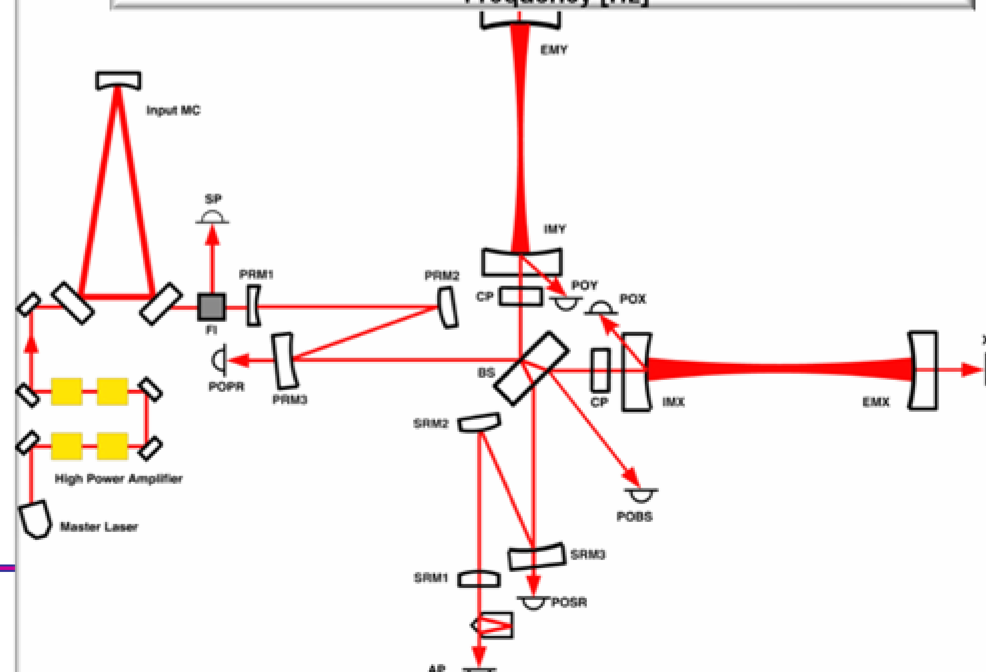
Advanced Virgo sensitivity



Optical configuration and readout

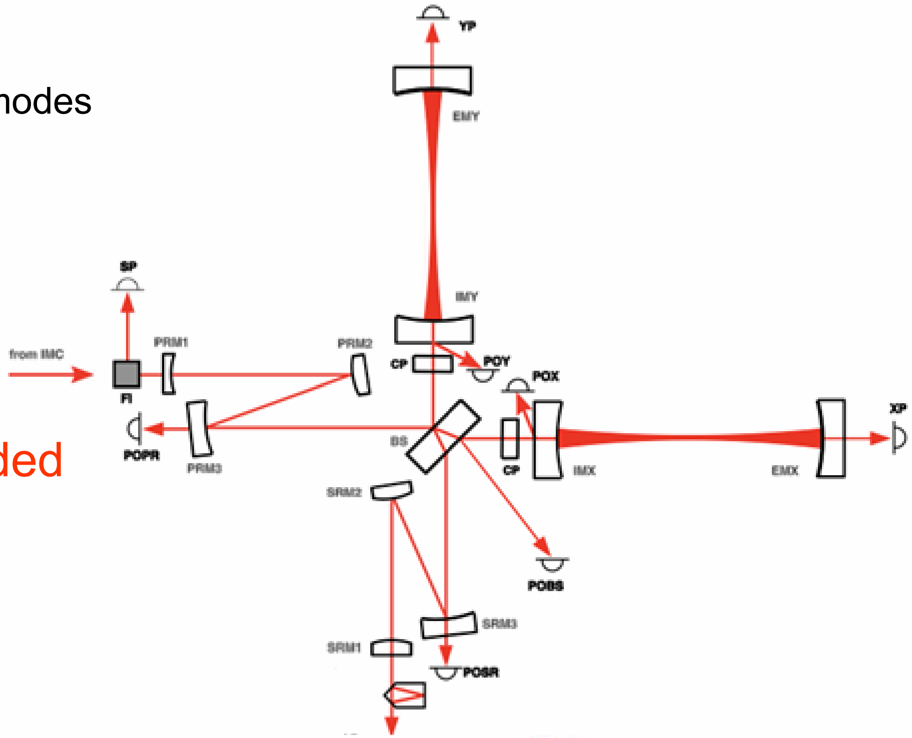
- Main drivers
  - Reduce impact of quantum noise
  - Mitigate coating thermal noise
  - Allow for sensitivity tunability
- Use of signal recycling
  - Foreseen since the beginning
  - Compatible with vacuum infrastructure
  - Mature technique
- Increase cavity finesse (~450)
- Enlarged spot size on test masses
  - From 2 cm to 5 cm
- Use DC detection
  - New higher finesse output mode cleaner

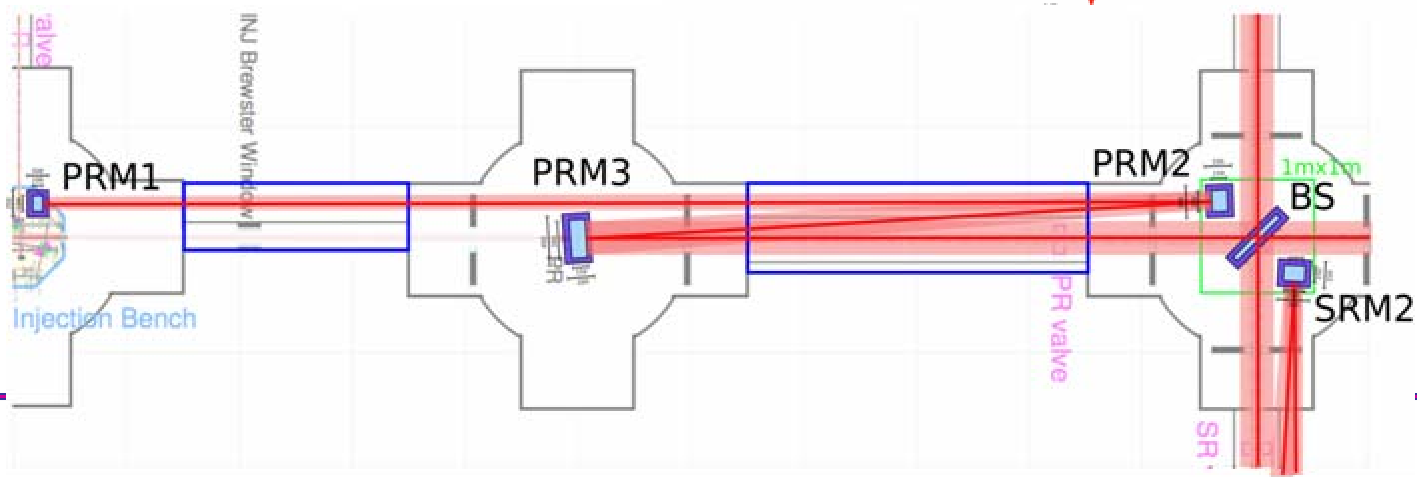




Non degenerate cavities/ Multiple payloads

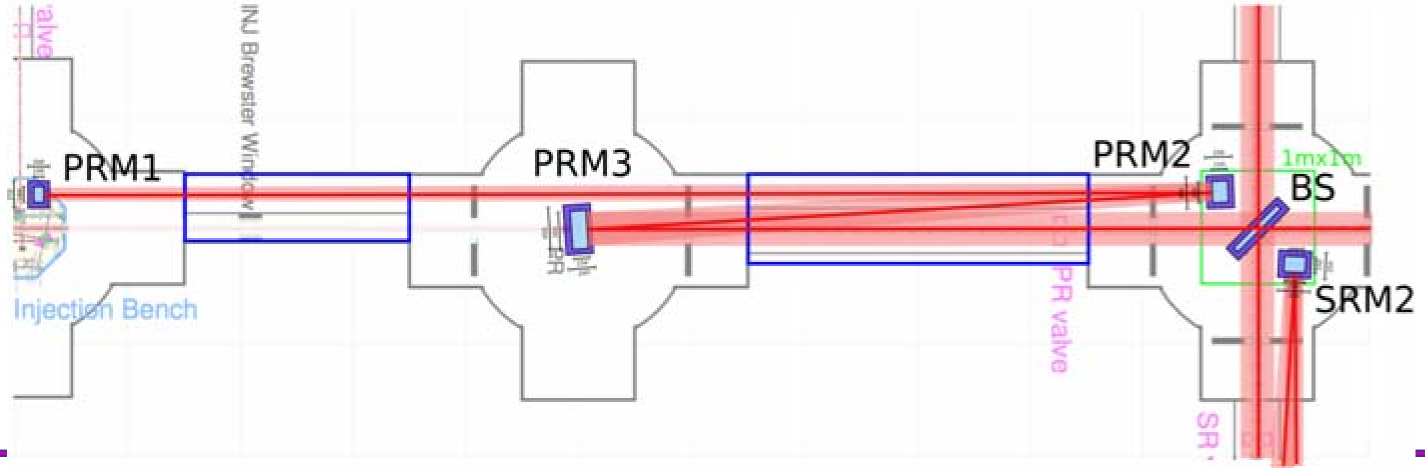
- Main drivers
  - Reduce signal loss due to scattering into higher modes
  - Improve interferometer control signals
  - Relax spec on thermal compensation system
- Use non degenerate recycling cavities
  - Telescope in the recycling cavity
  - Reduce beam size on input/output bench (from ~5 cm to ~ 1 mm)
- Problem: need for several mirrors suspended to a seismic isolator
  - Impact on couplings and mirror position control
  - Problem appeared as such in 2010





