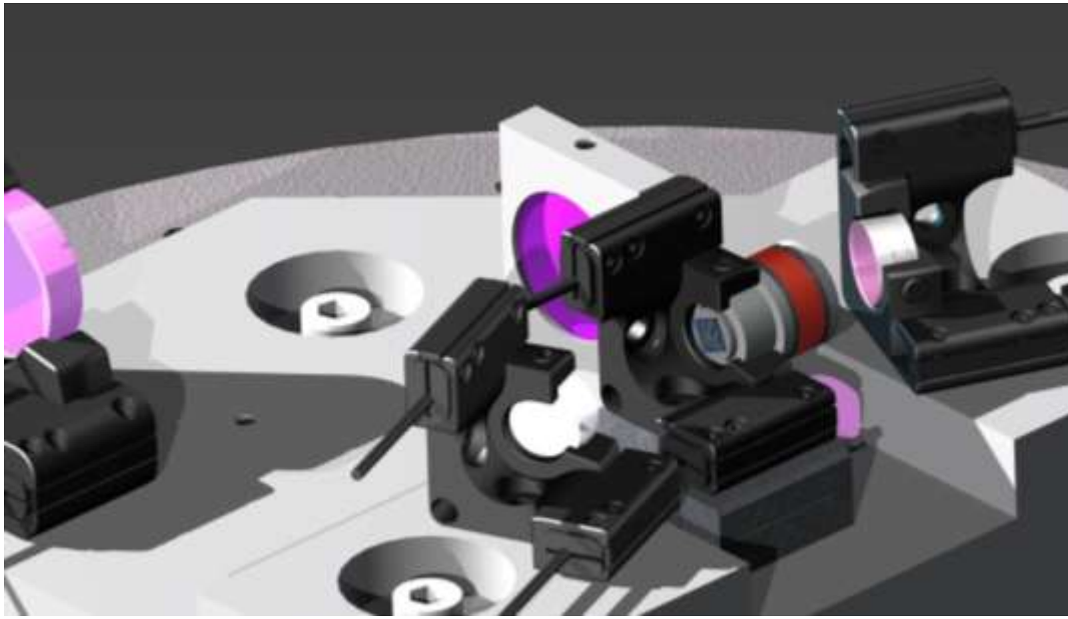
Dissipative Optomechanical Coupling



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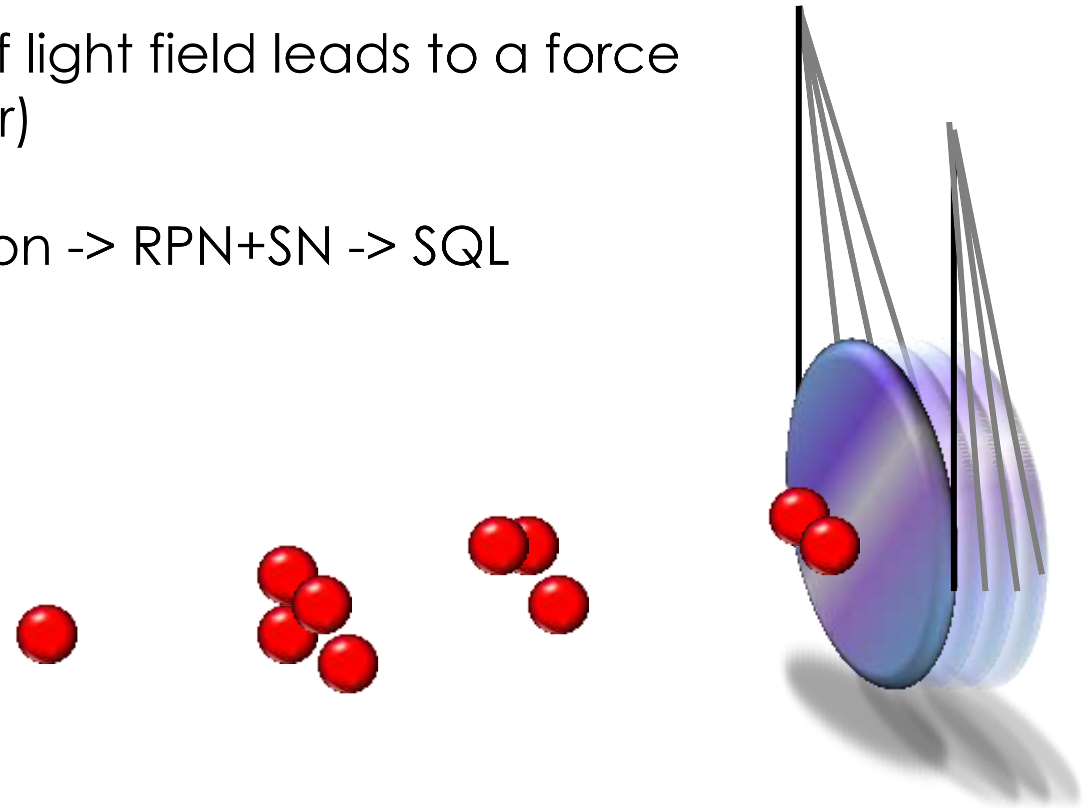
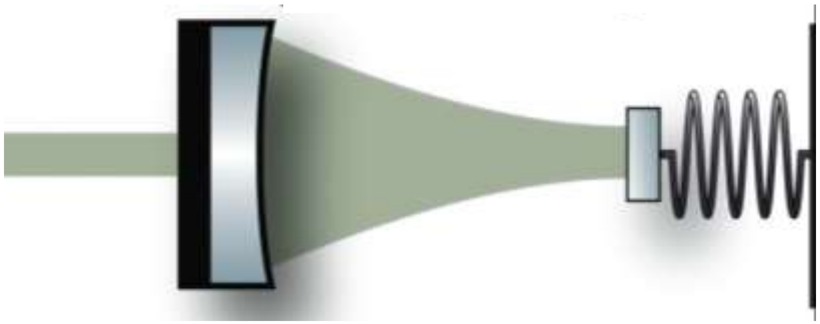
Optomechanical coupling: Back-action

- Radiation pressure of light field leads to a force on a test mass (mirror)

