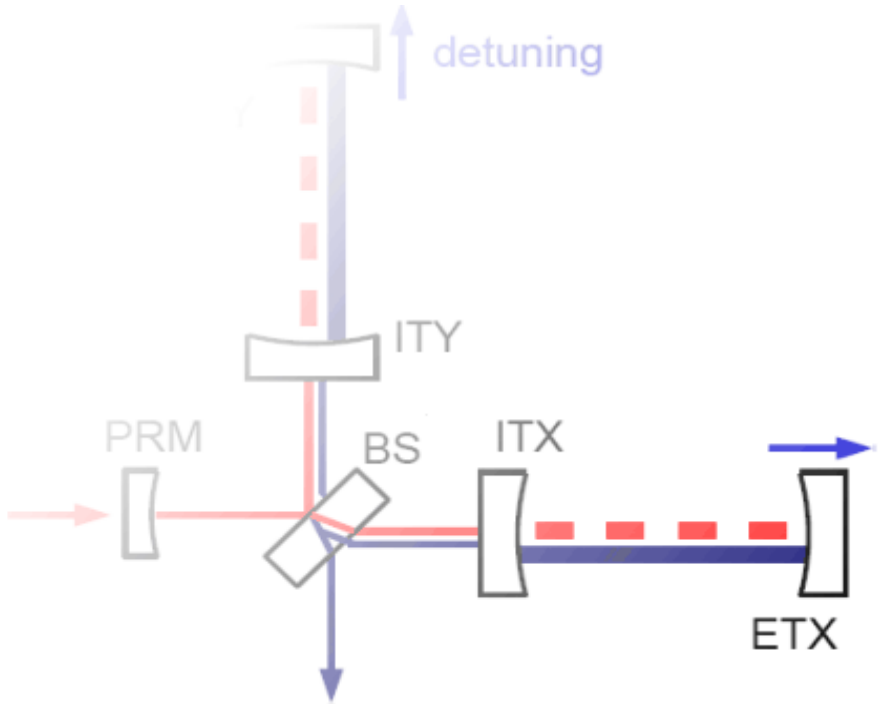
UNIVERSITY OF BIRMINGHAM

Interferometers with detuned arm cavaties

Stefan Hild

October 2007

LSC-Virgo meeting Hannover



LIGO-G070729-00-Z

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

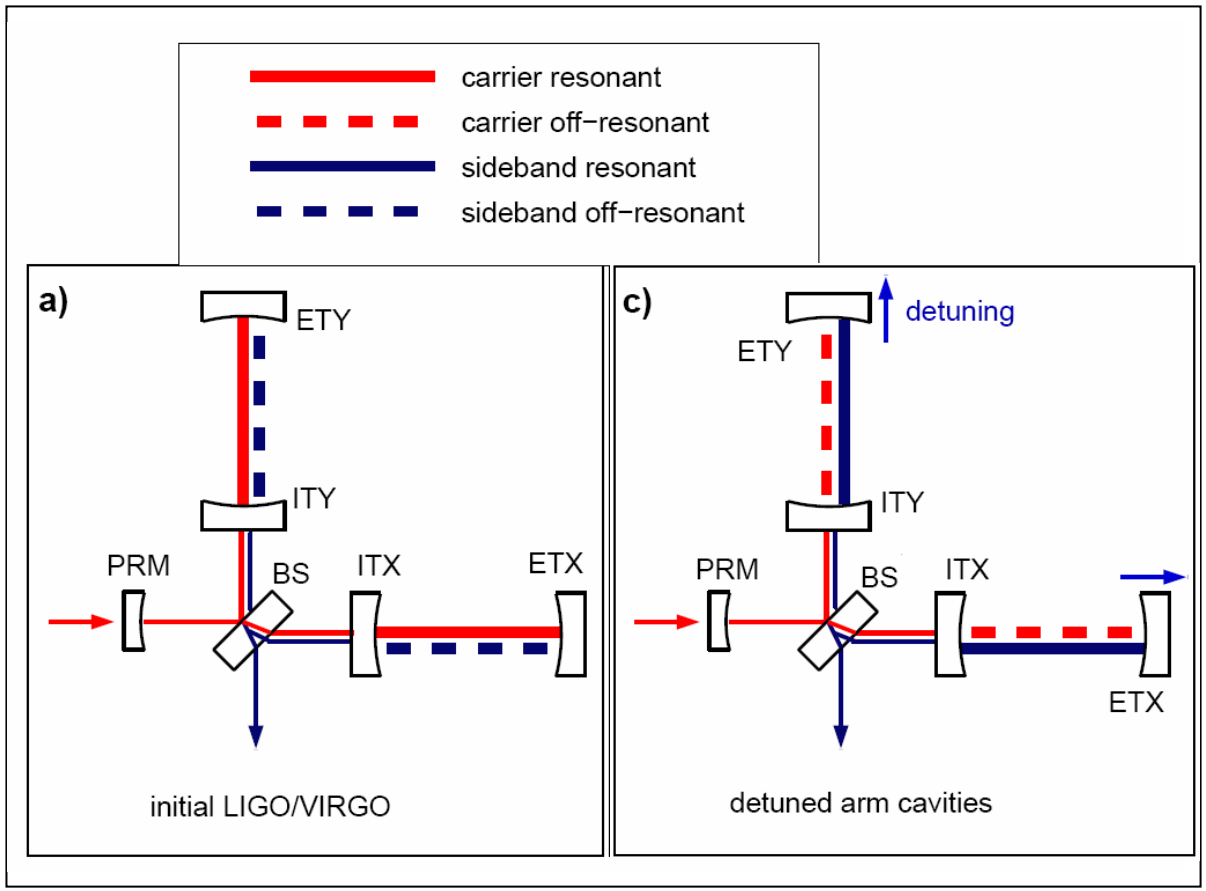
Initial LIGO/Tama/Virgo:

- 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

H. Rehbein

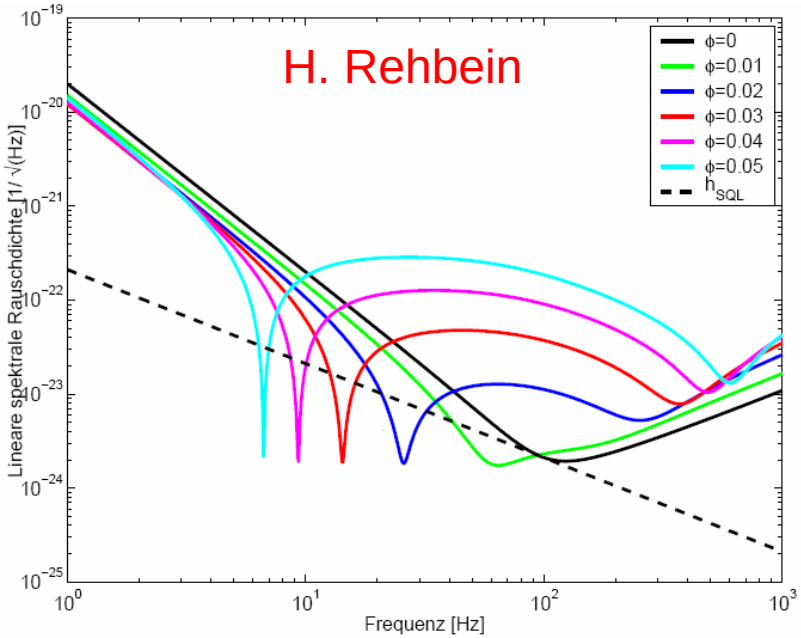


Abbildung 2.10: Lineare spektrale Rauschdichte für Interferometer mit verstimmten Armresonatoren bei unterschiedlicher Wahl der Verstimmung δ

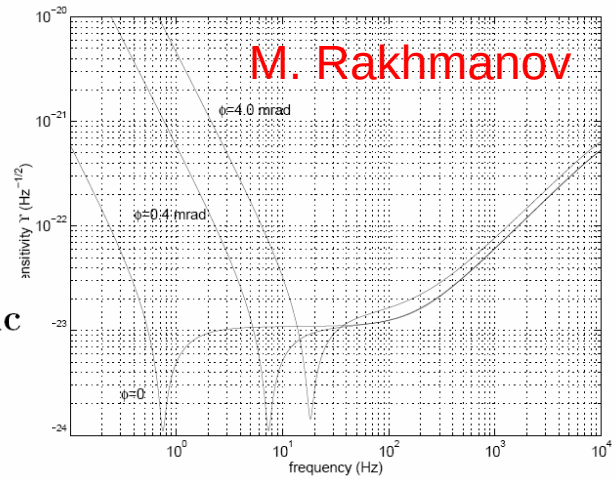
Universität Hannover
Institut für Atom- und Molekülphysik

Albert-Einstein Institut
Max-Planck Gesellschaft

Optische Bistabilität und gequetschtes Licht in einem Kerr-Interferometer

Diplomarbeit
von
Henning Rehbein

M. Rakhmanov



Dynamics of Laser Interferometric Gravitational Wave Detectors

Thesis by
Malik Rakhmanov

Simple picture

B:

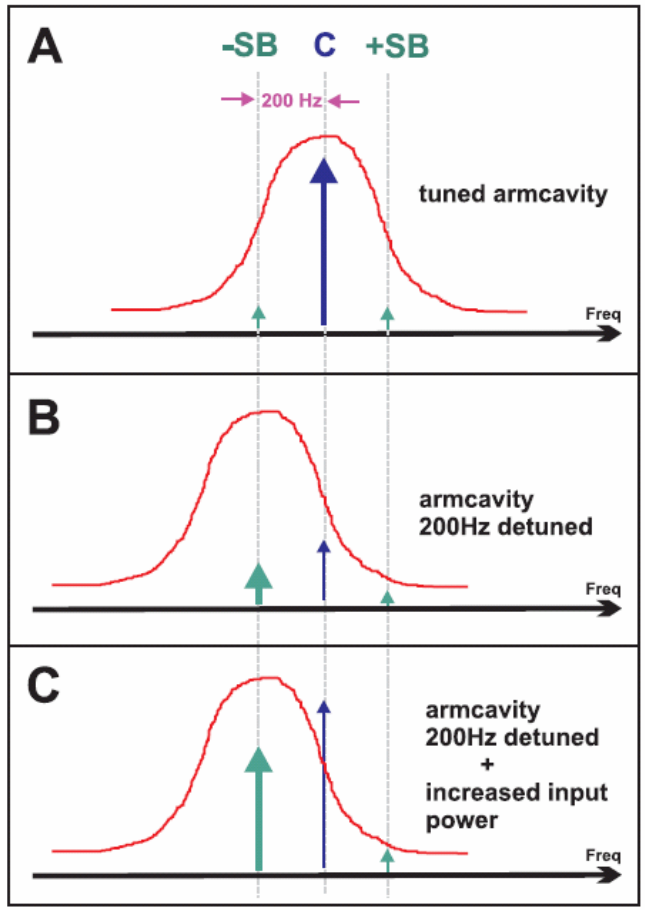
- less carrier light in cavity => less GW sidebands are produced.
- Since one GW sideband is resonant, it gets enhanced.

=> 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

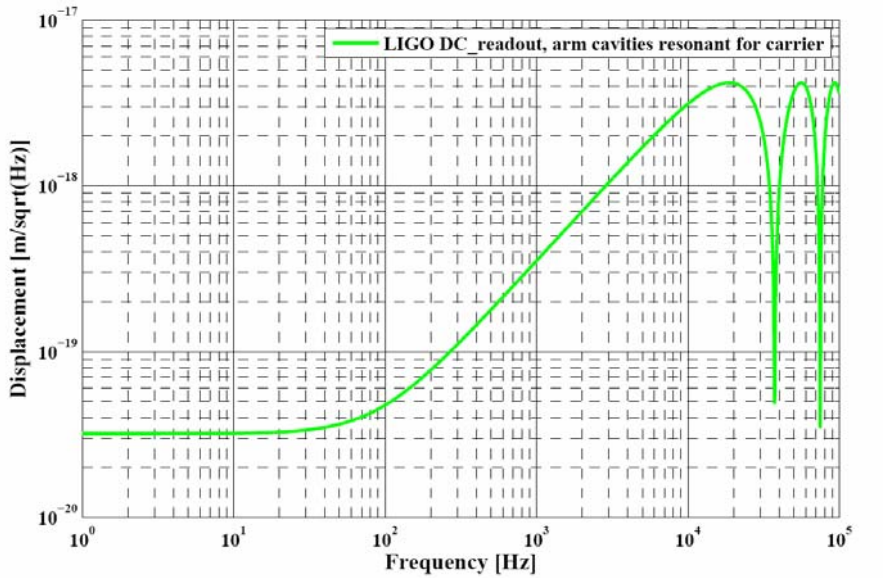


Example: Idealized initial LIGO configuration (without losses)