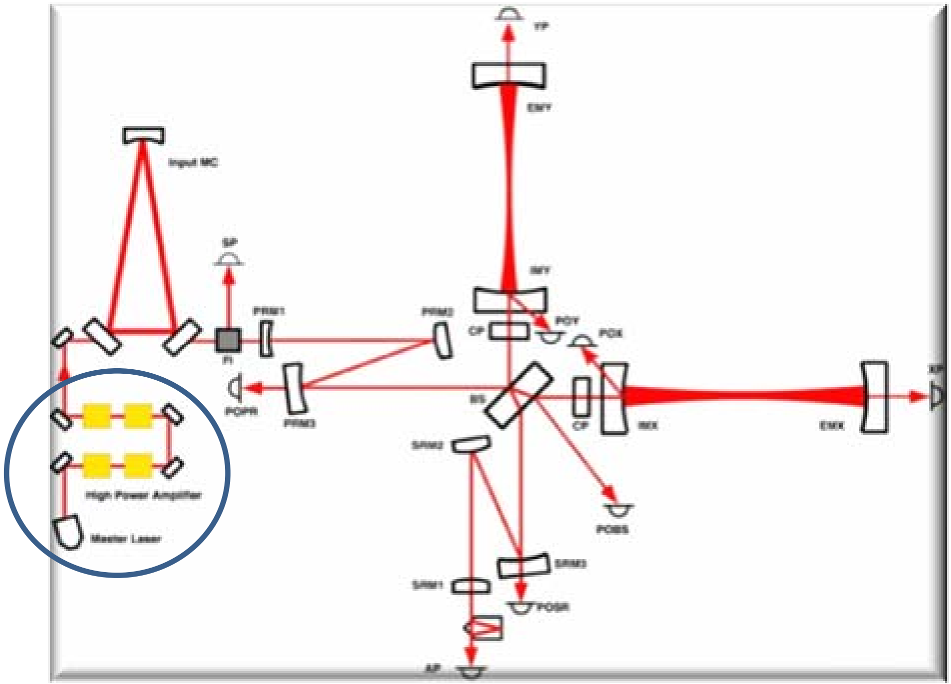
Non degenerate cavities/ Multiple payloads

- Several solutions explored
  - Suspend several mirrors to one suspension: risky
  - Put several suspensions in one vacuum chamber: complex
  - Add buildings and vacuum chambers: expensive
  - Use folded vertical cavities: cost, risk?
  - Return to degenerate cavities: risk?, sensitivity?
- Main issue for Advanced Virgo at present
  - Work in progress

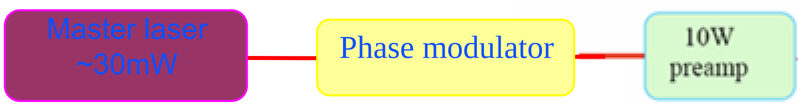


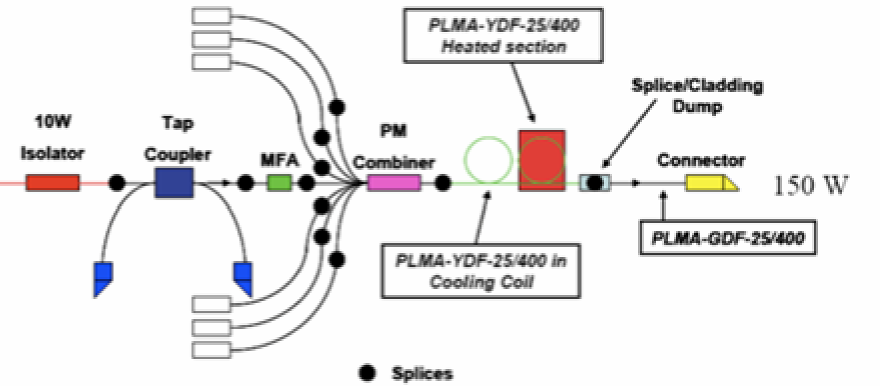
Laser

- Main driver
  - Reduce shot noise
  - Improve high frequency sensitivity
- Increase laser power 10x
  - Adv Virgo input power: 125 W
- Drawbacks
  - Radiation pressure noise
  - Mirror thermal lensing
- Mitigation
  - Heavier mirrors
  - Improved thermal compensation

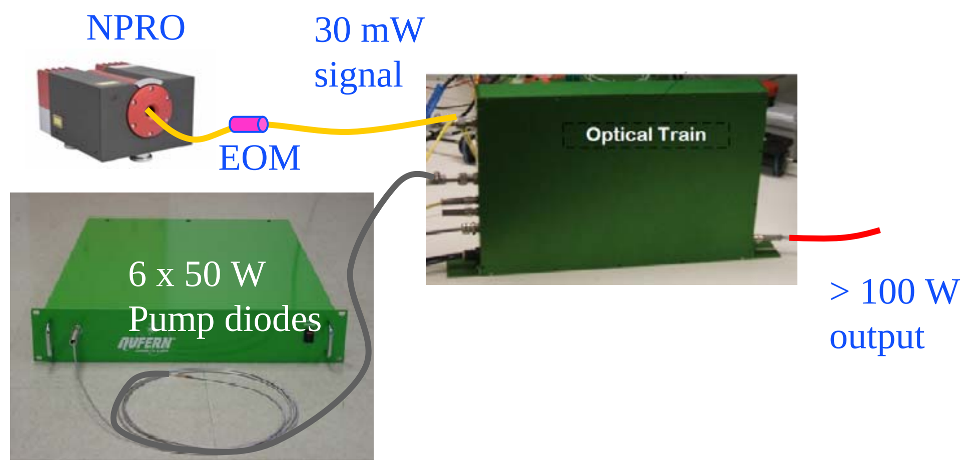


The Virgo solution: Fiber laser



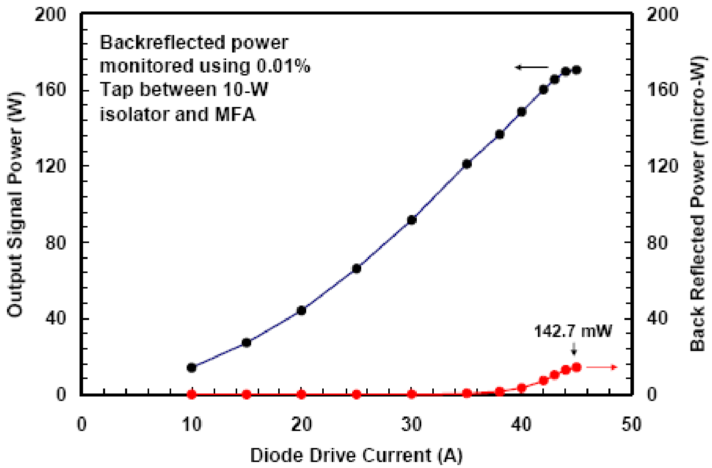


- Y doped fiber amplifier
- Advantages
  - Efficient (50%)
  - Low maintenance (welded fibers)
  - Easy to operate
  - High beam quality
  - Technology rapidly developing
  - Compact
  - Low cost
- Drawback
  - New technology
    - » Noise and controllability to be verified
    - » Reliability