- Quantum back-action -> RPN+SN -> SQL



Dynamical back-action



Effective FP-Cavity

- Micro-and nano oscillators
- Movebale mirror

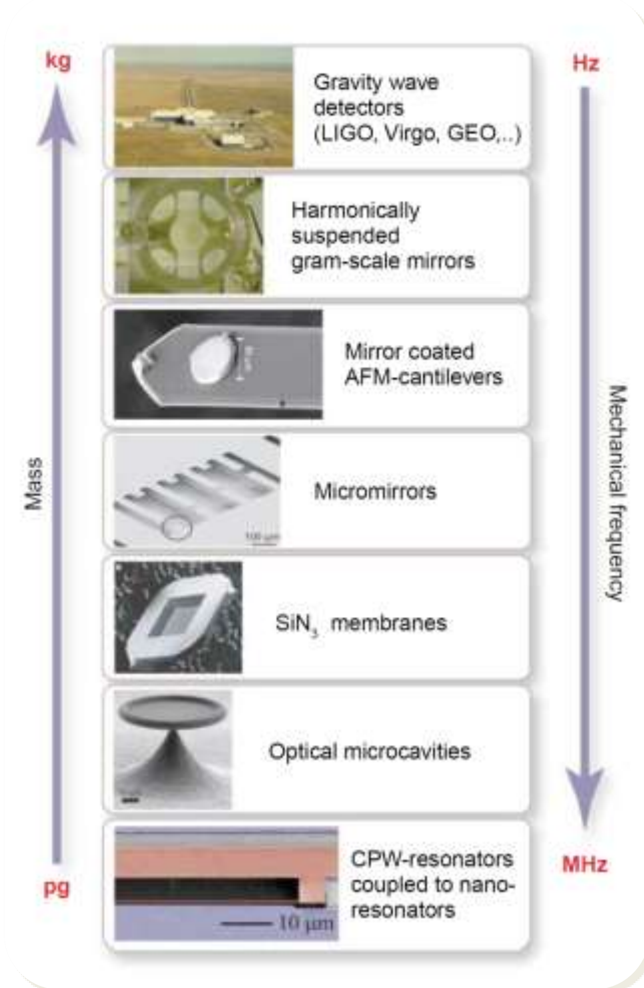
[S. Gigan et al., Nature 444, 67 (2006), T. Corbitt et al., PRL . 98, 150802 (2007), J. D. Thompson et al., Nature 452, 72 (2008), etc…]

