Detuned arm cavities

„Increasing the peak sensitivity of initial LIGO by detuning the arm cavities"

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Initial LIGO/VIRGO-configuration with resonant and detuned arm cavities

Initial LIGO/Virgo:
Arms resonant for carrier.

⇒ Optimal power buildup

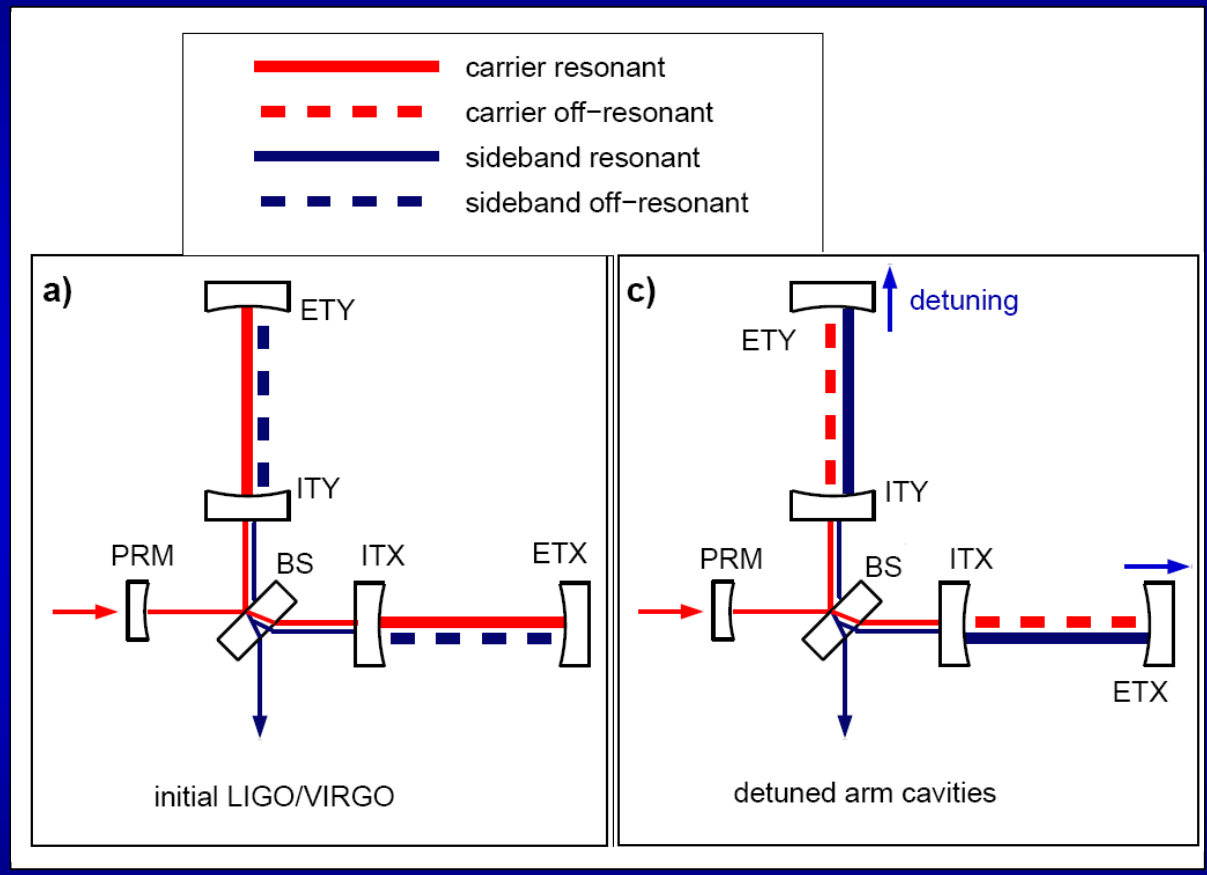
⇒ Not optimal for GW-signal-SB

Detuned arm cavities
Arms resonant for one GW-sideband.

⇒ Less power buildup

⇒ Increased single sided GW-signal-SB

⇒ restore optical power by increased input power or increased PR-gain



Detuned arm cavities in the literature

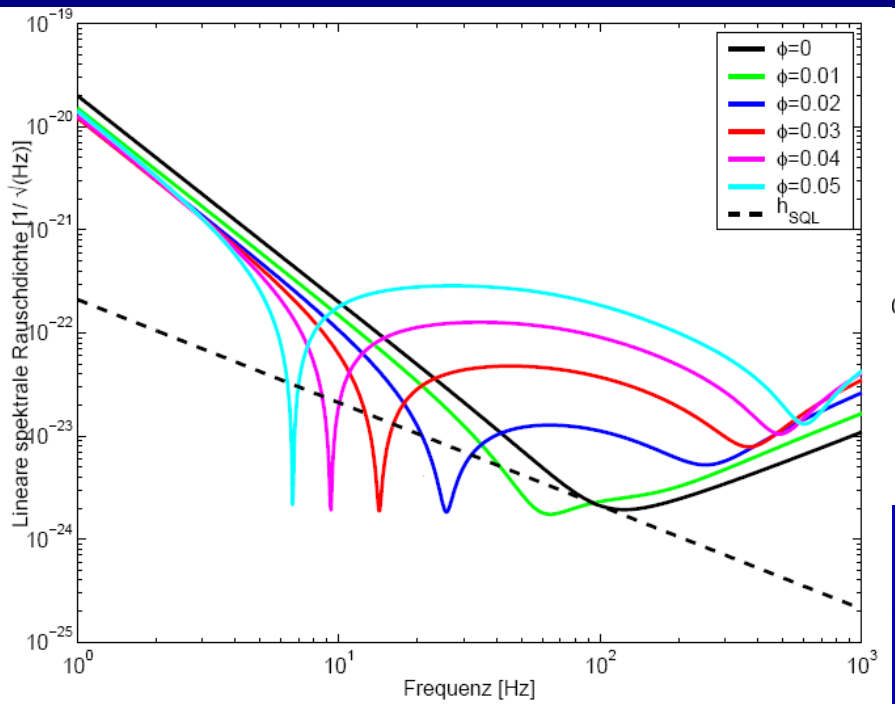


Abbildung 2.10: Lineare spektrale Rauschdichte für Interferometer mit verstimmten Armresonatoren bei unterschiedlicher Wahl der Verstimmung δ