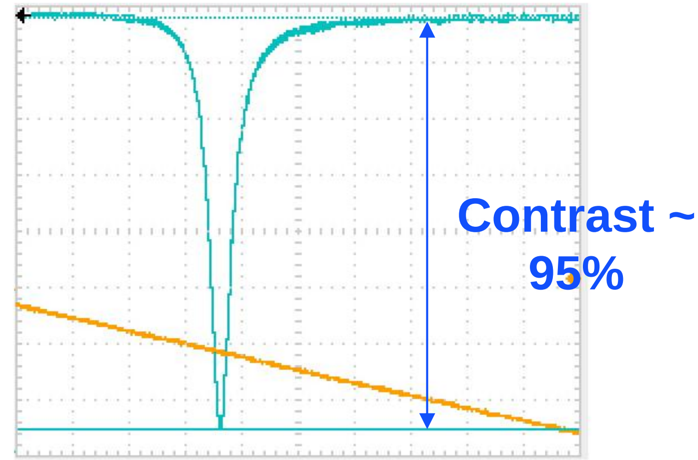


Fiber laser results: very promising

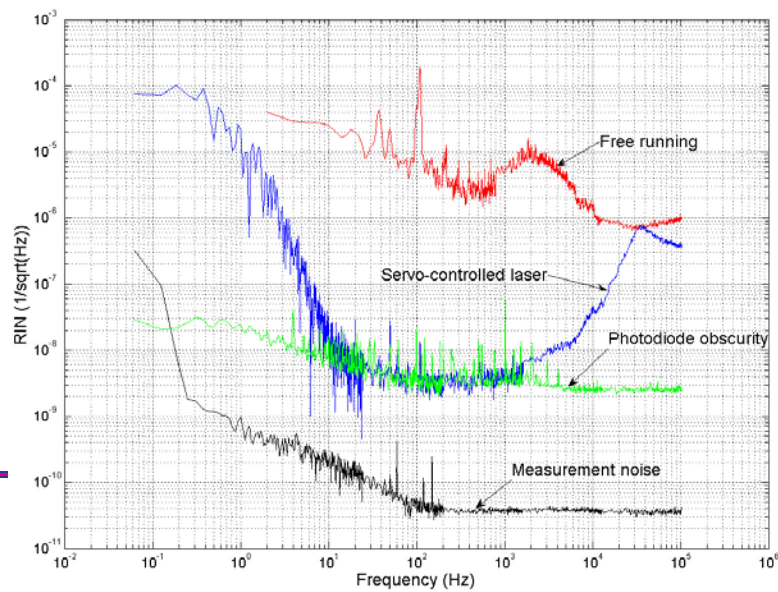
Power > 170 W



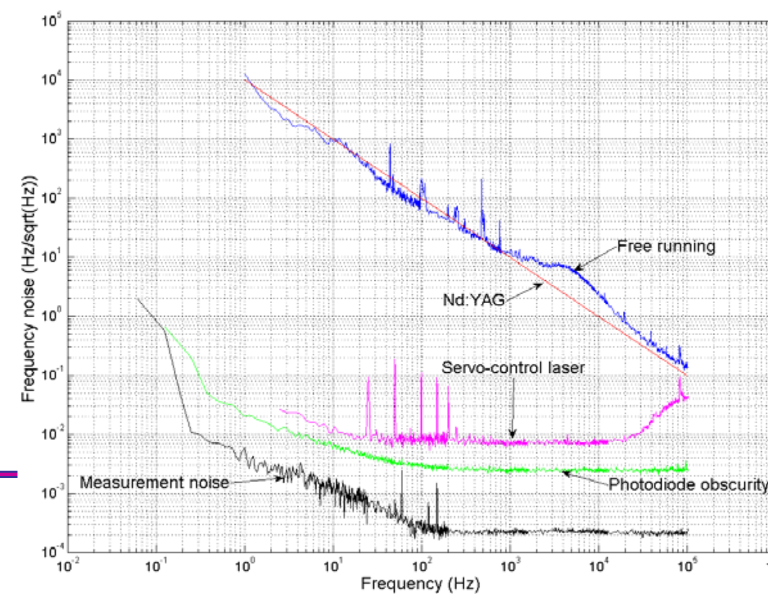
Beam quality: 95% matching



Power stabilization: 3 10^{-9} @ 100 Hz

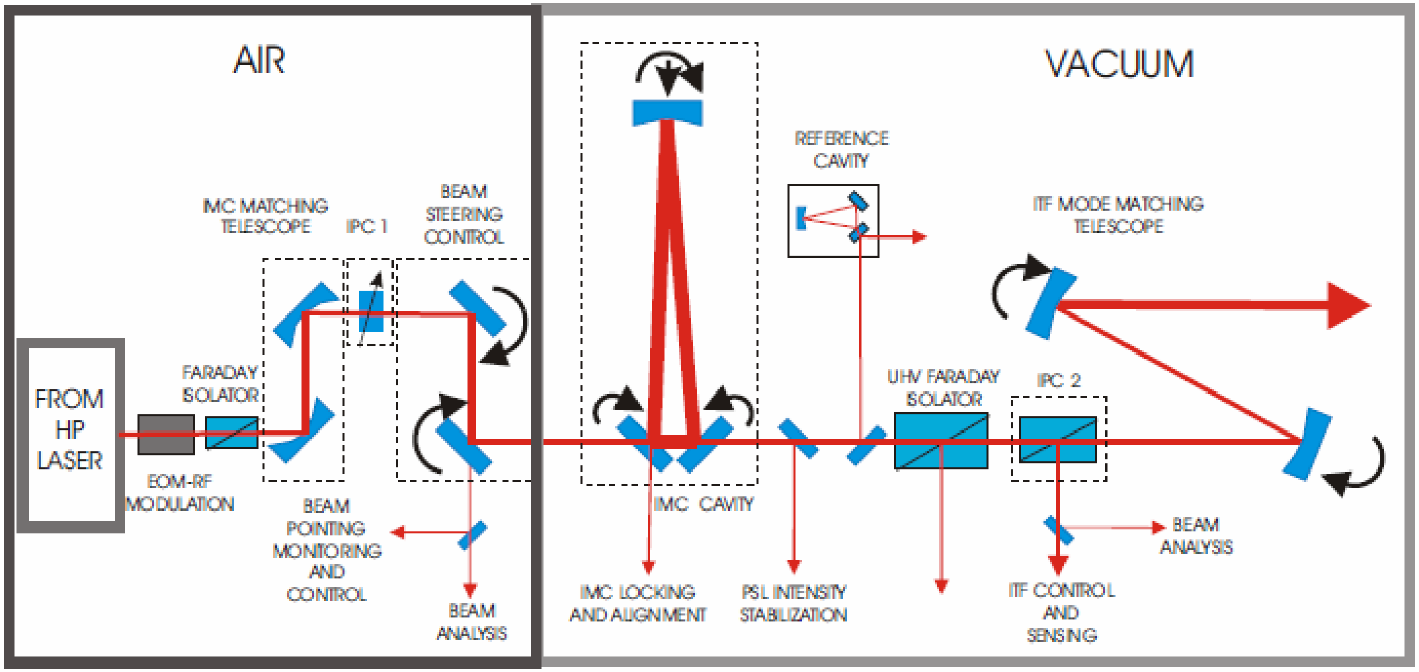


Frequency stabilization 6 10^{-3} Hz/$\sqrt{\text{Hz}}$



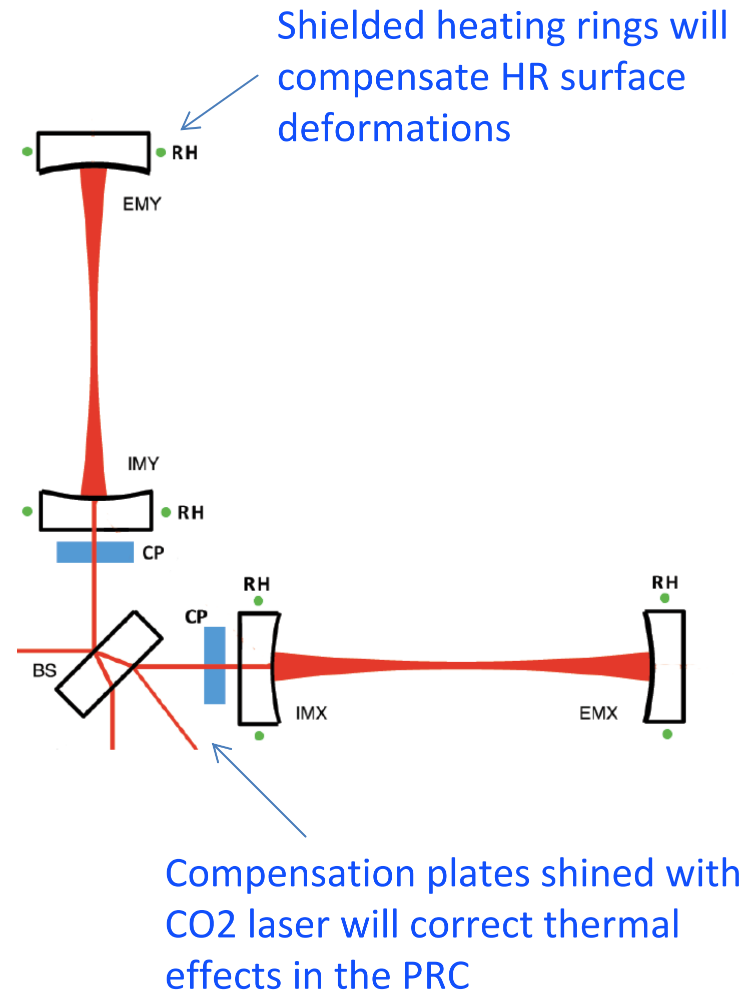
Input optics

- Main drivers
  - Manage higher power, Meet AdV noise requirements
- Input mode cleaner
  - Keep 144 m suspended triangular cavity: more noise filtering, easier modulation frequency choice, existing infrastructure
  - Mirrors: heavier for radiation pressure mitigation, improved polishing for smaller low angle scattering
- Electro-optics modulators
  - Low thermal lensing KTP crystals
- Faraday isolator
  - Realized at IAP (Russia), meets AdV specs