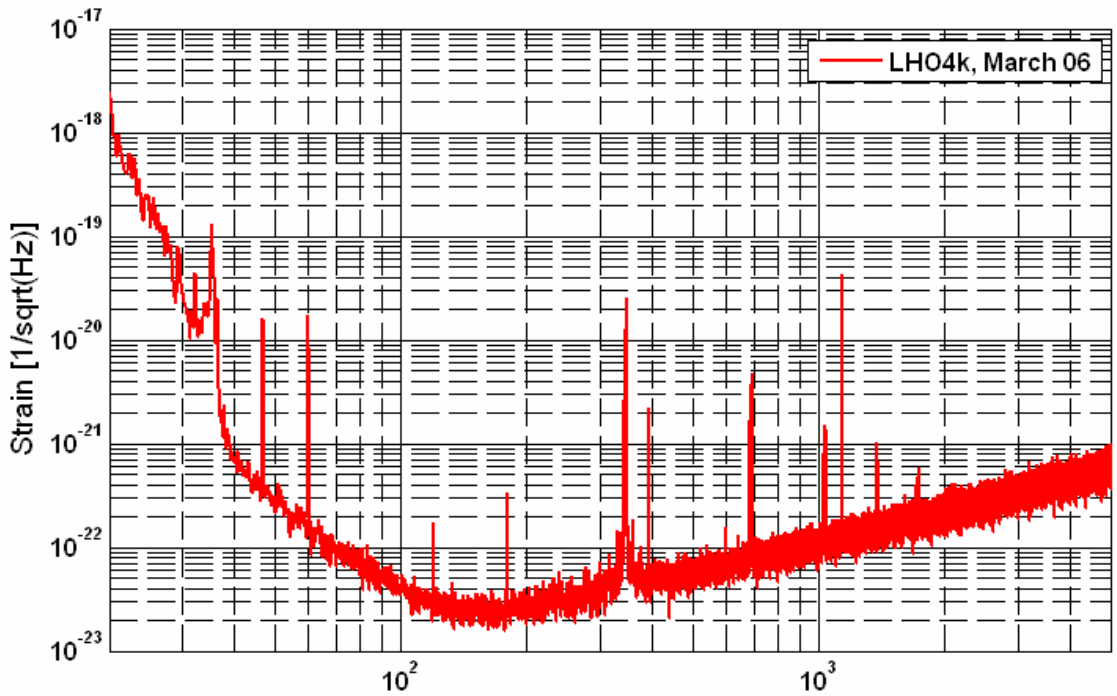
Building a dummy FINESSE file:

- 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 would be reasonable for initial LIGO?



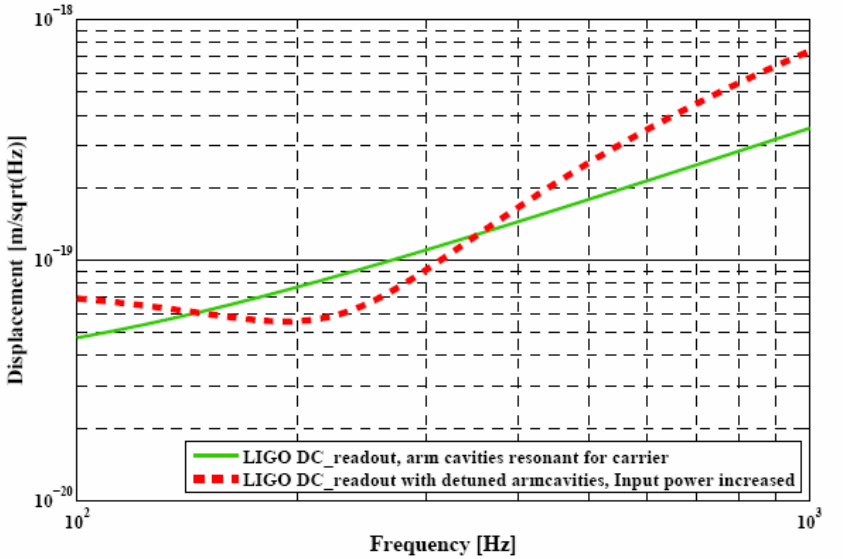
The 3 initial LIGO detectors are currently shot noise limited above 150 Hz

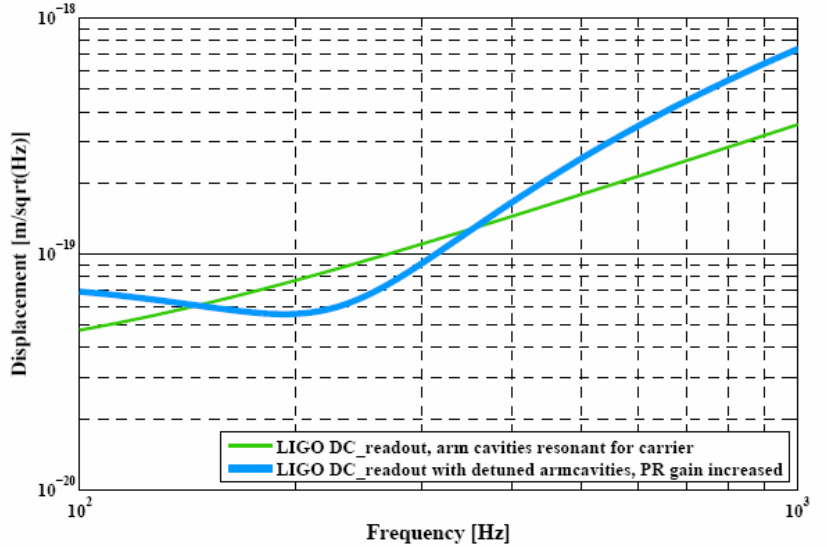
=> A detuning of 200 Hz might give best improvement of peak sensitivity and binary inspiral horizons

UNIVERSITY OF BIRMINGHAM

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.





