Detuning the signal recycling cavity in Advanced Virgo +

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Context : Marginally stable Signal Recycling cavity in AdV+

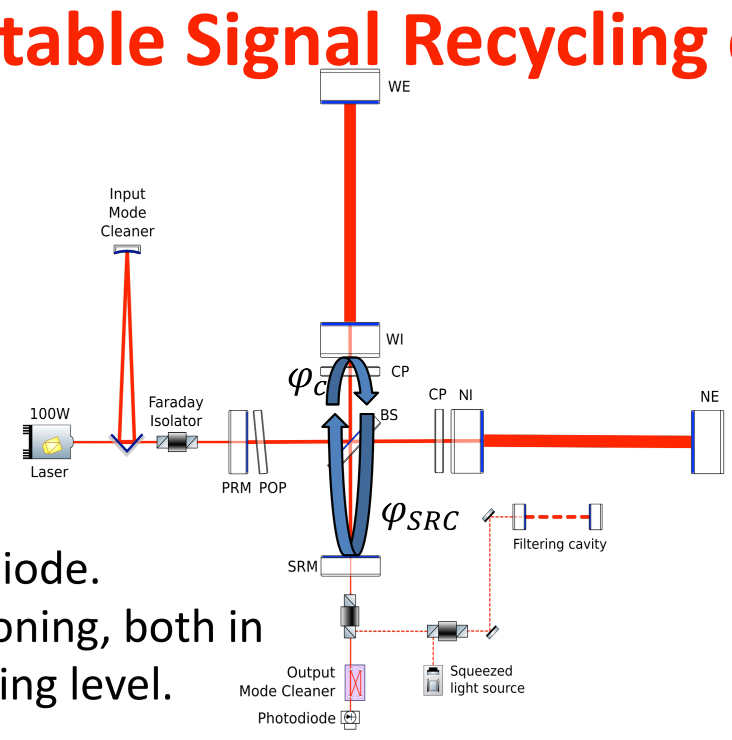
- Advanced Virgo Plus (AdV+) is a Dual Recycled, Fabry Perot Michelson interferometer which operates in the so-called **Resonant Sideband Extraction (RSE) configuration** for broadband GW detection.
- The Signal Recycling Cavity (SRC) is **marginally stable**: the carrier field is anti-resonant inside of the SRC while the Higher-Order Modes (HOMs) are transmitted out of the SRC ($\varphi_{SRC} \sim \varphi_c^{HOM} \sim \pi\ [2\pi]$) :

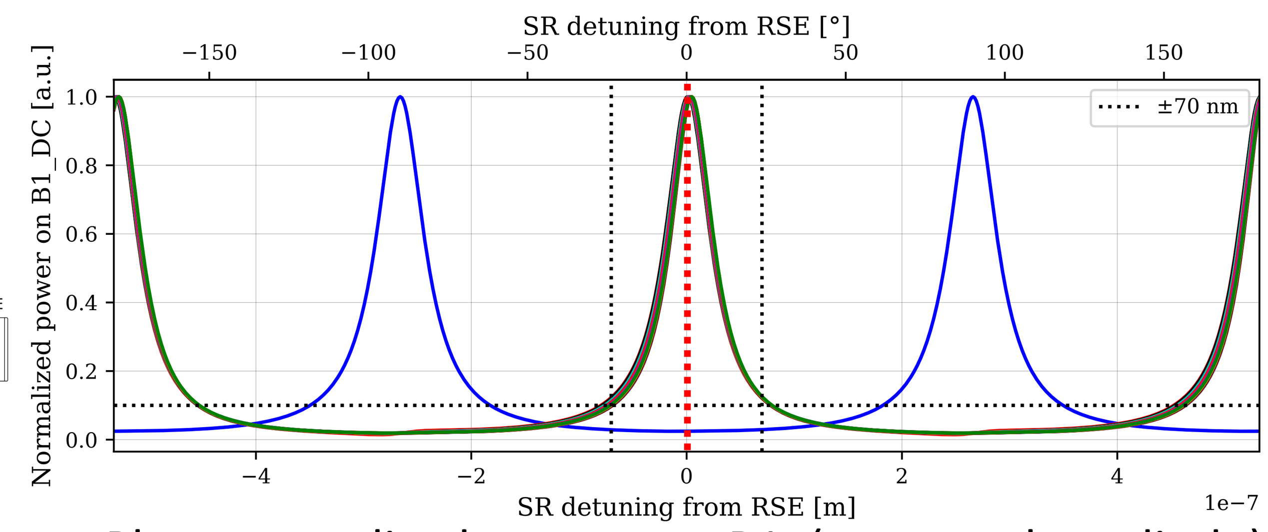
$$\varphi_{SRC} + \varphi_c^{HOM} = 2n_{HOM}\,\pi$$