Universität Hannover
Institut für Atom- und Molekülphysik

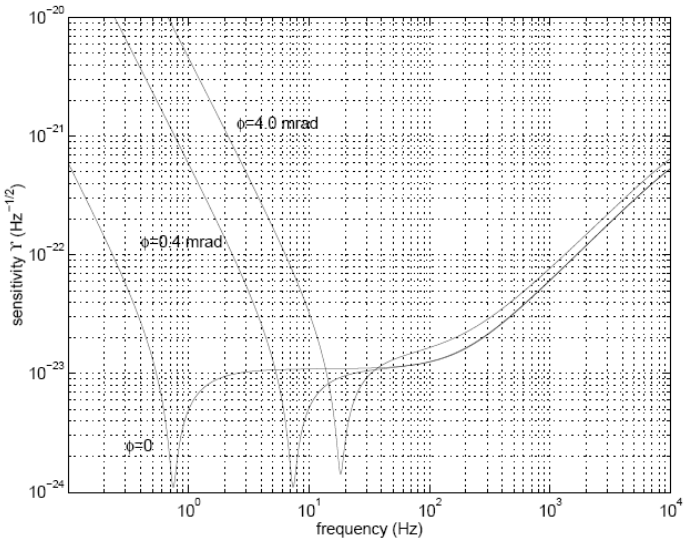
Albert-Einstein Institut
Max-Planck Gesellschaft

Optische Bistabilität und gequetschtes Licht in einem Kerr-Interferometer

Diplomarbeit

von

Henning Rehbein



Dynamics of Laser Interferometric Gravitational Wave Detectors

Thesis by

Malik Rakhmanov

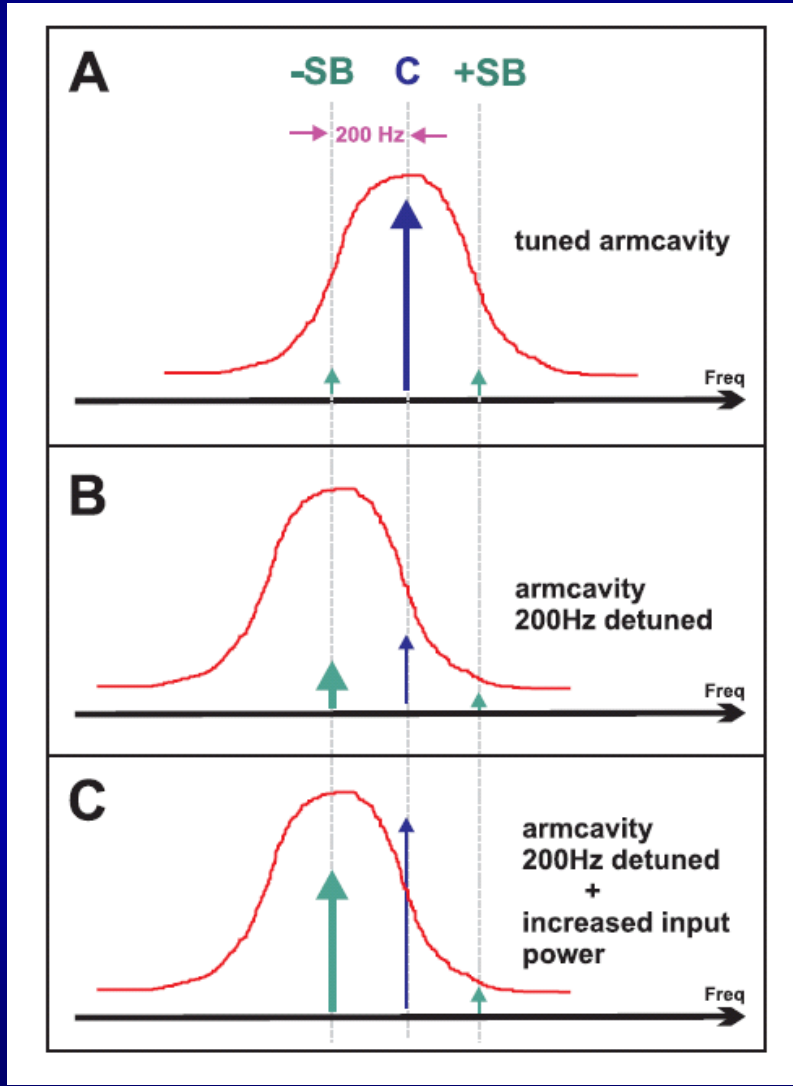
Simple picture

B:
• less carrier light in cavity => less GW sidebands are produced.
• Since one GW sideband is resonant, it gets enhanced.

=> Smaller GW signal

C:
• optical power is restored in the cavity by larger PR-gain.
• Same amount of GW sidebands are produced.
• Since one GW sideband is resonant, it gets enhanced.
Overall we win GW signal.