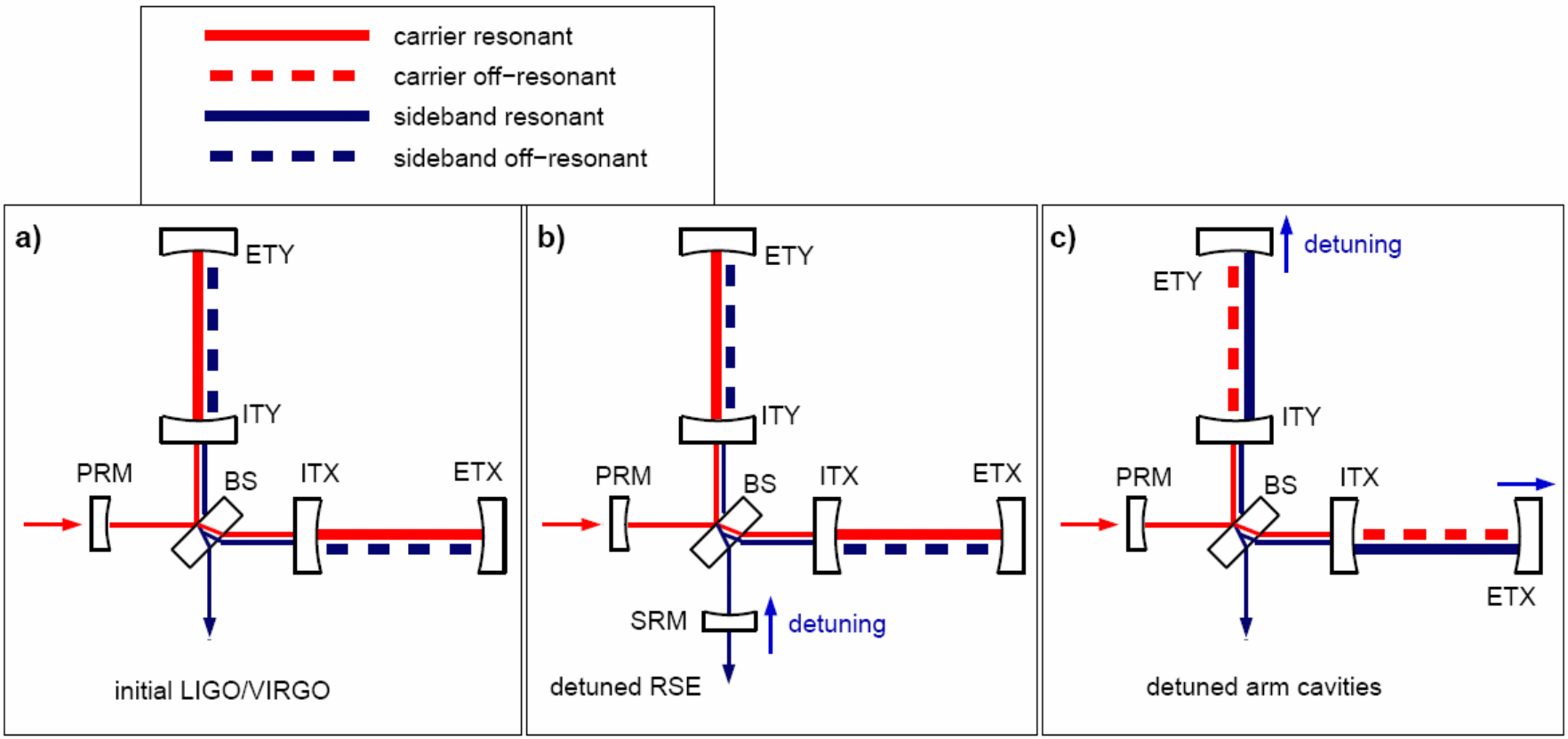
This factor of 6 can be compensated by increasing the input power from 4 to 24 Watts.

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.

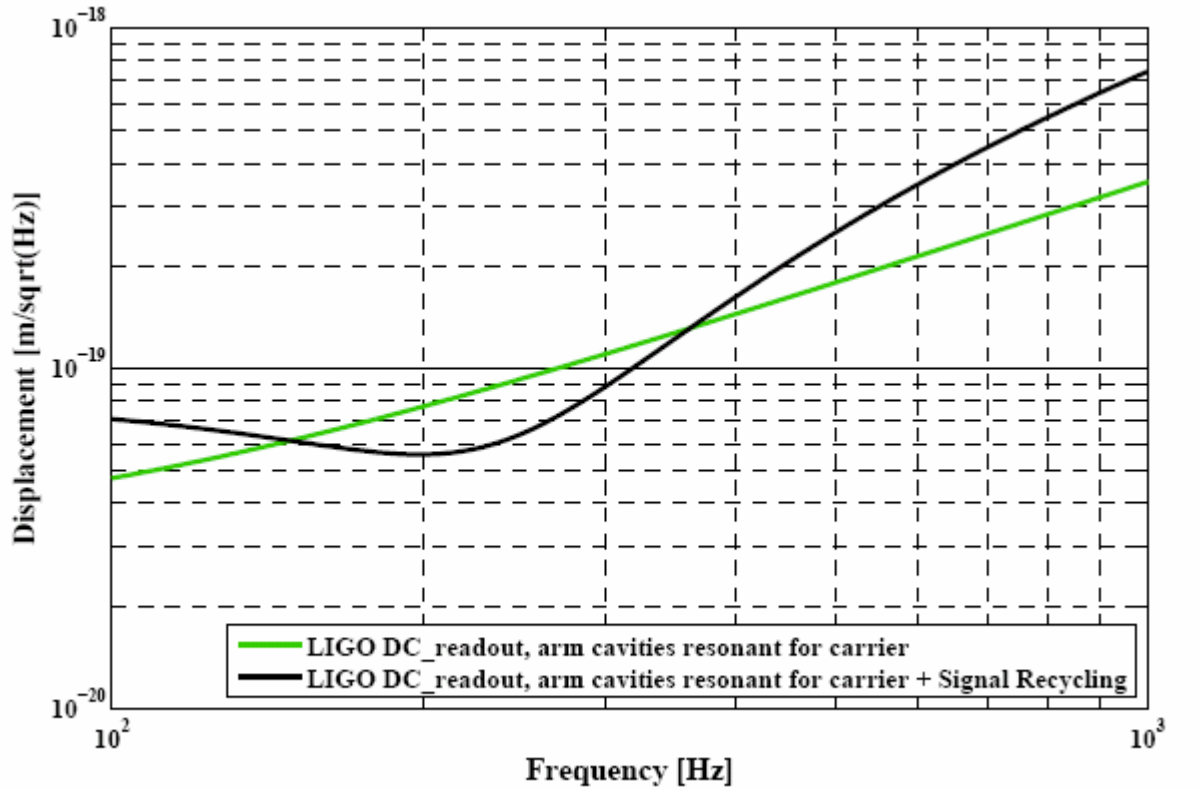
Detuned arm cavities similar to detuned Signal-Recycling ?