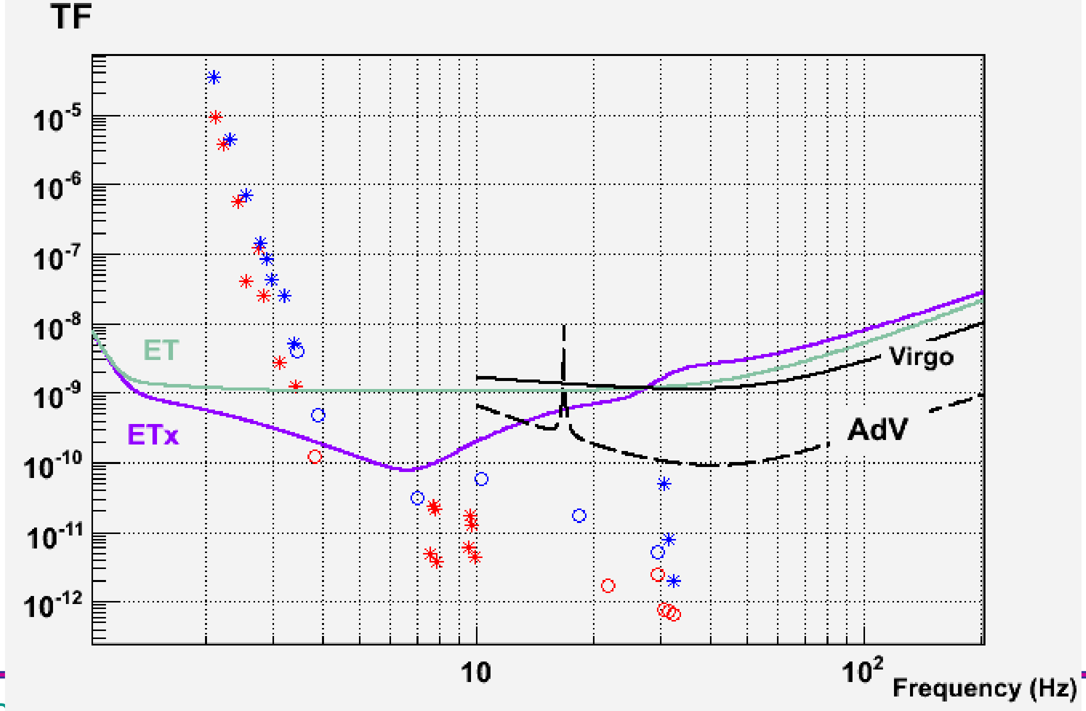
Thermal compensation

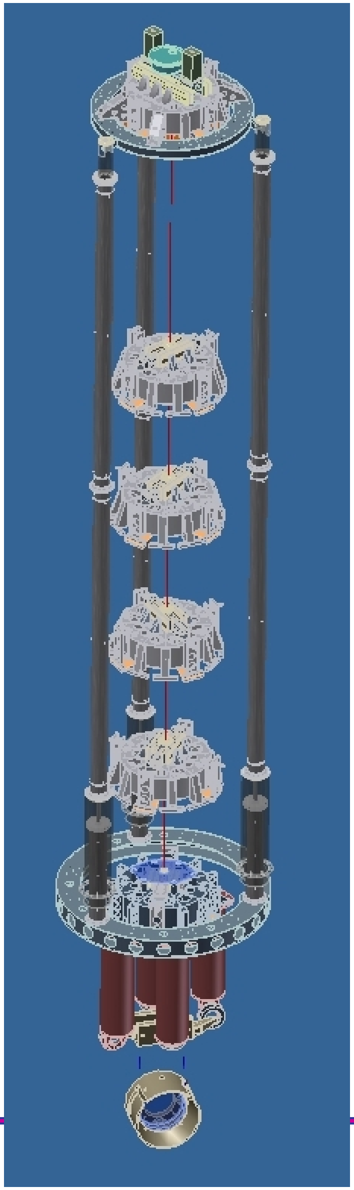
- Main driver
  - Avoid degradation of interferometer performance due to thermal lensing
- Main effects
  - Reduce wavefront distortion in recycling cavities
  - Correct mirrors surface deformation
- Thermal compensation
  - Combined action of a CO2 laser and heating rings
  - CO2 laser cannot act directly on test masses
  - Project CO2 laser on silica compensation plates
- Drawback
  - Additional transmissive optics on the main beam
- Mitigation
  - CP seismically isolated
  - Wedge on CP
  - Tilted to suppress impact on alignment signals



Seismic isolation

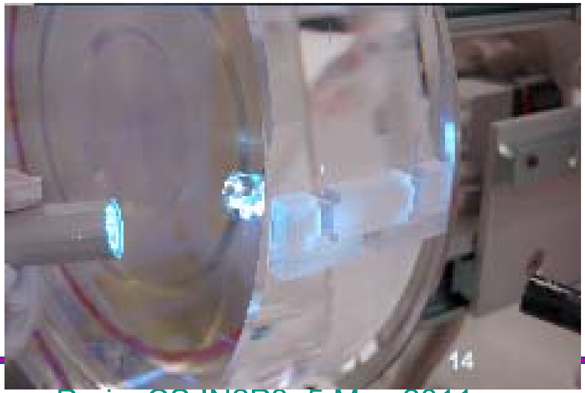
- Main drivers
  - Isolate test mass form seismic noise
  - Control mirror positions
- Use present Virgo super-attenuators (SA)
  - New TF measurements done in 2009
  - Results: SA is compliant with AdVirgo requirements

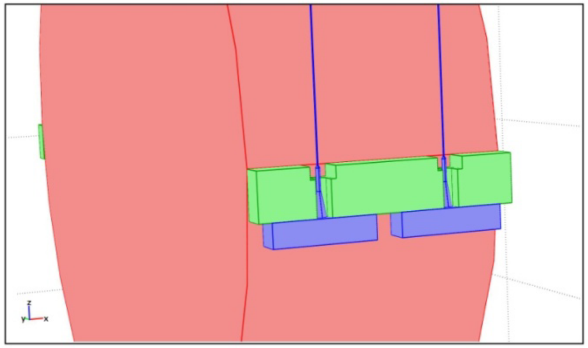


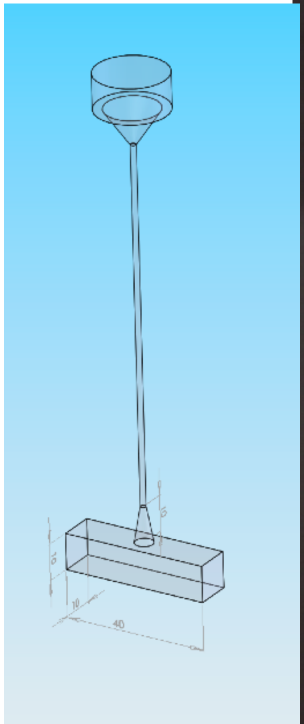


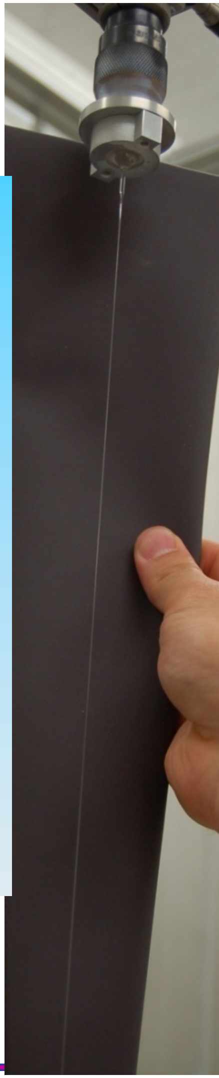
Monolithic suspensions

- Main driver
  - Reduction of suspensions thermal noise
- Use of fused silica fibers to suspend the test masses
- Important progress in 2009-10
  - Fiber production
    - Geometry under control
    - Excellent reproducibility
  - Clamp design
  - Welding technique
  - Assembly procedure thoroughly tested
  - Fully monolithic suspension installed in Virgo+ last year
    - Risk reduction for Advanced Virgo