=> Larger GW signal

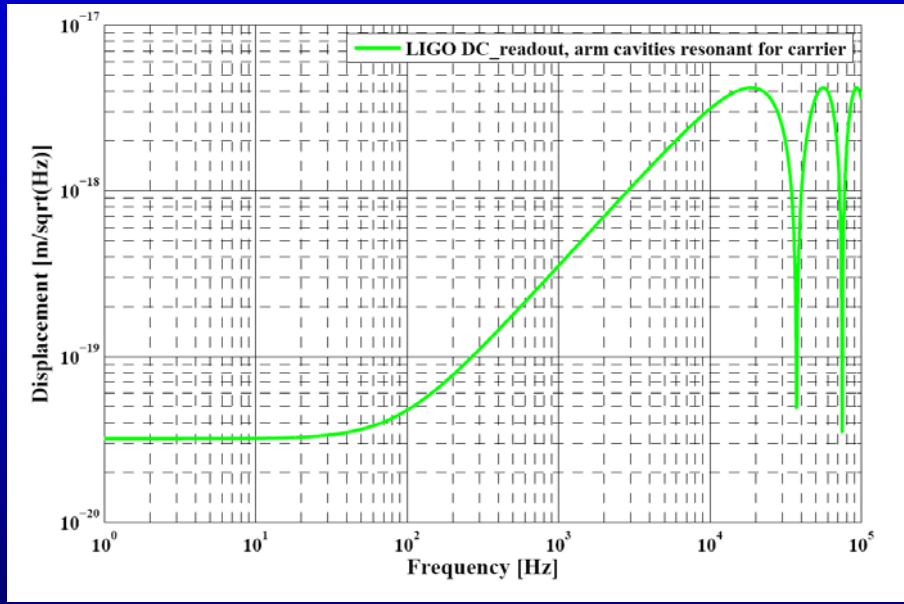


Example: Idealized initial LIGO configuration (without losses)

Building a dummy FINESSE file:

- **4km arm length**
- **Reproducing roughly the same optical powers as in initial LIGO, but with ideal optics**
- **For simplicity using a DC-readout scheme for the simulations**
- **Main difference to real intial LIGO: 90% reflectivity of PRM instead of 97% in real system with losses.**

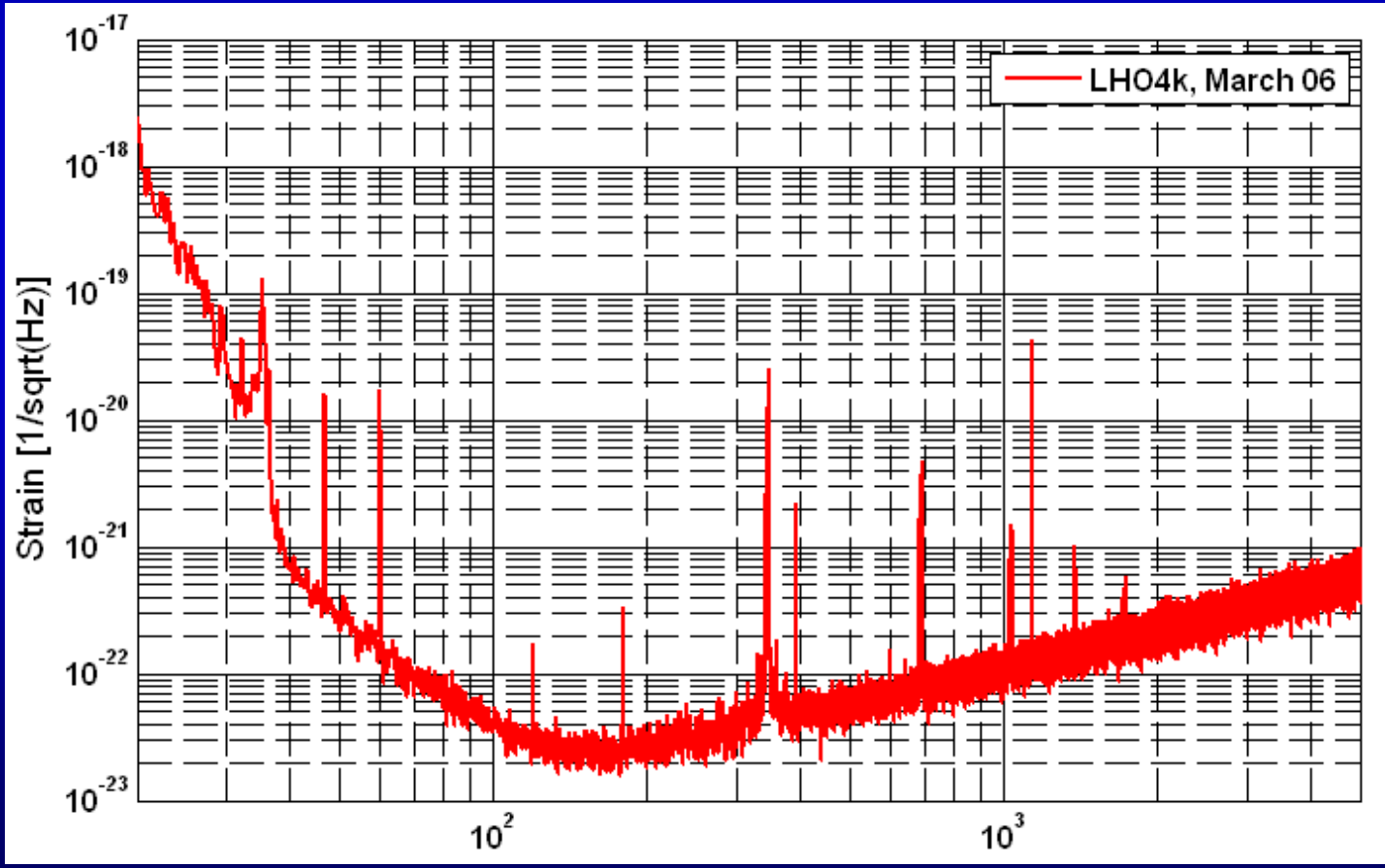
Transmission PRM	10 %
Transmission ITX/ITY	3 %
Transmission ETX/ETY	0 %
Input light power at PRM	4 W
Light power in each arm	10 kW
Dark fringe offset at BS for DC-readout	0.3 deg



Which detuning is reasonable for initial LIGO?