Idealized initial LIGO with Signal Recycling (RSE)

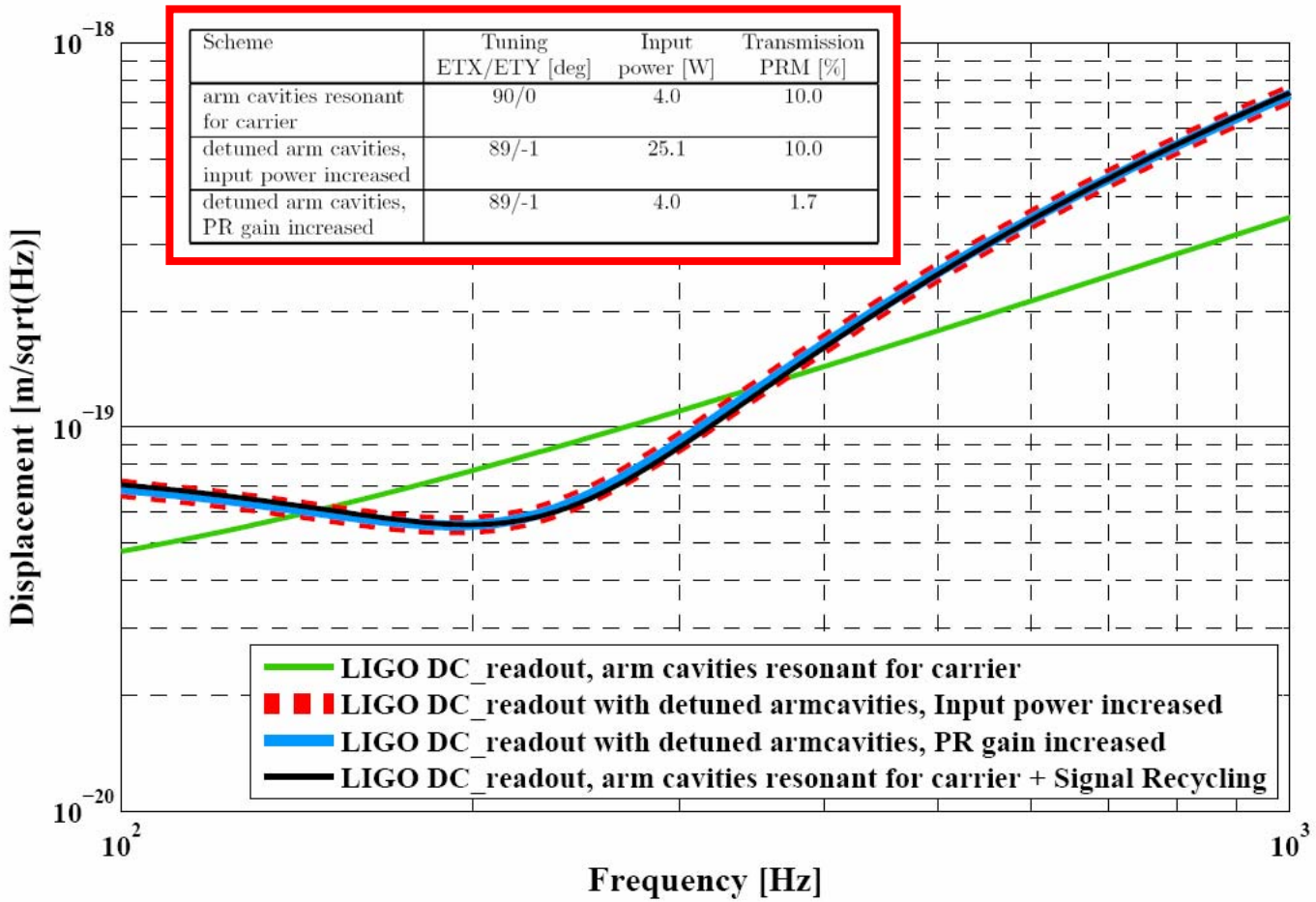
Using:

- **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.**

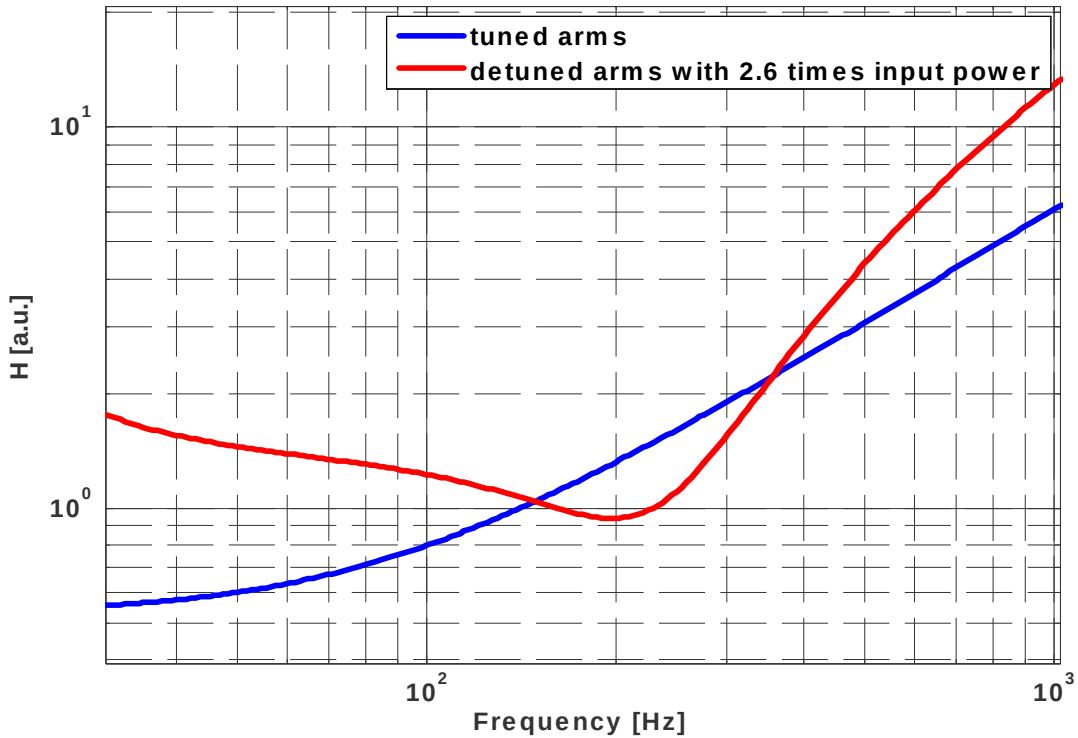
The prize to pay:

- 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.
- You have to modify the length control systems of the interferometer.

Jumping to the real world…

… real parameters, losses, imperfect optics …

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

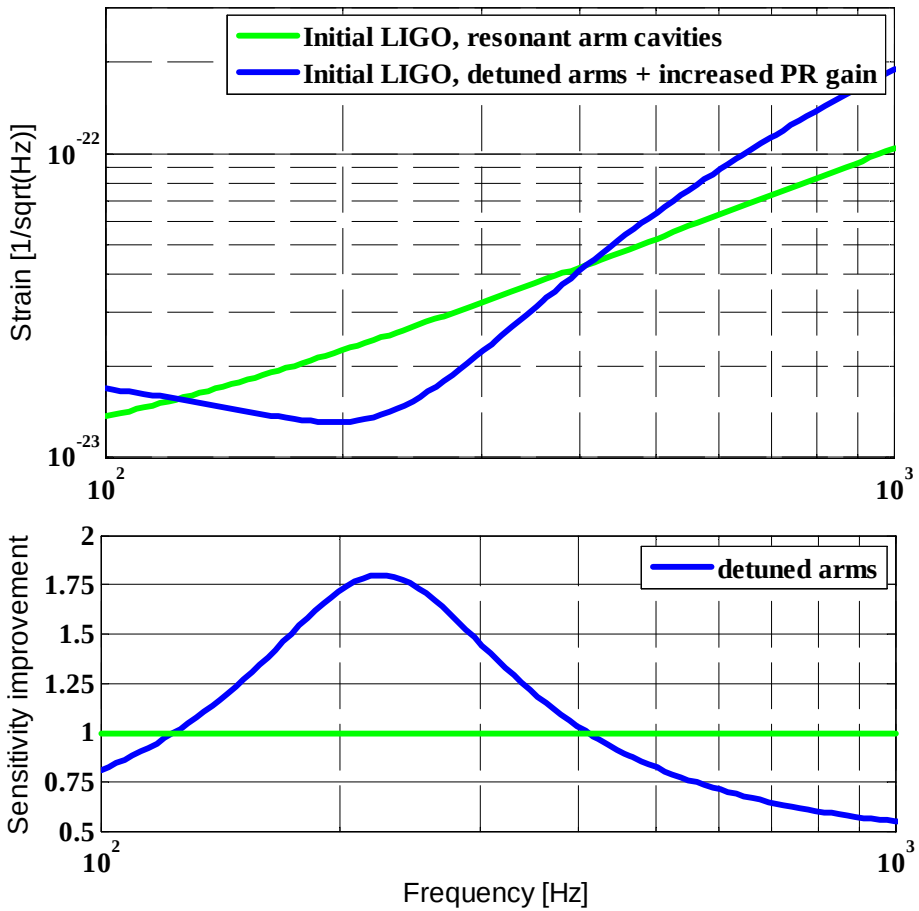


- Increased shot noise limited sensitivity in a band between 150 and 350 Hz.
- A maximum of improvement of 50% is achieved.

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

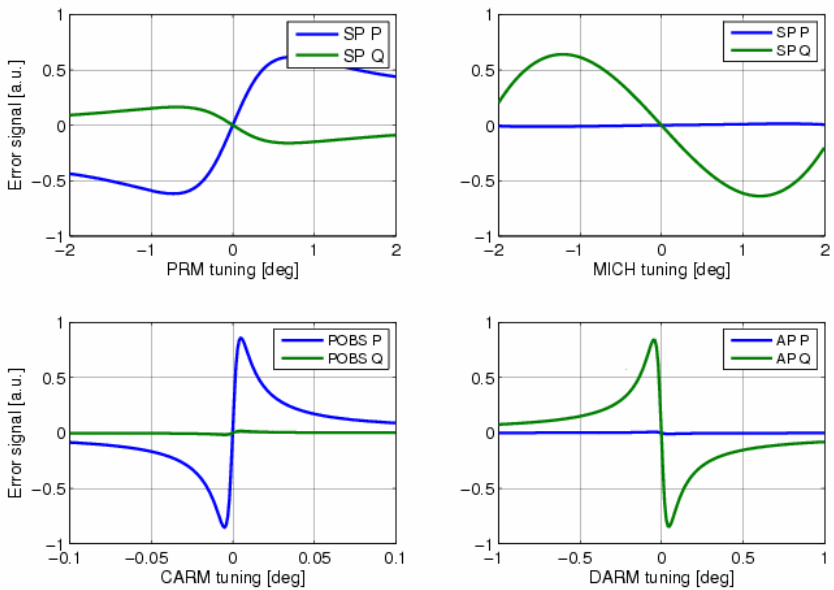
- Increased shot noise limited sensitivity in a band between 150 and 400 Hz.
- A maximum of improvement of 75% is achieved.

FINESSE and OPTICKLE in good agreement !!