➢ Any spurious HOM generated inside the ITF leaks to the detection photodiode.

➢ HOMs contributions are hard to estimate and cause trouble for commissioning, both in DC (contrast defect) and AC (optical spring). They could also degrade squeezing level.

➢ **In this poster, we explore the opportunities and the difficulties of the Detuned Resonant Sideband Extraction configuration as a possible solution to current commissioning challenges.**





Plot: normalized power at B1 (output photodiode) when scanning SRC length (SRCL) for 00 and HOMs up to $n + m = 10$ (blue = 00 mode, red dotted line = RSE setpoint). Simulated with Finesse 3.

The Detuned Resonant Sideband Extraction configuration

Optical scheme

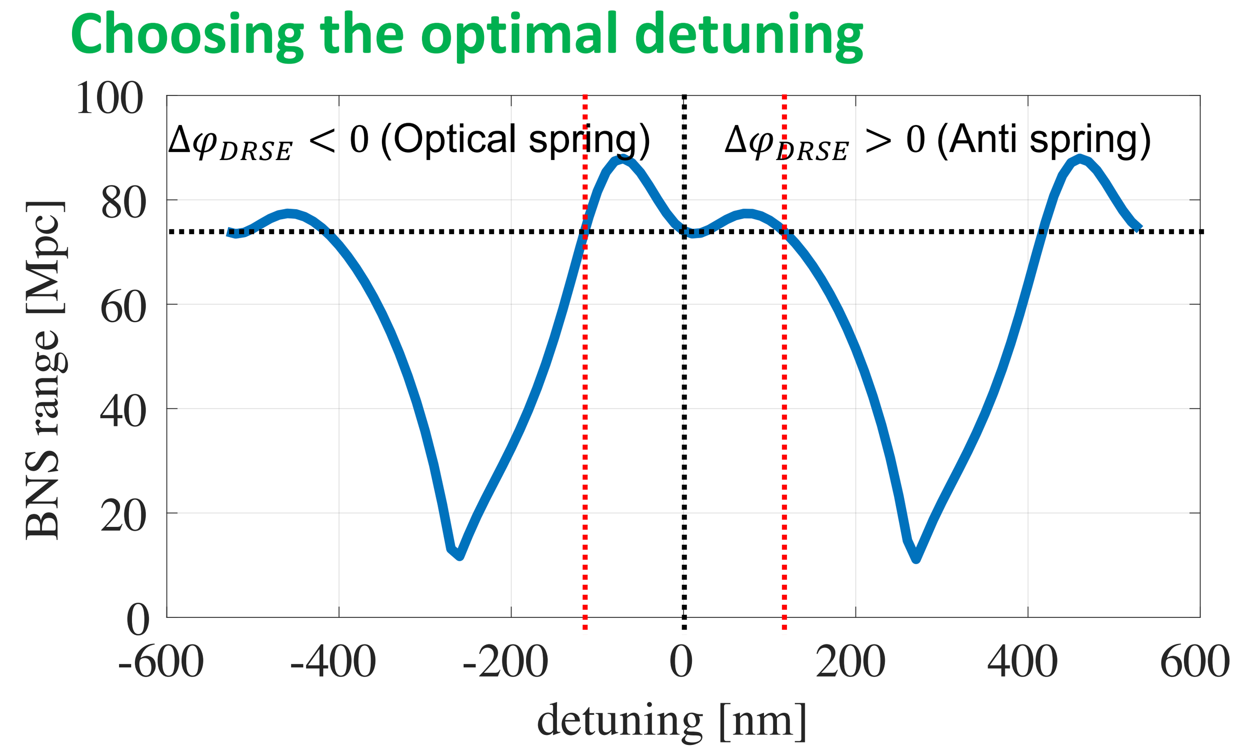
- In RSE the macroscopic SRCL tuning (with respect to the carrier) is $\varphi_{SRCL,RSE} = \frac{\pi}{2}$
- In DRSE the macroscopic SRCL tuning (with respect to the carrier) is defined as