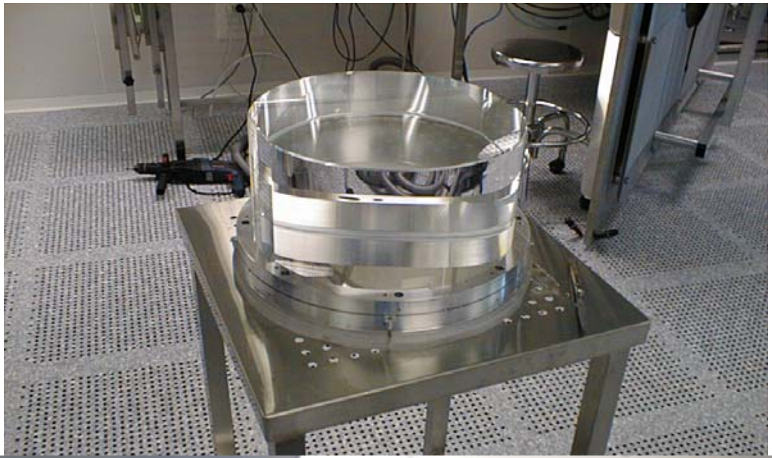






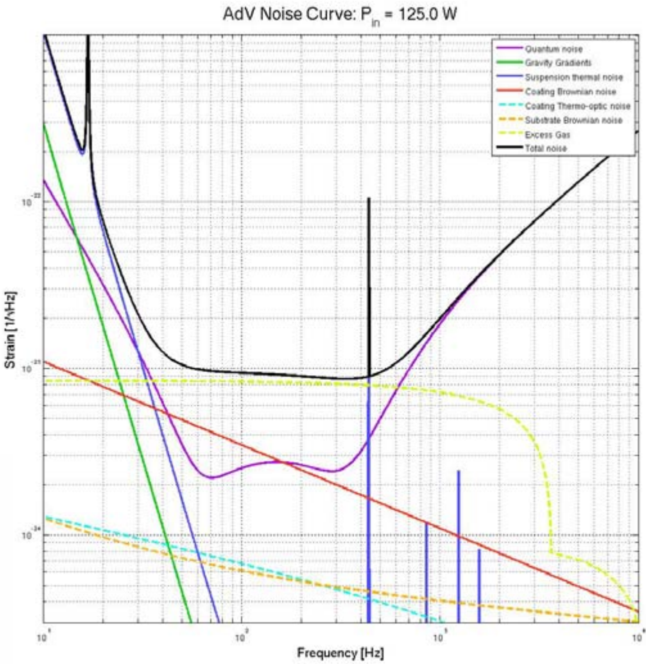
Mirrors

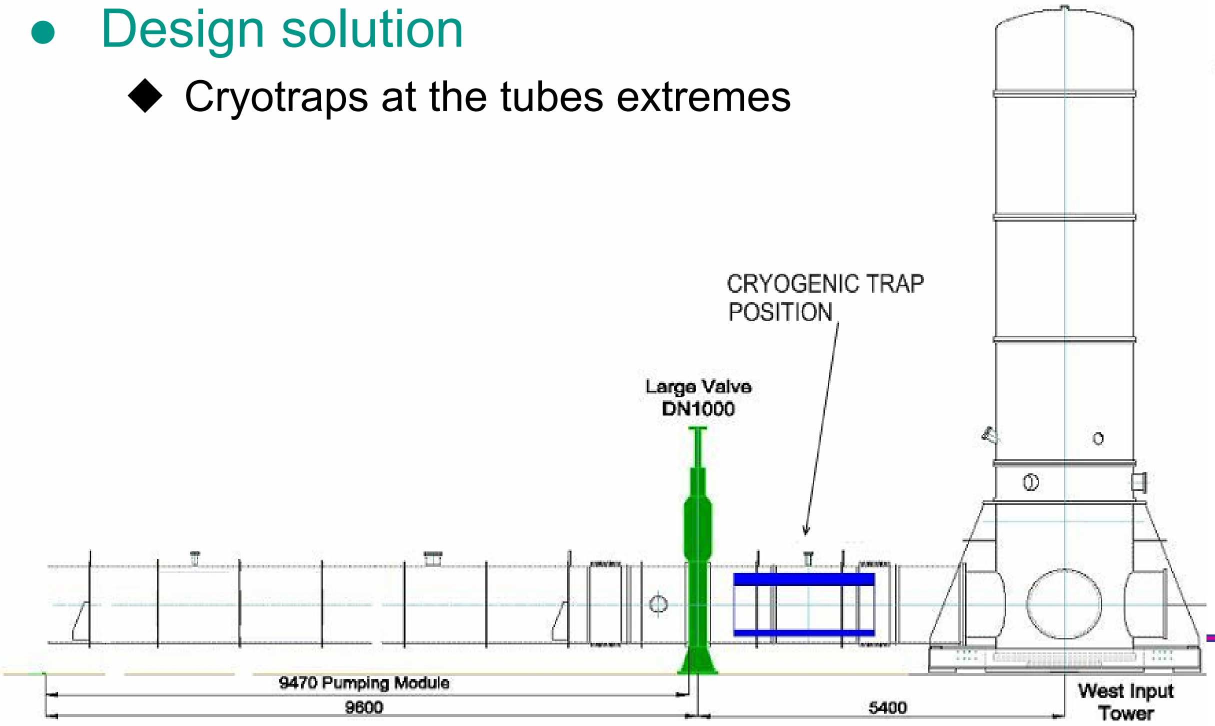
- Main drivers
  - Thermal noise reduction
  - Radiation pressure noise mitigation
  - Scattering losses reduction
- Use state of the art coating in 2011
  - Ti:Ta_2O_5 reference solution
- Larger mass
  - 35 cm diameter, 20 cm thick
  - 42 kg
- Low absorption fused silica
- Scattering loss reduction
  - Specs: flatness < 1 nm, Roughness < 1 Å
  - Reference solution: corrective coating
  - Alternative: ion beam polishing



Vacuum envelope

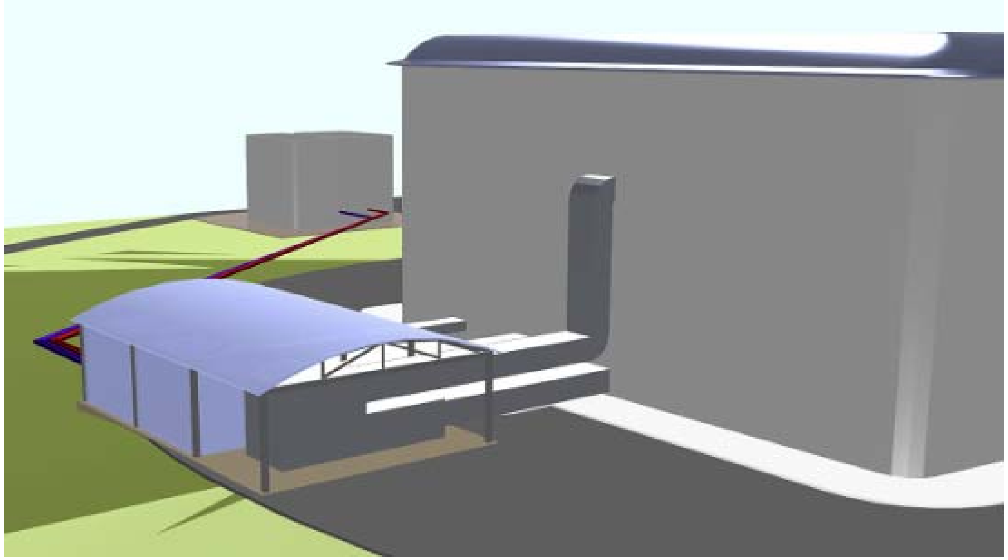
- Main driver
  - Reduction of index of refraction fluctuation noise
- Reduce residual pressure in the Virgo tubes
  - Current pressure ~ 10^{-7} mbar (dominated by water)
  - Reduction 100x required
  - Tubes bakeout needed
  - Need to separate tubes from towers
- Design solution
  - Cryotraps at the tubes extremes