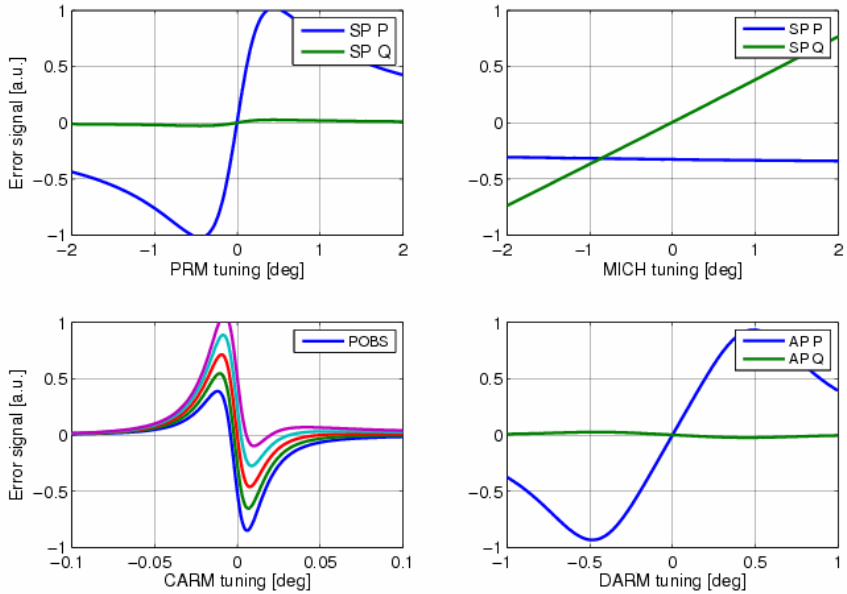


UNIVERSITY OF BIRMINGHAM

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



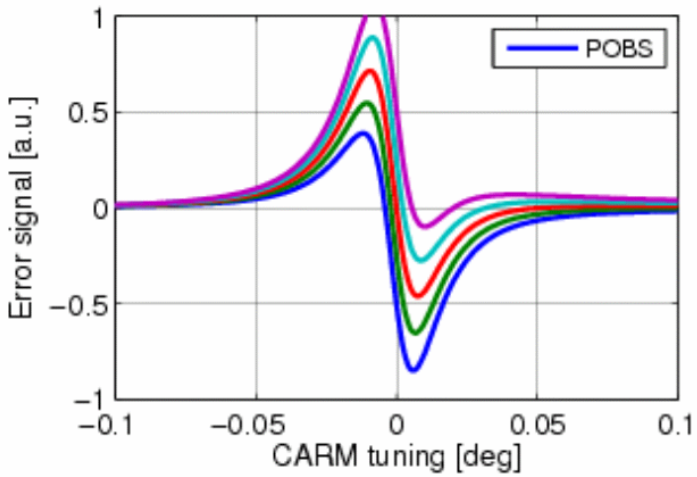
Initial LIGO with ***resonant*** arms (realistic parameters)



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

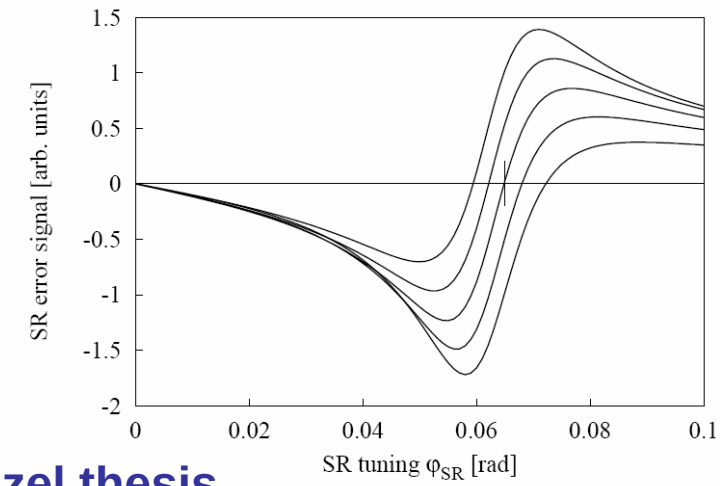
- **Using a second modulation frequency (in this case 14.9 MHz) allows to useful locking signals in the detuned arms configuration.**
- The offset in P quadrature of the MICH-loop needs to be treated with care.

Further analogy between detuned arms and Signal-Recycling



Detuned arm cavities

RSE configuration



G. Heinzel thesis

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.