$$\varphi_{SRCL,DRSE} = \frac{\pi}{2} + \Delta\varphi_{DRSE}$$

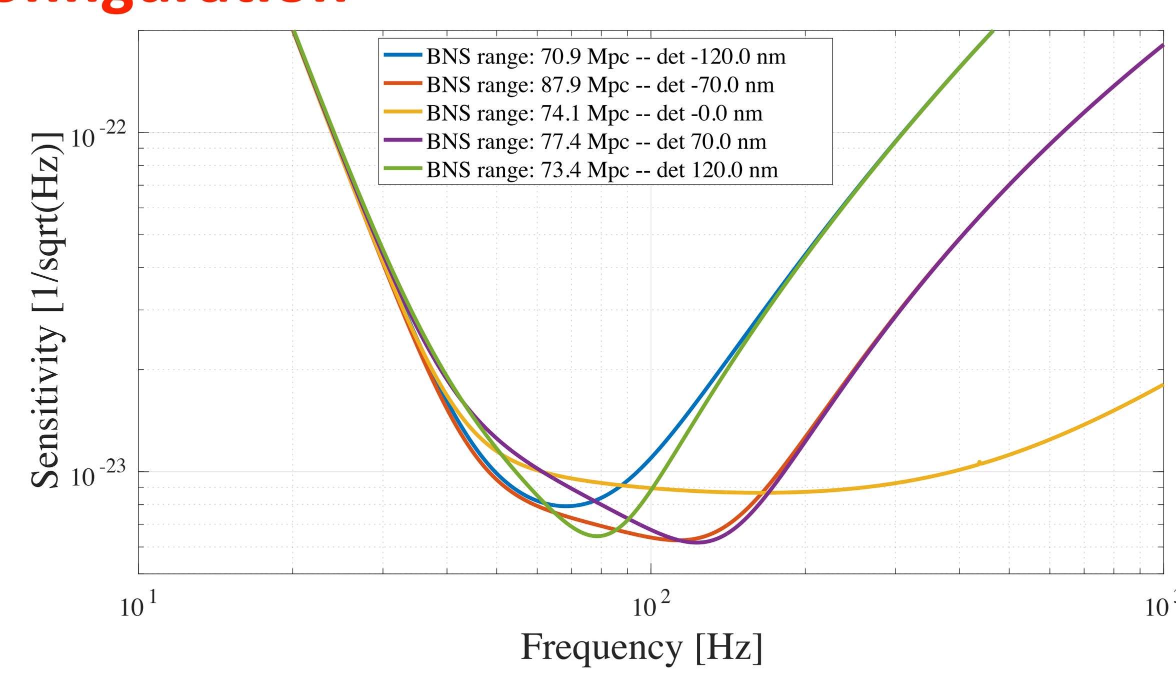
➢ In order to reduce the transmitted HOM power by a factor of 10 :

$$|\boldsymbol{\Delta\varphi_{DRSE}}| \geq \frac{\mathbf{70\ nm}}{\mathbf{1064\ nm}} \times \mathbf{360° = 24°}$$