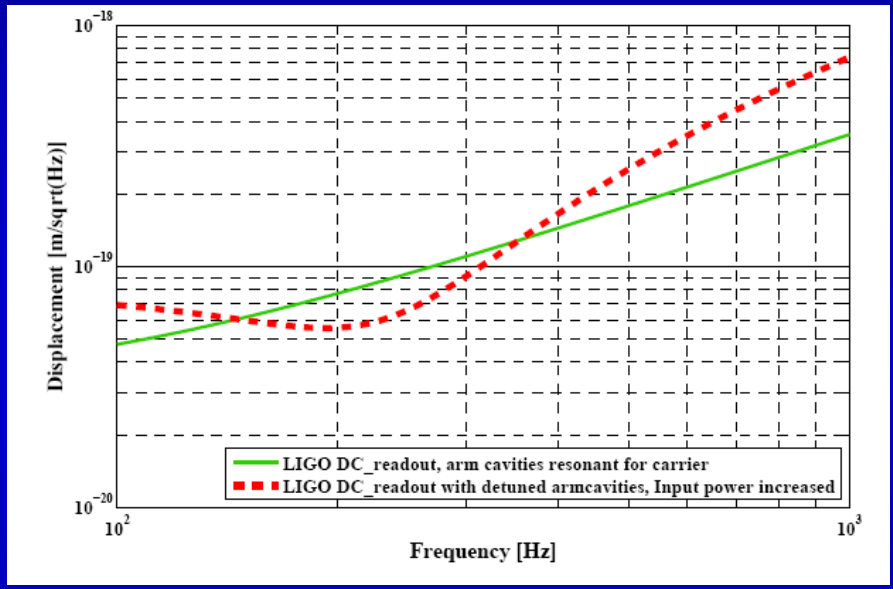
The 3 initial LIGO detectors are currently shot noise limited above 150 Hz

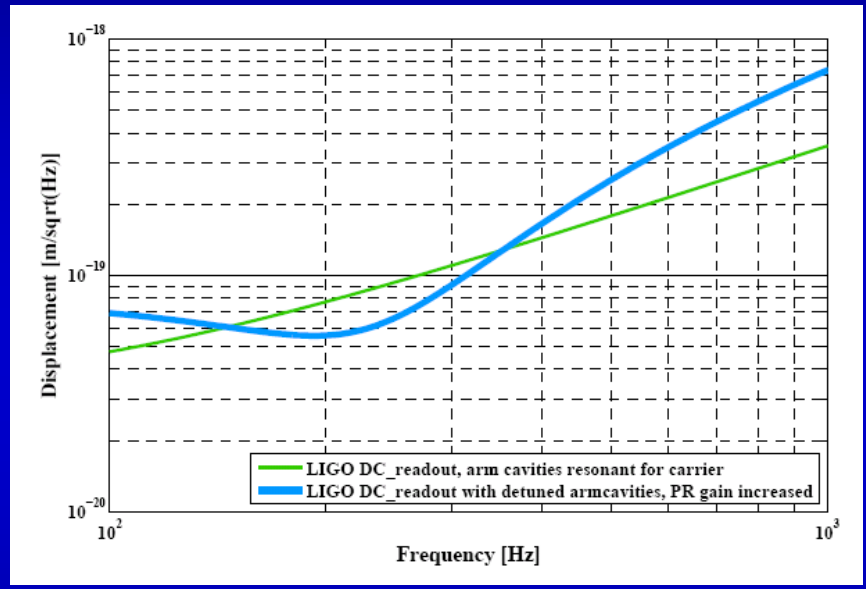
=> An detuning of 200 Hz might give best improvement of peak sensitivity and binary inspiral horizons



Detuned arm cavities in an idealized initial LIGO configuration

A detuning of 200 Hz corresponds to 1 deg.
Such a detuning, decreases the intra cavity power by a factor of 6.