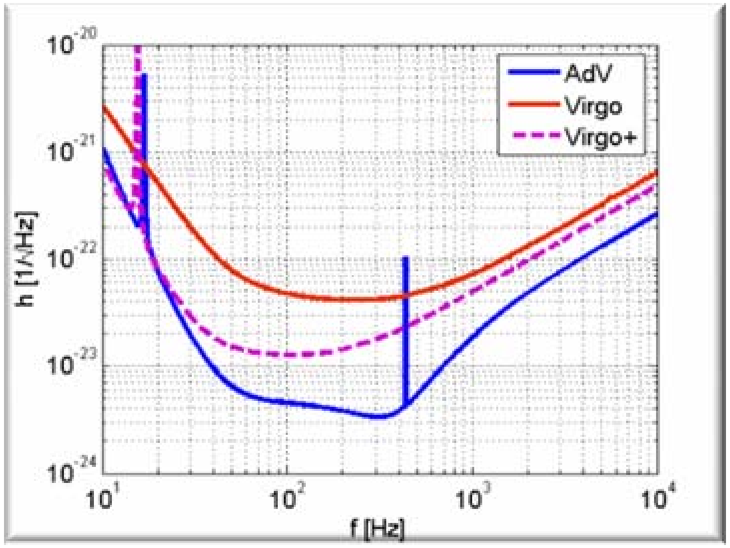
Environmental noise reduction

- Main driver
  - Reduce environmental noise and its effect on the interferometer
- Reduce noise: infrastructure works
  - Replacement of old air conditioning machines and relocation out of experimental halls
  - Insulated rooms for noisy racks, power supplies, scroll pumps
  - Improvement of laser/detection acoustic isolation
- Reduce sensitivity to noise
  - Photodiodes moved under vacuum



Risk reduction: Virgo+

- The Virgo+ program is helping reducing the AdV risk by tackling in advance some relevant issues:
  - ◆ Higher power laser
  - ◆ Use of TCS
  - ◆ Monolithic suspensions
  - ◆ Higher arm cavity finesse

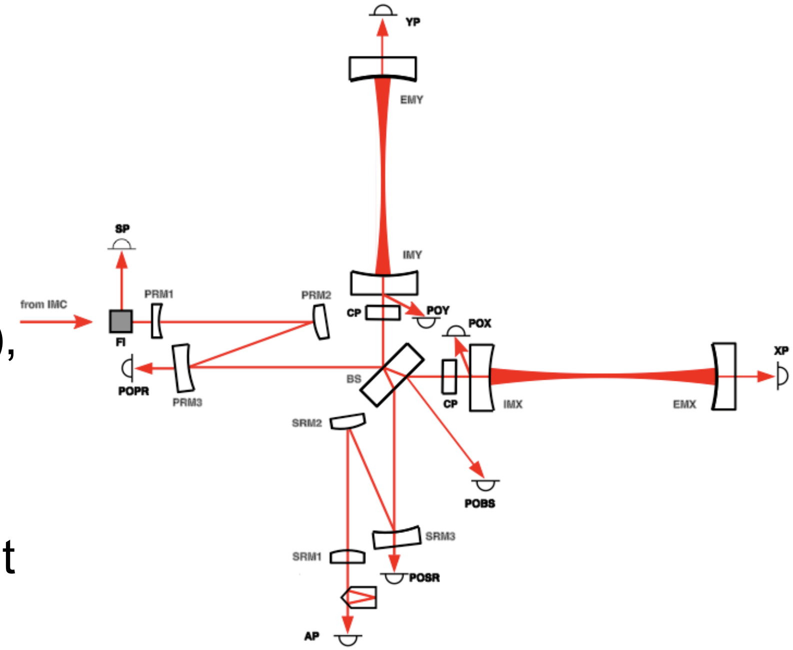


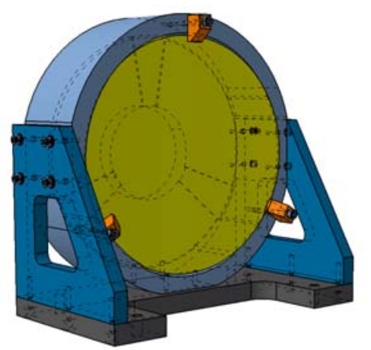
- The use of monolithic suspensions in Virgo+ is crucial to reduce the risks connected to the fused silica fibers

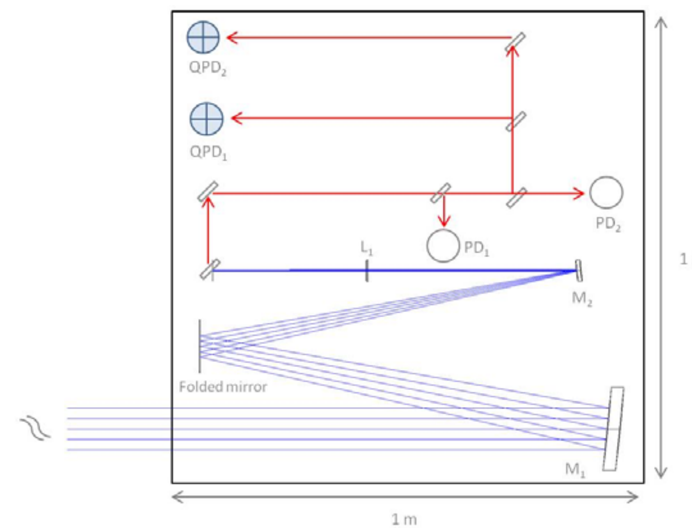
Contribution of the IN2P3 groups
(to the construction of Advanced Virgo)

APC

- Optical System Design
  - Responsible for the interferometer optical configuration
  - Optical simulation studies
  - Coordination work (not the easiest one …), several labs involved
- Mode Matching Telescopes
  - Increase (or reduce) the beam size without introducing aberrations or astigmatism
  - Four different type of telescopes
  - Telescopes design, construction and commissioning
    - » Optics + Mechanics







LAL

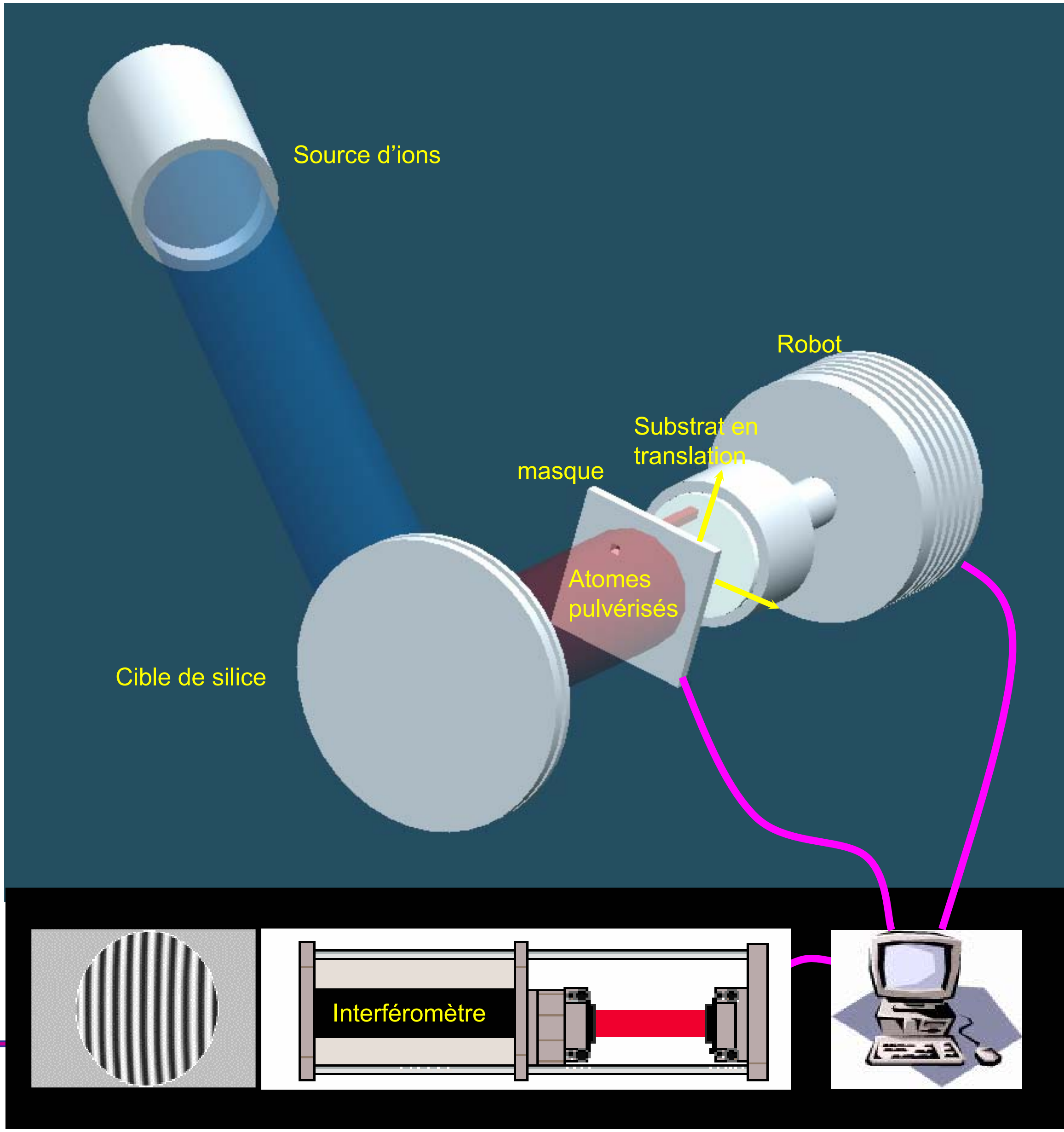
- Locking acquisition system
  - Principle: auxiliary lasers injected from the back of the end mirrors and used to lock each cavity independently
  - Experience with CALVA in progress at LAL
  - Need depends on final choice for optical configuration
- Vacuum control upgrade
  - Mainly motivated by obsolesce of present system