Choosing the optimal detuning



$\simeq \pm$ 120 nm (DRSE has higher BNS range than RSE)



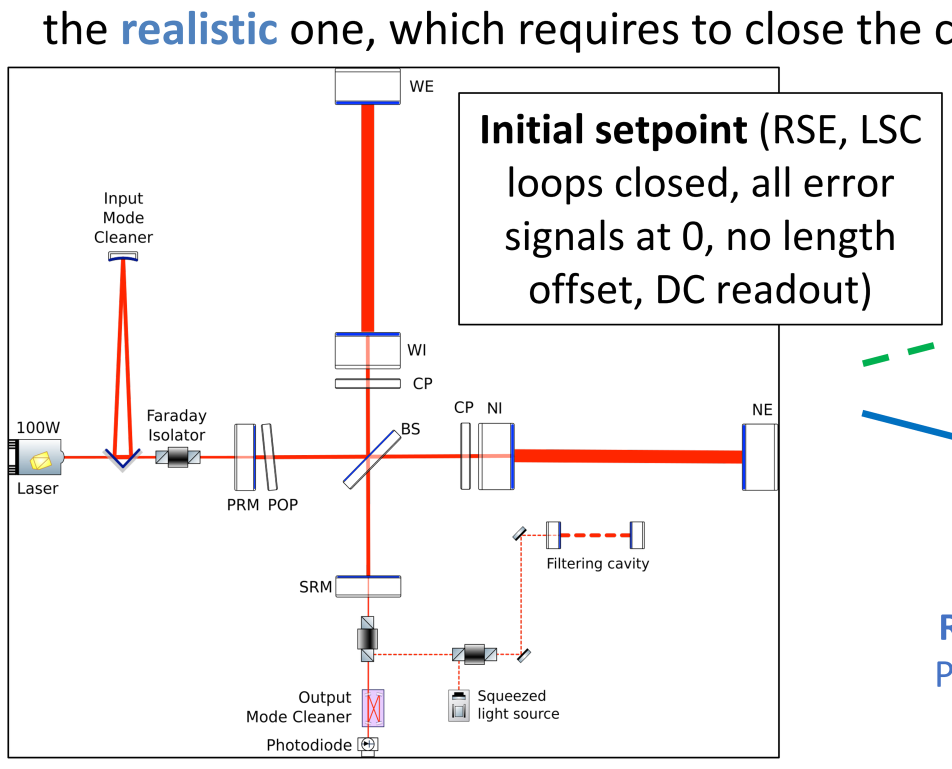
- Obtained with "AdV+ O4 high & no SQZ" in GWINC

➢ **Optimal BNS range obtained for $\boldsymbol{\Delta\varphi_{DRSE} = -70}$ nm**