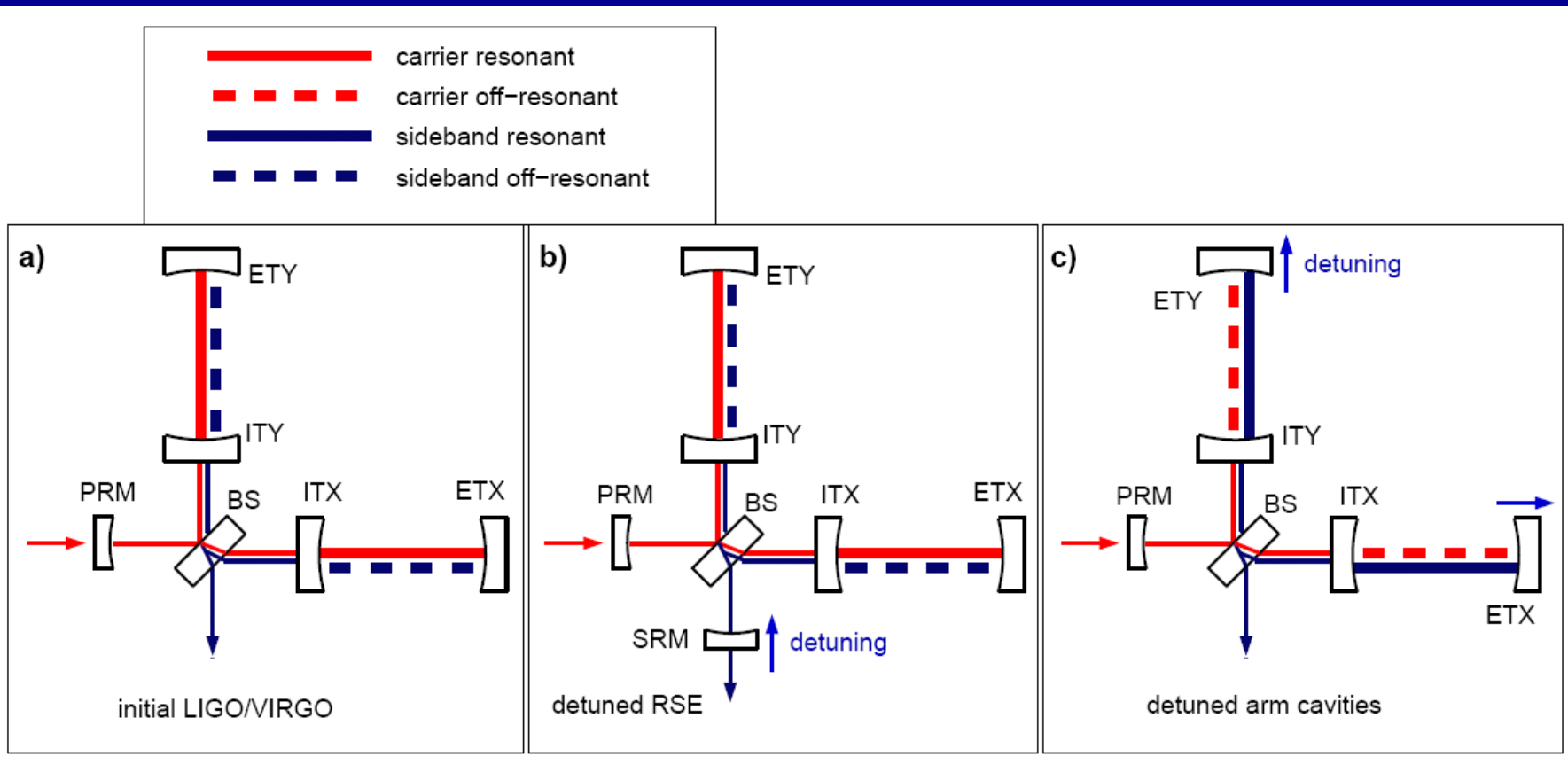


This factor of 6 can be compensated by increasing the input power from 4 to 24 Watts.

Or by increasing the Power-Recycling gain (from 10% Reflectivity of PRM to 1.7%)

Both ways are equivalent !!
The shape of the achieved curve reminds of detuned Signal-Recycling.

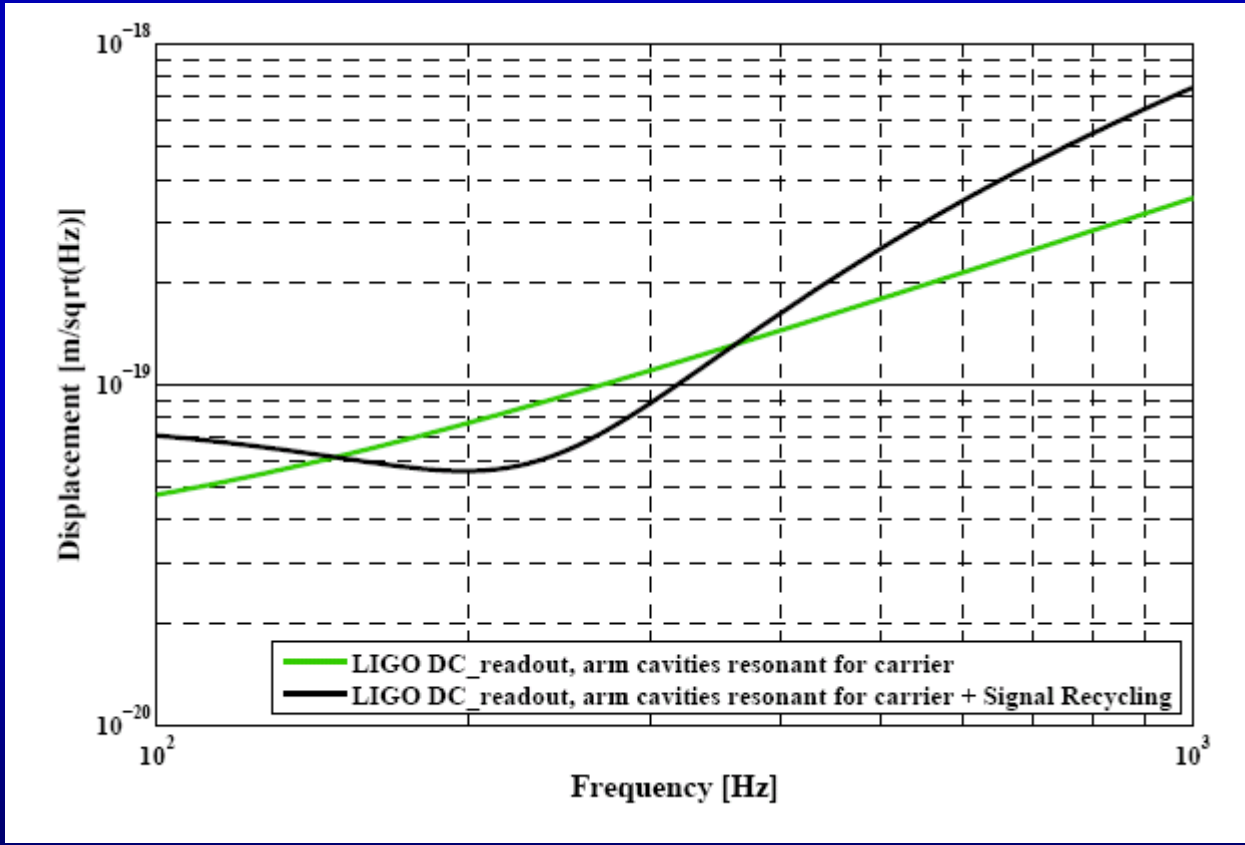
Detuned arm cavities similar to detuned Signal-Recycling ??