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

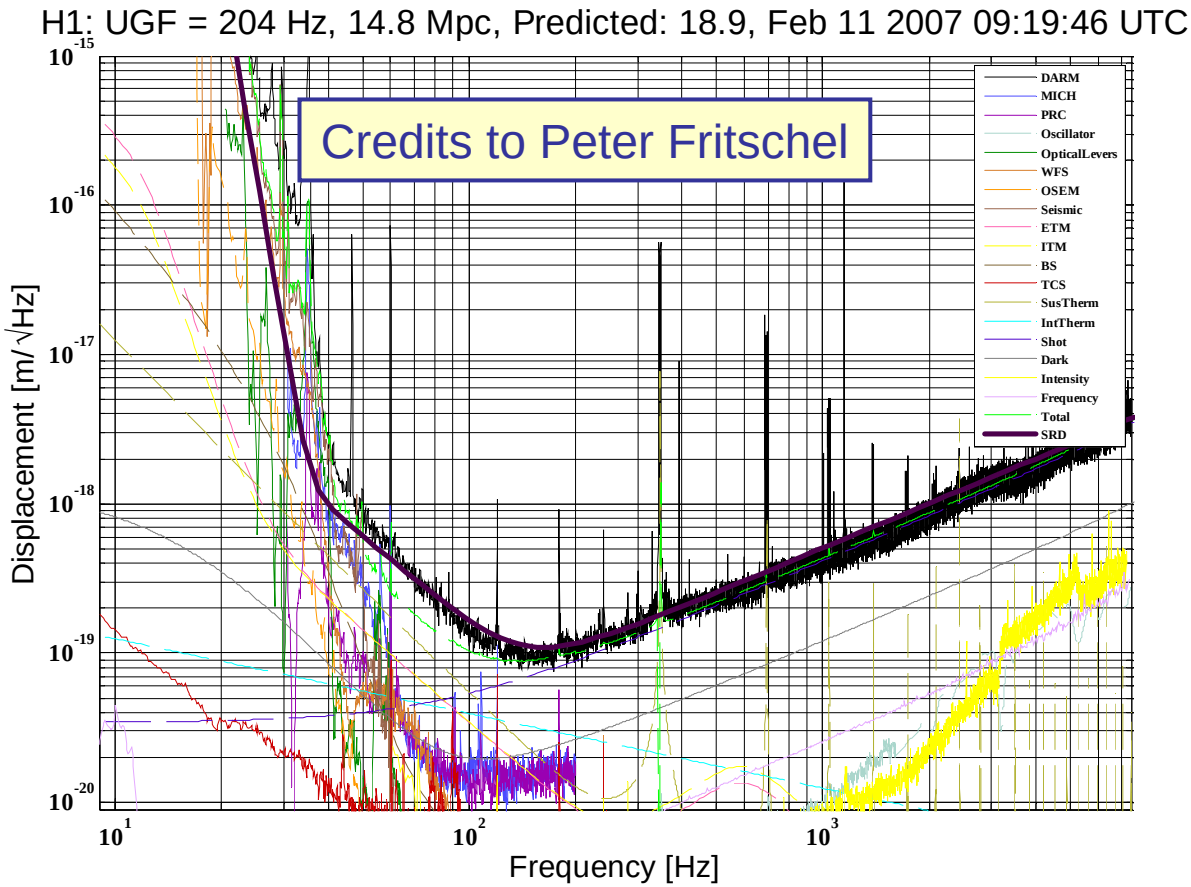
UNIVERSITY OF BIRMINGHAM

What can be gained in the full noise budget of initial LIGO??

For correct evaluation not only the shot noise, but the full noise budget has to be taken into account.

Steps to do:

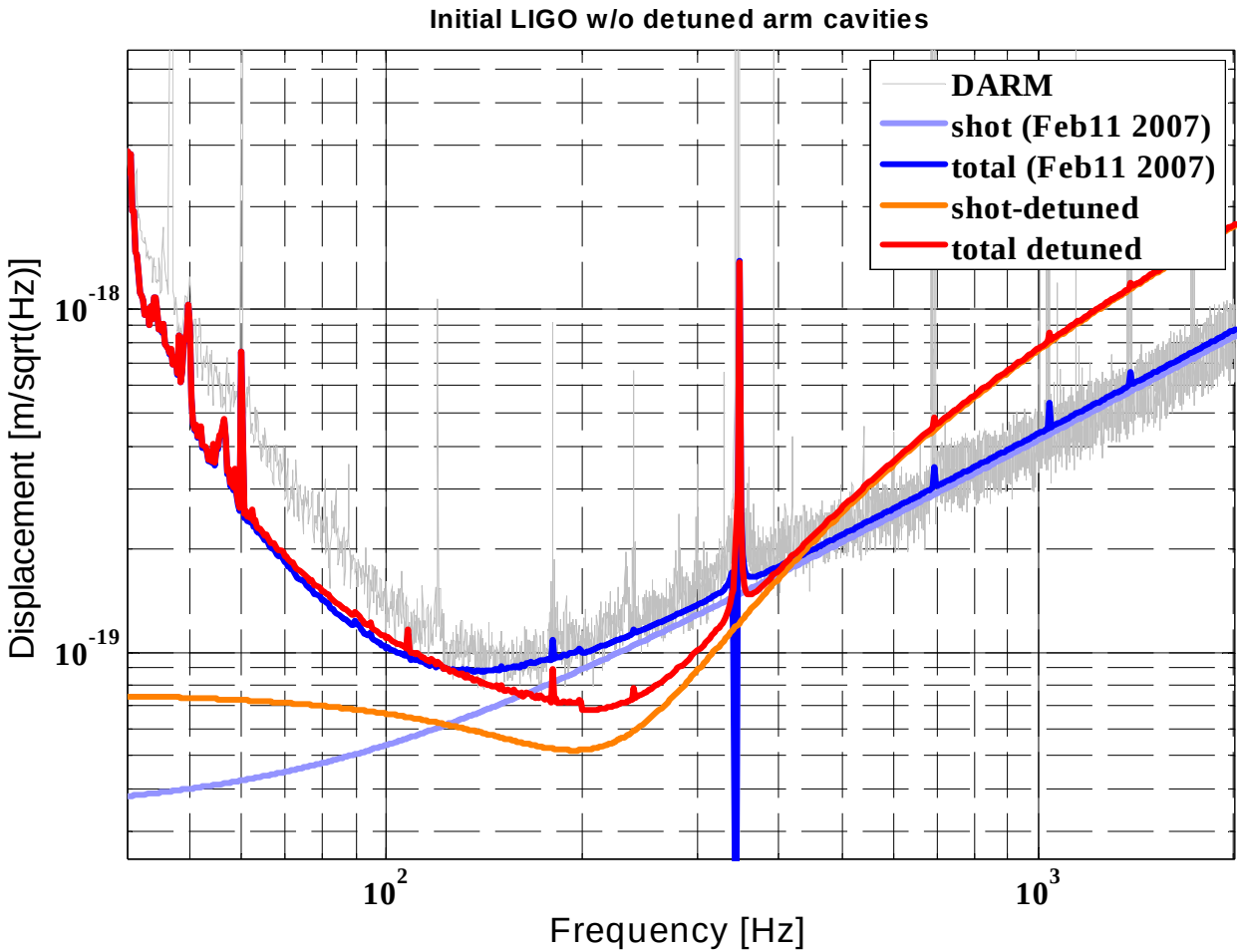
1) Exchanged the shot noise contribution.
2) Recalculating the uncorrleated sum of all noise contributions



What can be gained in the full noise budget of initial LIGO??

Blueish curves
= resonant arms

Reddish curves
= detuned arms



Comparison of RSE and detuned arm cavities

	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 + modified locking scheme)
Alignment control	Implement alignment for SRM	No new component needs be be controlled

Detuned arm cavities might be a beneficial alternative to RSE, due the potentially less hardware intensive implementation.

Summary

- Detuning the arm cavities can give better peak sensitivity (with same optical power inside the arm cavaities).
- Detuned arms are similar to a RSE configuration with resonant arms.
- Simulations (Finesse & Optickle) for intial LIGO with real parameters show improvement in shot noise limited sensitivity (between 150 and 400 Hz)
- Reasonable locking signals for all DOF can be generated using a second modulation frequency.
- Detuned arm cavities might also be benificial for enhanced LIGO and Virgo+ (simulations are on the way...)

Paper accepted by CQG: Stefan Hild and Andreas Freise
'A novel concept for increasing the peak sensitivity of LIGO by detuning the arm cavities'
http://arxiv.org/abs/0709.1488