Lock acquisition & length control of DRSE AdV+

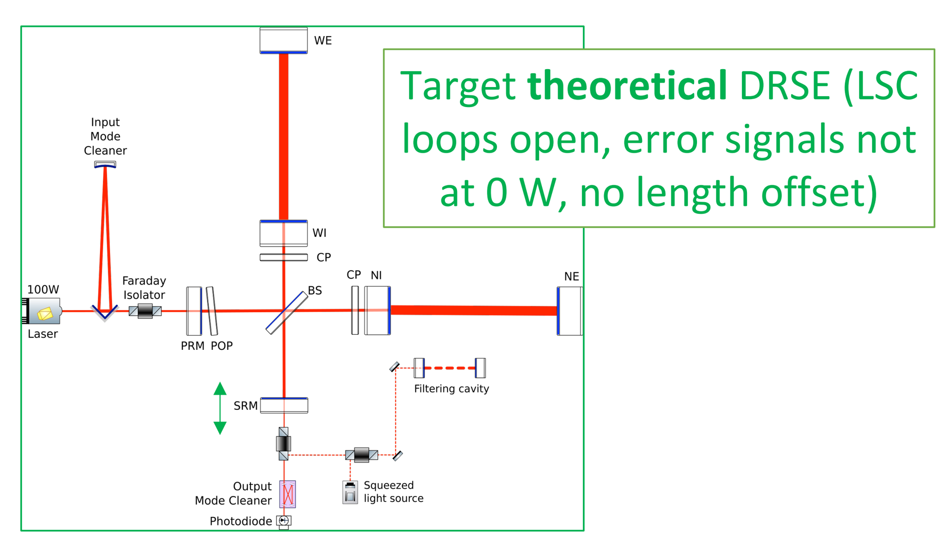
Control strategy

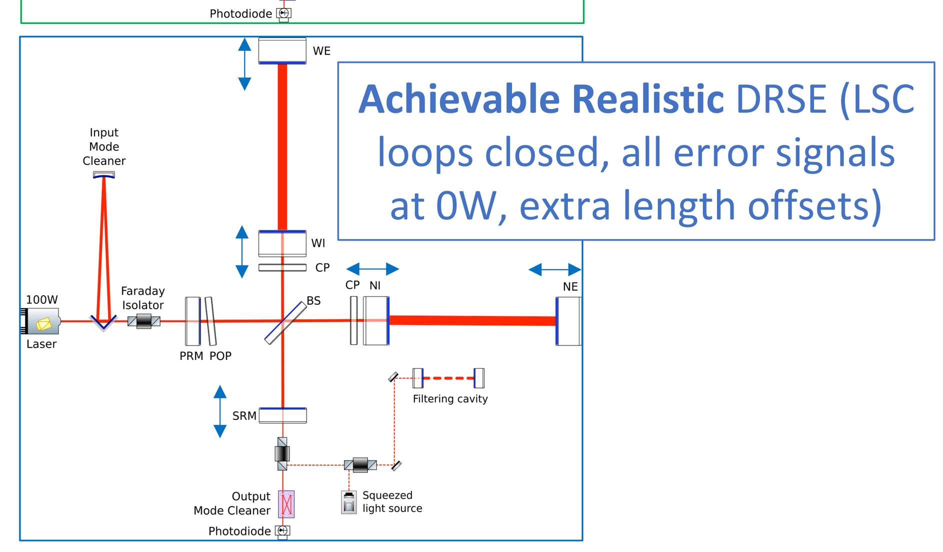
- Simple strategy: add an offset to SRCL while keeping the same DC loops for the other longitudinal DoFs as in RSE. But due to the non-diagonal sensing matrix, a detuning on SRCL also shifts the error signals for the other DoFs away from 0
- We compare the **theoretical** case of DRSE (no consideration of control loops) to the **realistic** one, which requires to close the control loops on the DoFs.



Theoretical case: add SRCL $\Delta\varphi_{DRSE} = -70$ nm + compensating DARM offset + open DC loops

Realistic case: Add B4_56_I offset (SRCL Pound Drever Hall photodiode, ~mW) to have $\Delta\varphi_{DRSE} = -70$ nm + close DC loops





Simulation results (Finesse)

- O4 high loss budget, steady state without misalignment & HOMs.

➢ Length tunings (in pm):

Optics	Initial setpoint	Theoretical	Realistic
North end	-2.77	-2.55	-26.2
West end	2.77	2.55	-26.3
North input	0	0	-23.8
West input	0	0	-23.8
Power recycling	0	0	16.5
Signal recycling	-266000	-196000	-195161

➢ Carrier power distribution (in W):