Idealized initial LIGO with Signal Recycling (RSE)

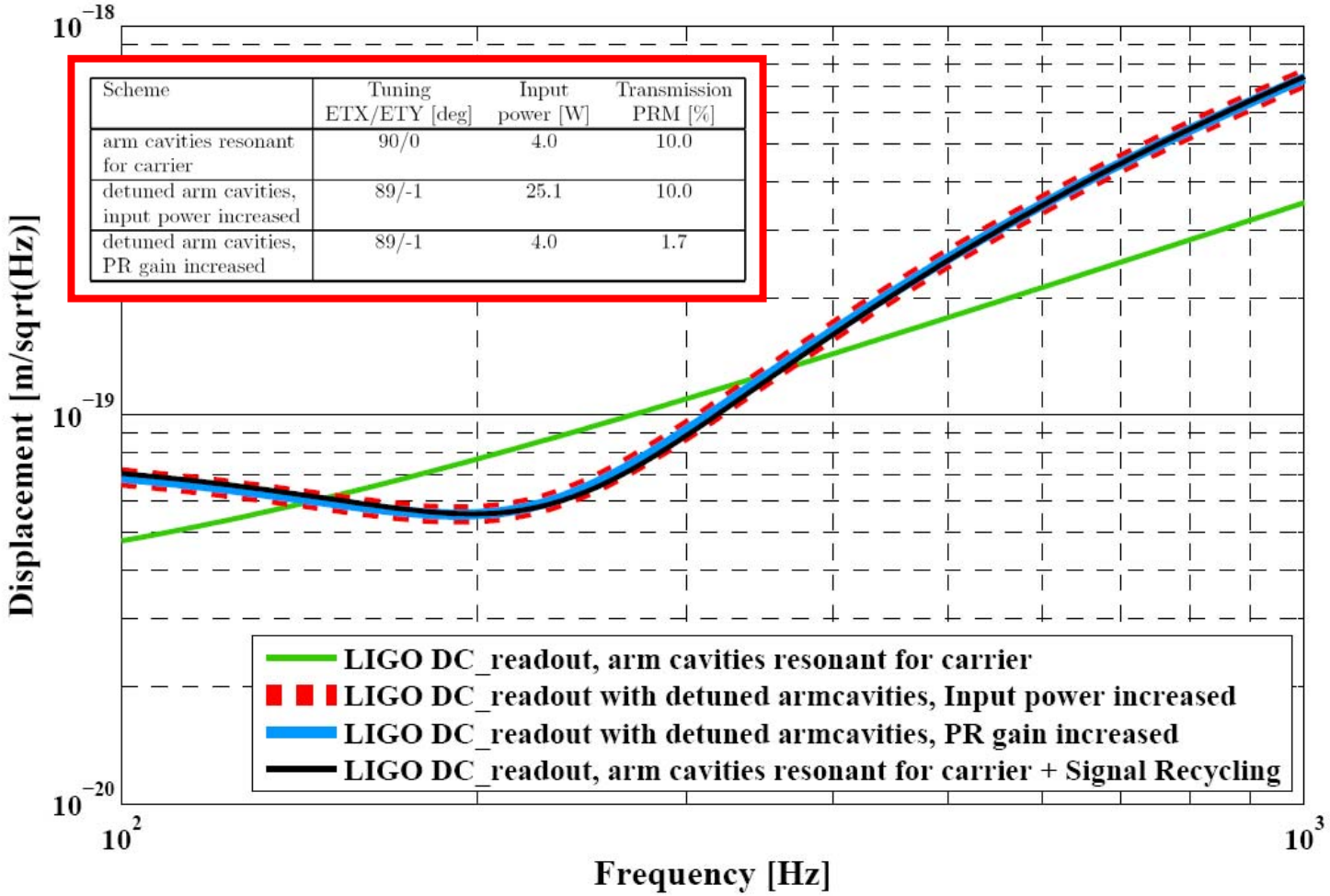
Using:

- **Signal-Recycling mirror of 58% reflectivity.**
- **SR tuning of 70 degrees**



Detuned arm cavities are equivalent to detuned Signal recycling !!

Scheme	Tuning ETX/ETY [deg]	Input power [W]	Transmission PRM [%]
arm cavities resonant for carrier	90/0	4.0	10.0
detuned arm cavities, input power increased	89/-1	25.1	10.0
detuned arm cavities, PR gain increased	89/-1	4.0	1.7