LMA

- Optical system design
  - Optical simulations
  - Optical configuration design
- Mirrors
  - About 25% of the AdVirgo cost
  - Definition of specifications
  - Substrates acquisition
    - First substrates received at LMA
  - Polishing
    - Call for tender to be done
  - Corrective coating
    - Under development
    - Collaboration with LAPP
  - Cleaning & Coating
    - New cleaning machine developed
  - Metrology

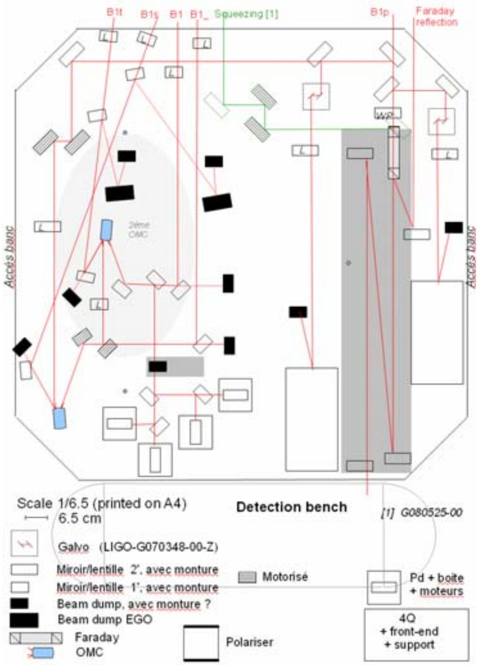
LMA

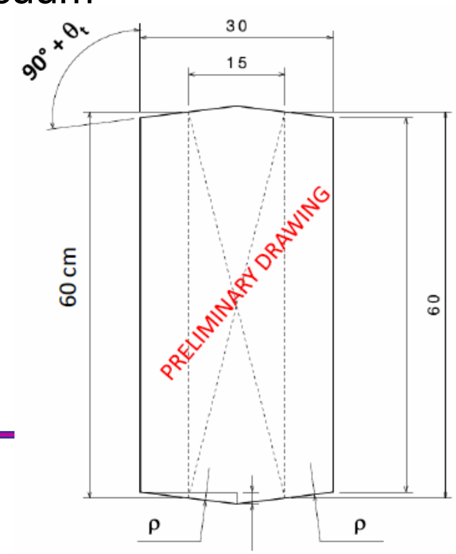
- Main challenge
  - Improve mirrors flatness
  - Current flatness ~ 3-4 nm
  - Goal ~ 0.5 nm
- Reference solution
  - Corrective coating
  - Collaboration with LAPP
    - » Robot development
- Alternative solution
  - Ion beam polishing
    - » 'Corrective polishing'

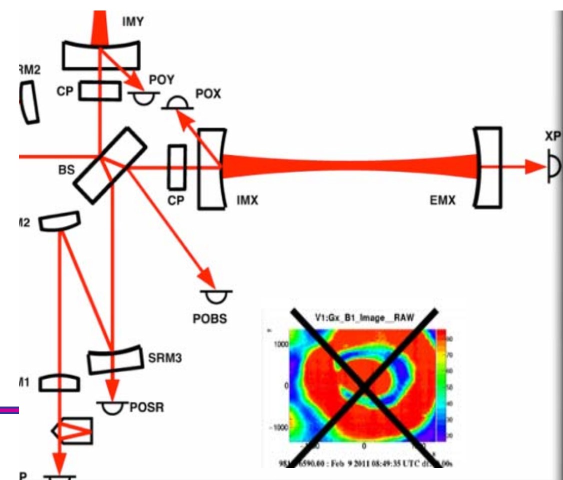


LAPP

- Detection system
  - Optics and electronics required to extract and to detect the interferometer output beams
  - Due to the new optical configuration and signal readout scheme everything is changing
    - » Beams/signals to be detected
    - » Output mode-cleaner requirements
    - » Modulation frequencies
    - » Front end electronics
    - » Photodiodes
      - – to be moved under vacuum
  - Coordination work

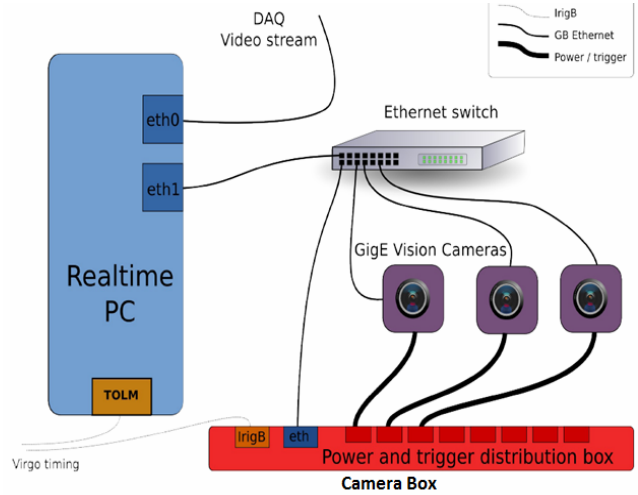


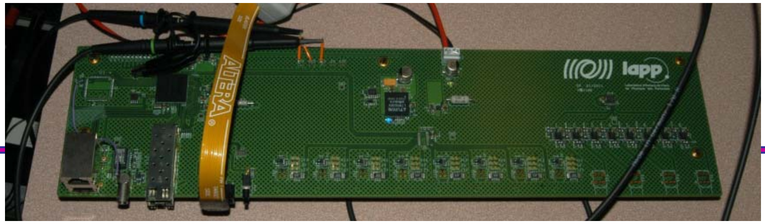




LAPP

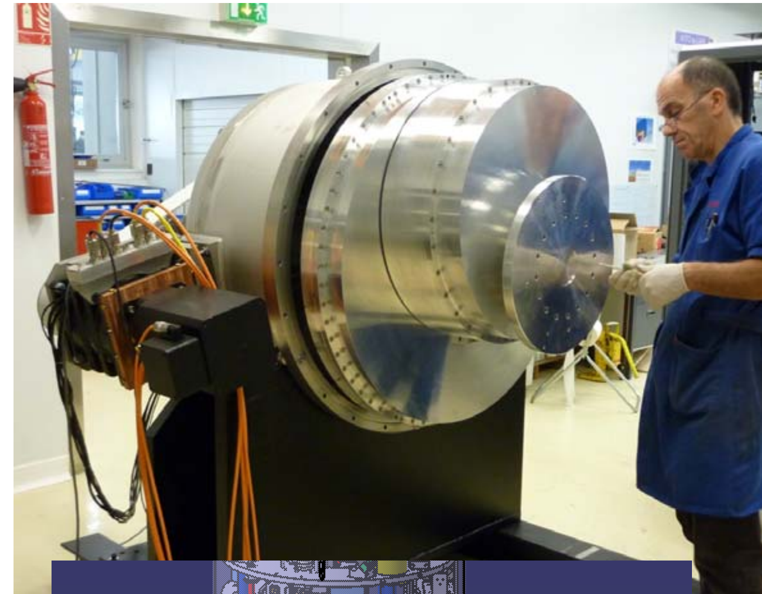
- Digital electronics
  - DAC, DAQ boards, …
  - Some already upgraded for Virgo+
- Video system
  - Present CDD cameras are obsolete
  - Hardware and software development
- Evolution of DAQ
  - More channels
  - More controls
- Important maintenance work