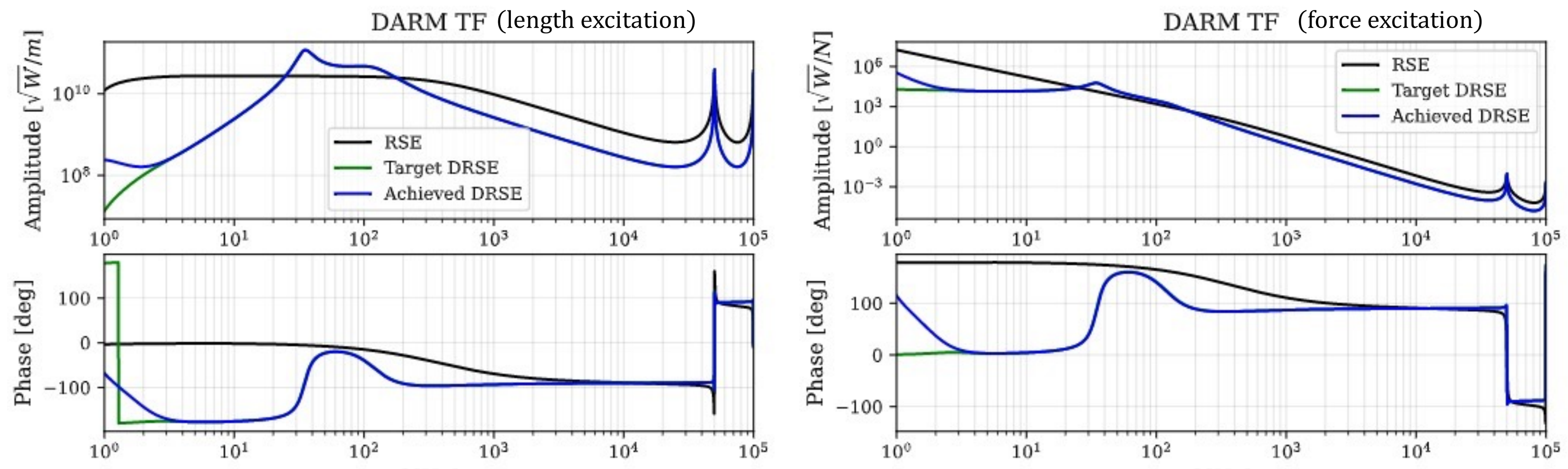
Location	Initial setpoint	Theoretical	Realistic
Input	23.4	23.4	23.4
North arm	1.02×10^5	1.01×10^5	1.01×10^5
West arm	1.01×10^5	1.01×10^5	1.01×10^5
Beam splitter	723	723	723
Output	7.96×10^{-3}	7.97×10^{-3}	7.97×10^{-3}