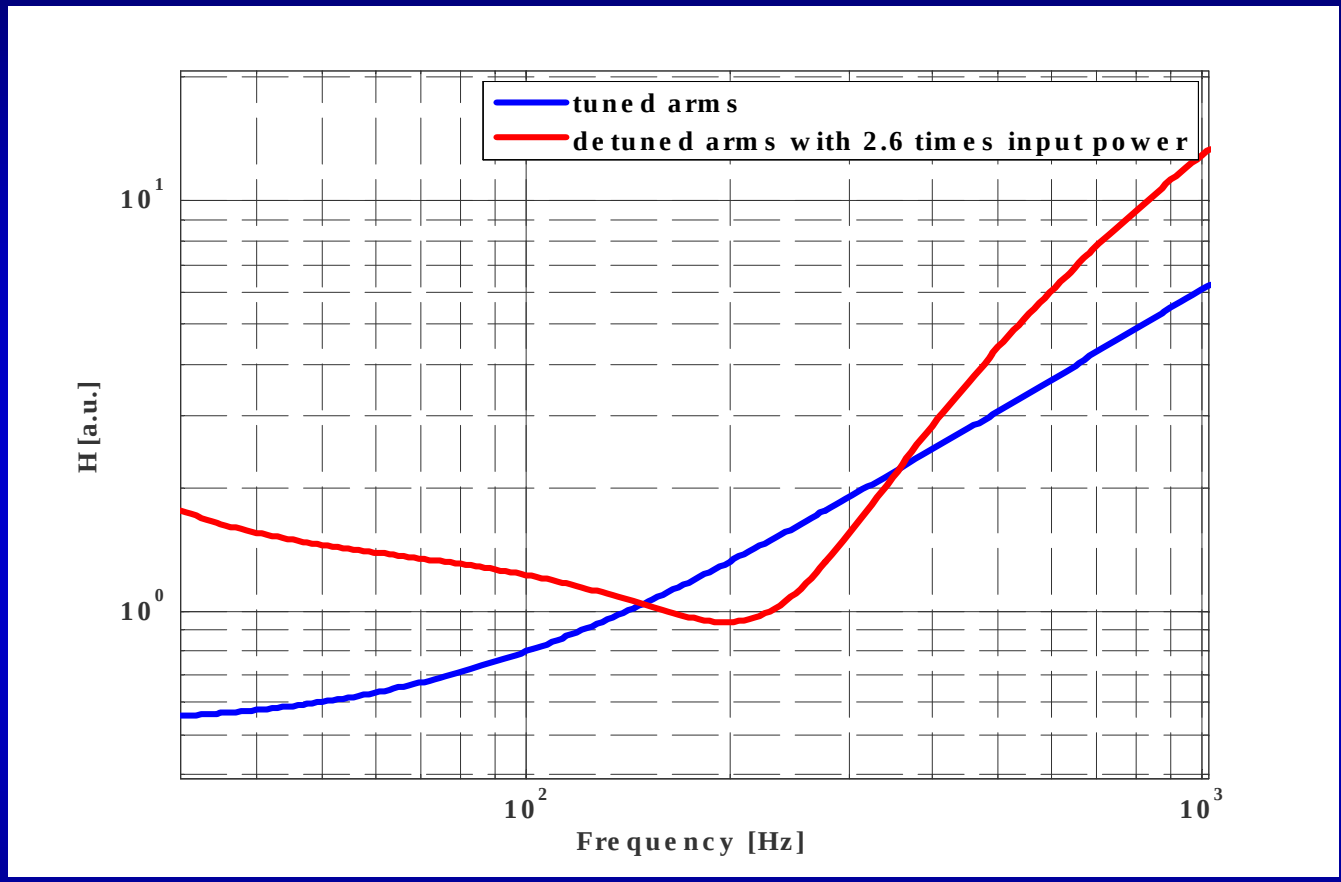
Summary: Principle of detuned arm cavities

- **A common mode detuning of the arm cavities can increase the sensitivity in a certain band, while sacrificing the sensitivity outside this band.**
- **Detuned arms provide us with the possibility to increase the peak sensitivity and to optimize the binary horizon.**
- **Detuned arm cavities are equivalent to Signal-Recycling and give similar flexibility.**

The prize to pay:

- You need to exchange the PRM by one with increased reflectivity (was already demonstrated by GEO and Virgo).
- You have to cope with slightly higher power in the small Michelson. No problem, since the intracavity power is limiting initial LIGO.

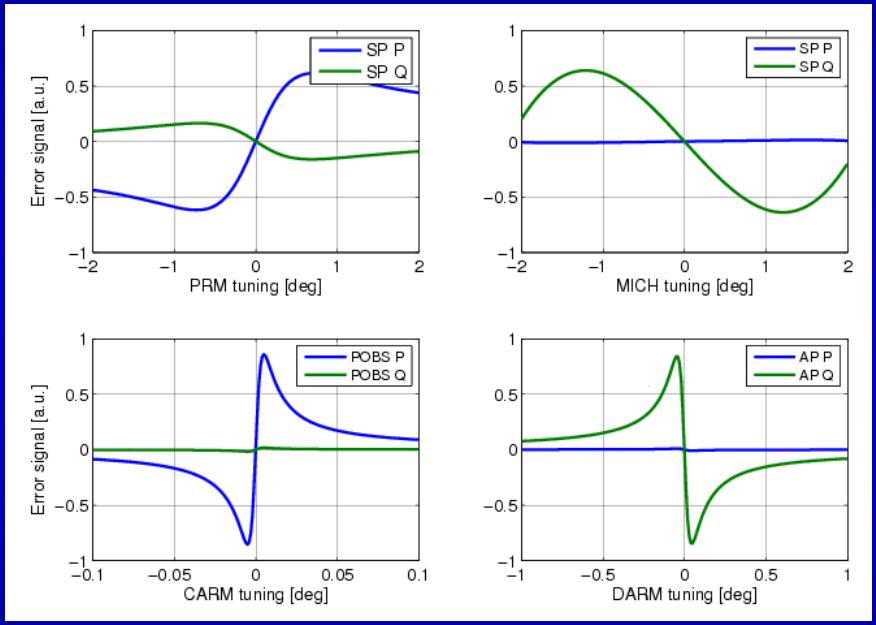
Simulation of initial LIGO with realistic parameters (done with OPTICKLE)