↕

Interferometer (GWD)

- Scaling law: noise + dynamics operated on dark port are equivalent to those of a *FP-Cavity*

  *[A. Buonanno, Y. Chen, Phys. Rev. D **67**, 062002 (2003)]*



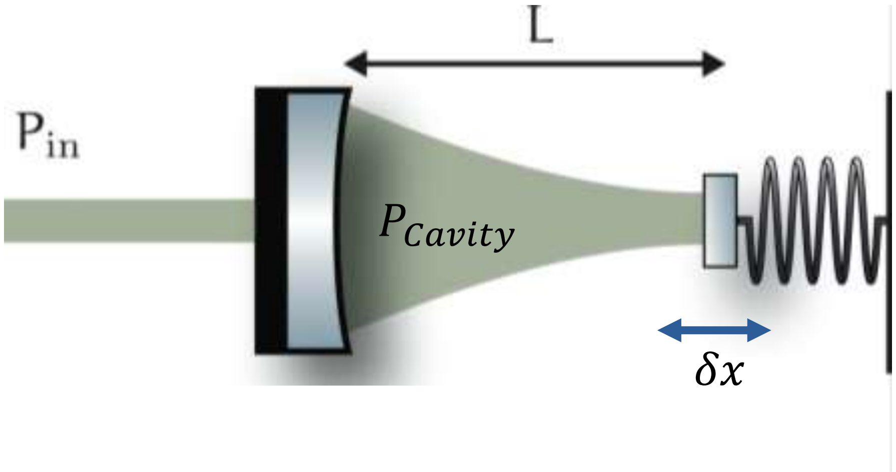
T. J. Kippenberg, K. J.Vahala, *Science 321*, 1172 (2008)