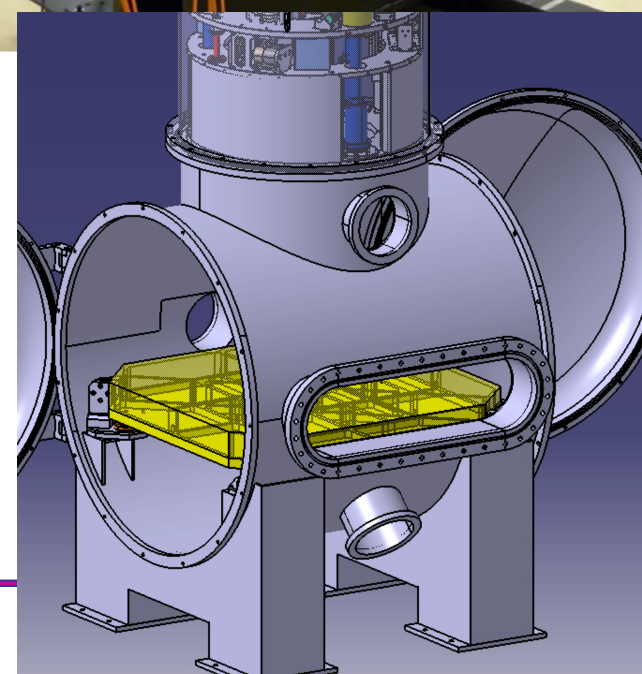


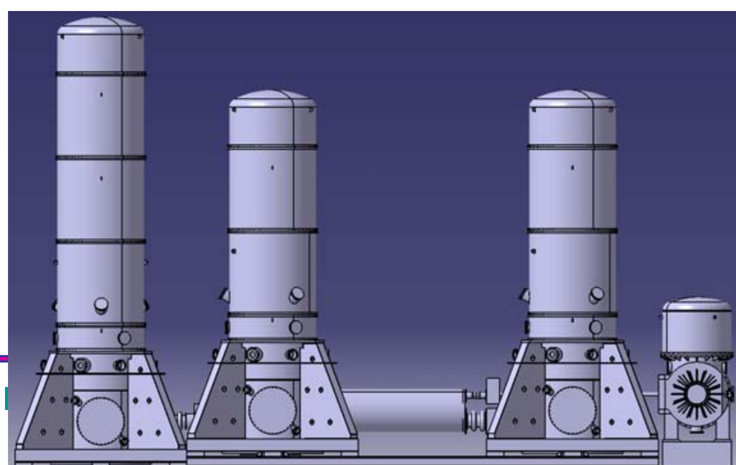


LAPP

- Robot for corrective coating
  - Already built
  - Tests near completion
  - To be installed soon at LMA
- Vacuum chambers
  - Additional vacuum chambers?
    - » Depends on the choice on the optical configuration
  - Re-shaffle of present vacuum chambers
    - » Depends on the choice on the optical configuration







Budget, Status and Planning

Budget

- Total cost as defined in the baseline design is 21.8 M€
  - 6.5 M€ from CNRS
  - 6.5 M € from INFN
  - 1.8 M€ from Nikhef
  - 7 M€ from the EGO running cost (~10 M€/year)
  - Cost includes taxes and contingency
  - Larger investment in mirrors and vacuum

Commitment	SS												
Year	DAQ	DET	IME	INJ	ISC	MIR	PAY	PSL	SAT	TCS	VAC	*MAN*	Grand Total
Grand Total	460	919	1296	822	240	5184	1180	1380	1981	307	4350	*3720*	21840

Status

- Main steps accomplished
  - 2005 Advanced Virgo White Paper
  - 2007 Conceptual design
  - 2008 Preliminary design
  - 2009 Baseline design, cost and planning
  - 2009 Project review
    - » External review committee (chair B. Barish)
    - » Positive report
- December 2009: project approved by EGO council (CNRS, INFN and Nikhef)

Advanced Virgo White Paper
VIR–NOT–DIR–1390–304

R. Flaminio, A.Freise, A. Gennai, P. Hello, P. La Penna, G. Losurdo, H. Lueck, N. Man, A. Masserot, B. Mours, M. Punturo, A. Spallicci, A. Viceré

for the Virgo Collaboration

12 November 2005

Advanced Virgo Conceptual Design

VIR–042A–07

The Virgo Collaboration
edited by
The Advanced Virgo Team*

October 26, 2007

Advanced Virgo Preliminary Design

VIR–089A–08

Issue 3

The Virgo Collaboration

written by
The Advanced Virgo Team*

October 28, 2008

Advanced Virgo Baseline Design

VIR–027A–09

Issue 1

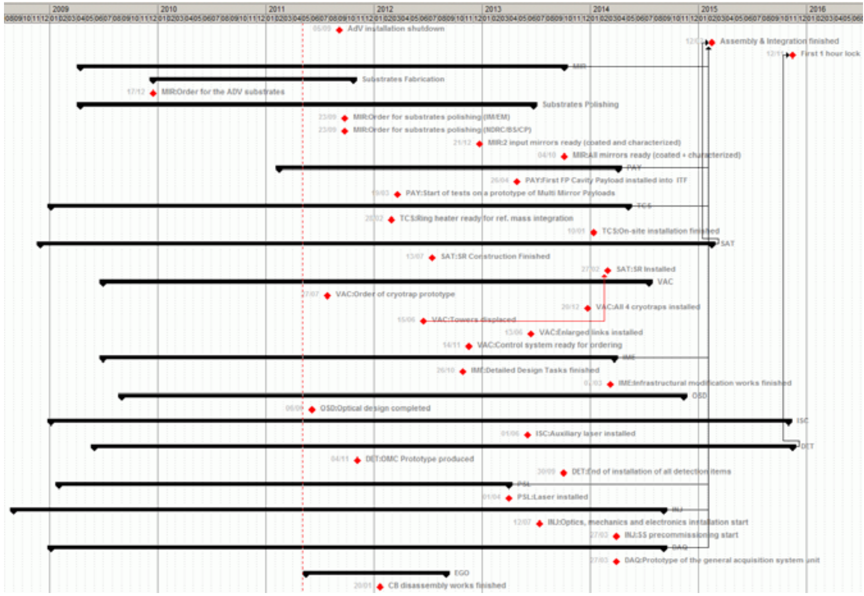
The Virgo Collaboration

May 16, 2009

Status

- Project management structure defined
  - G. Losurdo, project leader (PL)
  - H. Heitmann, technical manager (TM)
  - B. Mours, chair of internal review board
  - Project Supervisor Board
    - » PL, TM + Representatives from institutions and the collaboration
  - Internal reviewing and configuration control processes started
- Construction started
  - Technical design (e.g. cryotraps) & prototyping
  - Robot construction
  - Substrates acquisition
- Next step:
  - Release technical design report
  - Main issue: make a (good) decision on optical configuration

Planning



- Main steps
  - 2009-2013 Construction
  - 2011-2014 Assembly & Integration
  - 2014-2015 Commissioning
  - 2015 First lock
  - 2016 First run
  - The goal is to be there when LIGO starts first extended run

- LIGO plan
  - 2013 Installation completed
  - 2014 ITF acceptance
  - 2015 First short run (50-100 Mpc)
  - 2016-17 First extended run (100-140 Mpc)
  - 2018-19 Run at full sensitivity (140-200 Mpc)

Conclusions

- Advanced Virgo should open the GW astronomy
- Advanced Virgo baseline design and cost presented in 2009
  - Project positively reviewed by the External Review Committee (chair B. Barish)
  - EGO council approved Advanced Virgo in December 2009
    - Management structure defined
- Construction started last year
- Optical configuration being revisited
  - Important decision: one-way
  - Should be done and reviewed before the summer
- Advanced Virgo can arrive in time for the first detection but it needs:
  - Good decision / work
  - Funds
  - Adequate manpower ….
    - Need to pursued the Virgo+ commissioning and data analysis in parallel

Super attenuator control

- Upgrade of top stage control
  - Damping performances limited by ground tilt
  - Move to full 6 DOF control; add tilt control
  - Help control in windy days
- Sensing
  - Tiltmeters needed
  - Requirement: 10^{-8} rad/√Hz @ 30 mHz
- Actuation
  - PZT at the inverted pendulum base
  - Foreseen since the beginning