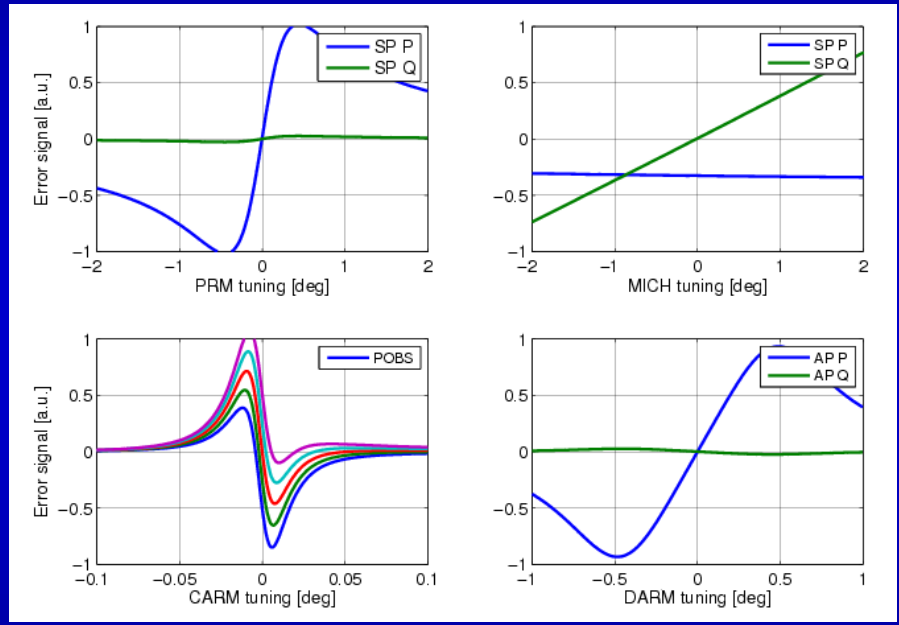
- Increased shot noise limited sensitivity in a band between 150 and 350 Hz.
- A maximum of improvement of 50% is achieved.

Do we get reasonable locking signals for all DFOs with detuned arms?

Initial LIGO with ***resonant*** arms (realistic parameters)



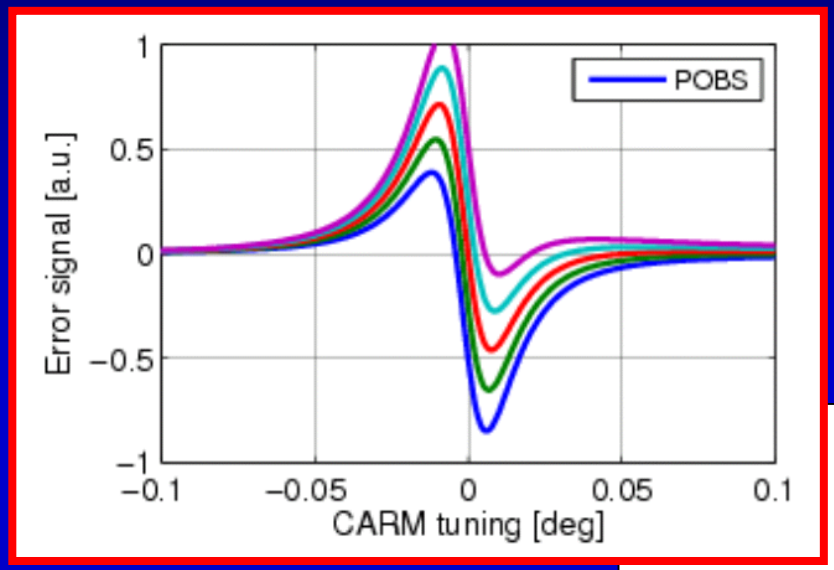
Initial LIGO with ***detuned*** arms (realistic parameters)



- **Using a second modulation frequency (in this case 14.9 MHz) allows to useful locking signals in the detuned arms configuration.**

- The offset in P quadrature of the MICH-loop needs to be treated with care.

Further analogy between detuned arms and Signal-Recycling



The CARM error signal for detuned arm cavities behaves analogues to the Signal-Recycling errorpoint in a RSE configuration !!

Advanced optical techniques for laser-interferometric gravitational-wave detectors

Von dem Fachbereich Physik der
Universität Hannover

zur Erlangung des Grades
Doktor der Naturwissenschaften
Dr. rer. nat.

genehmigte Dissertation von

Dipl.-Phys. Gerhard Heinzel,
geboren am 17.11.1964 in Biberach/Riß.

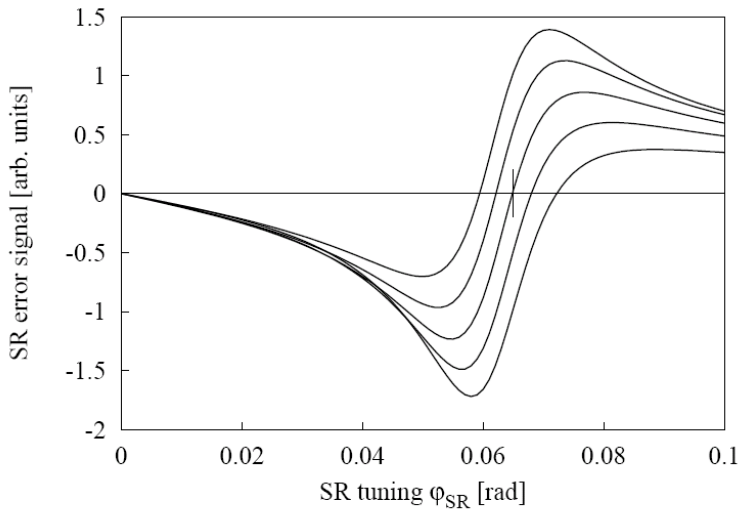


Figure 1.59: SR error signals as a function of the demodulation phase χ_{SR}. The five curves shown were computed with offsets of -0.5, -0.25, 0, $+0.25$ and $+0.5$ rad referred to the demodulation phase χ_{SR} used in Figure 1.57.

Signal-Recycling "light"

Detuned arm cavities with increased Power-Recycling gain are similar to a RSE configuration, but might come on much less cost !!

	Resonant arms with RSE	Detuned arm cavities
Hardware	Setup a new suspension with all necessary local and global actuators	Exchange PRM by one with higher Reflectivity
Longitudinal locking	Completely new locking scheme (several modulations, etc)	Introduce a second modulation frequency
Alignment control	Implement alignment for SRM	No new component needs be be controlled

E n d