➢ Optics **"close"** to their initial setpoints

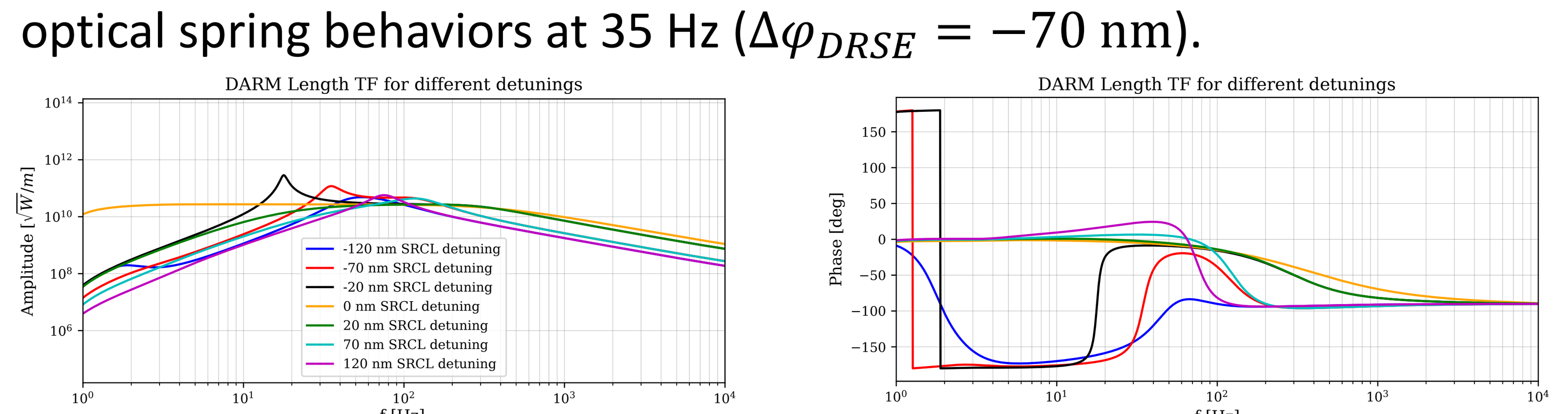
➢ **Power distribution unchanged**

Optical spring

- As reported in literature, DRSE produces resonances which depend on the interferometer's characteristics (power, SR transmissivity, SRCL detuning).

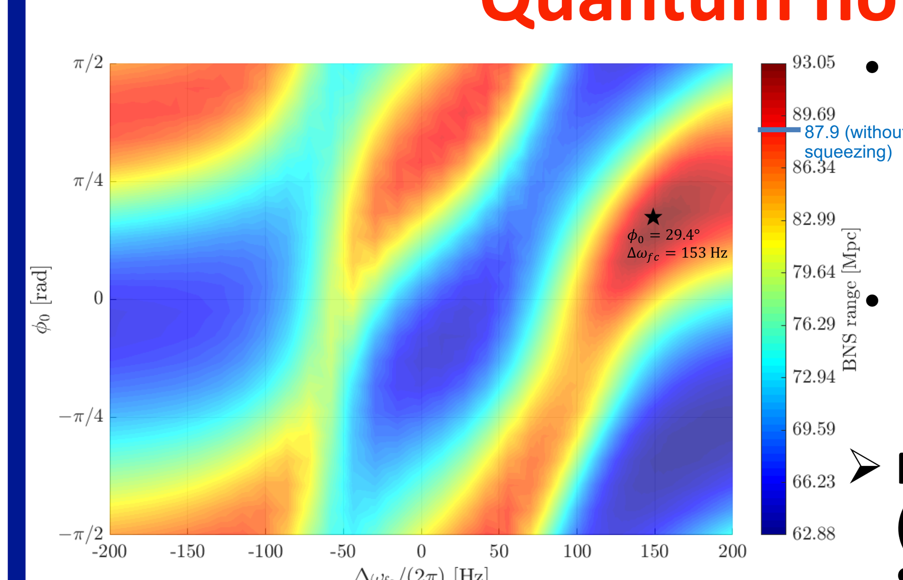


➢ Comparing the **theoretical** and **realistic** DARM transfer functions using Finesse: both curves are almost overlapped at all frequencies & exhibit optical spring behaviors at 35 Hz ($\Delta\varphi_{DRSE} = -70$ nm).



➢ Spring/anti-spring and resonance frequency depend on $\Delta\varphi_{DRSE}$ and **will influence the AC feedback loops.**

Quantum noise reduction



- With Frequency Dependent Squeezing (FDS) with the Virgo filter cavity (FC), no broadband quantum noise reduction in DRSE since 2 FC are needed.
- Figure: BNS range for -70 nm DRSE when varying squeezing input angle & FC detuning, for current FDS specifications.

➢ **Marginal increase of 5 Mpc in BNS range (93 Mpc) with current optimized FDS (& 89 Mpc with optimized FIS).**

Conclusion

- Detuning SR allows to **eliminate the HOMs** at the output detector, mitigate the problem of marginally stable cavities & improve BNS range by up to ~**15 Mpc**.
- Simulations done so far show no particular issue transitioning from RSE to DRSE in DC setpoints but **predict challenges in the AC feedback loops to control the optical spring**.

Next steps

➢ Simulation of misalignment, HOM propagation & noise couplings.

➢ **Following the simulation results, possible experimental tests of DRSE in AdV+ for phase I or II.**

References

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