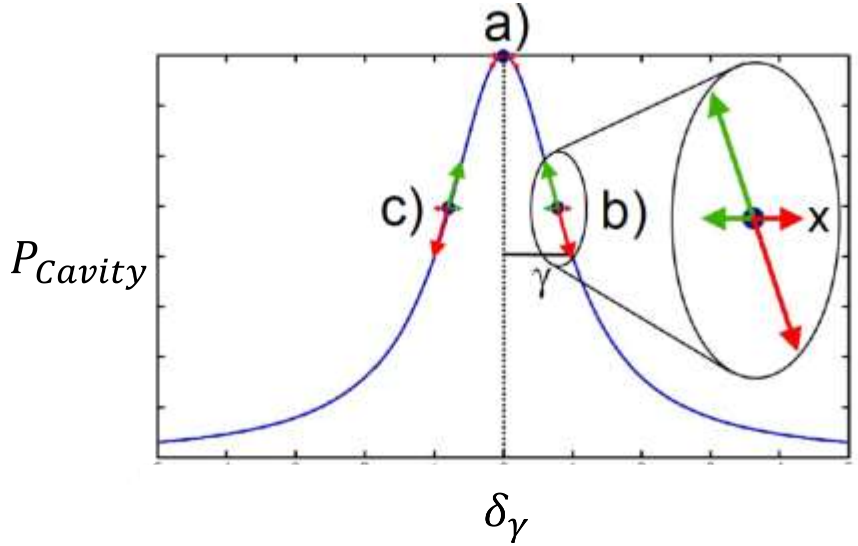
Dynamical Back-Action: Optical Spring

Interaction Hamiltonian: $\mathcal{H}_{int} = g_\omega \hat{x}\hat{a}^+\hat{a}$

dispersive coupling: $g_\omega = \frac{\delta\omega}{\delta x}$

Resonance condition: $L = \frac{n\pi c}{\omega_L}$





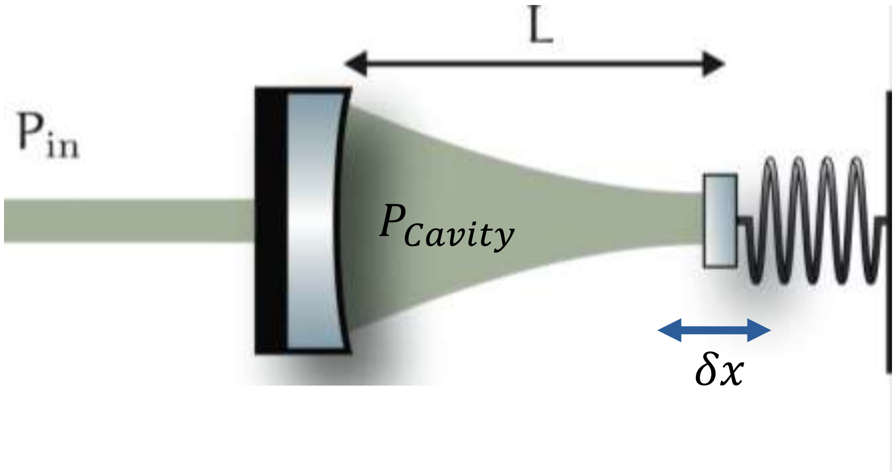
a) $\delta = 0$:
P_{Cavity} depends only in
2. order of magnitude to δx.

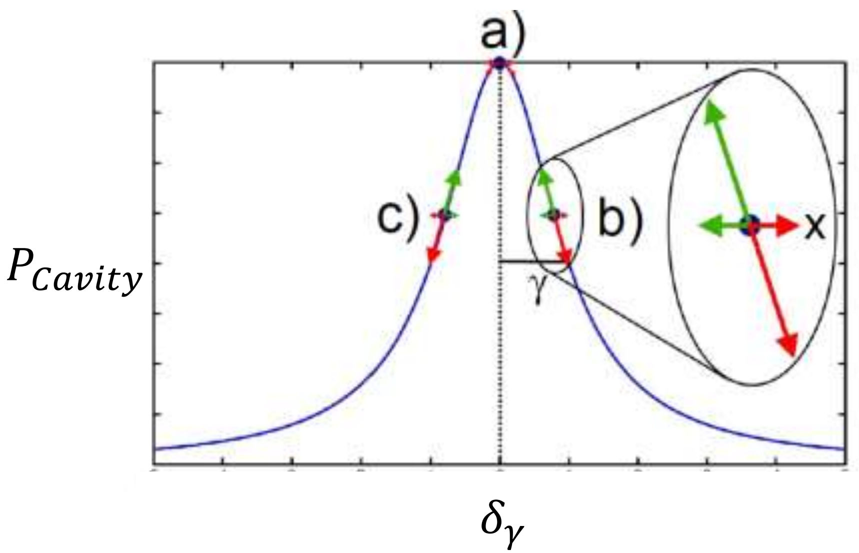
Dispersive Coupling

Interaction Hamiltonian: $\mathcal{H}_{int} = g_\omega \hat{x}\hat{a}^+\hat{a}$

dispersive coupling: $g_\omega = \frac{\delta\omega}{\delta x}$

Resonance condition: $L = \frac{n\pi c}{\omega_L}$





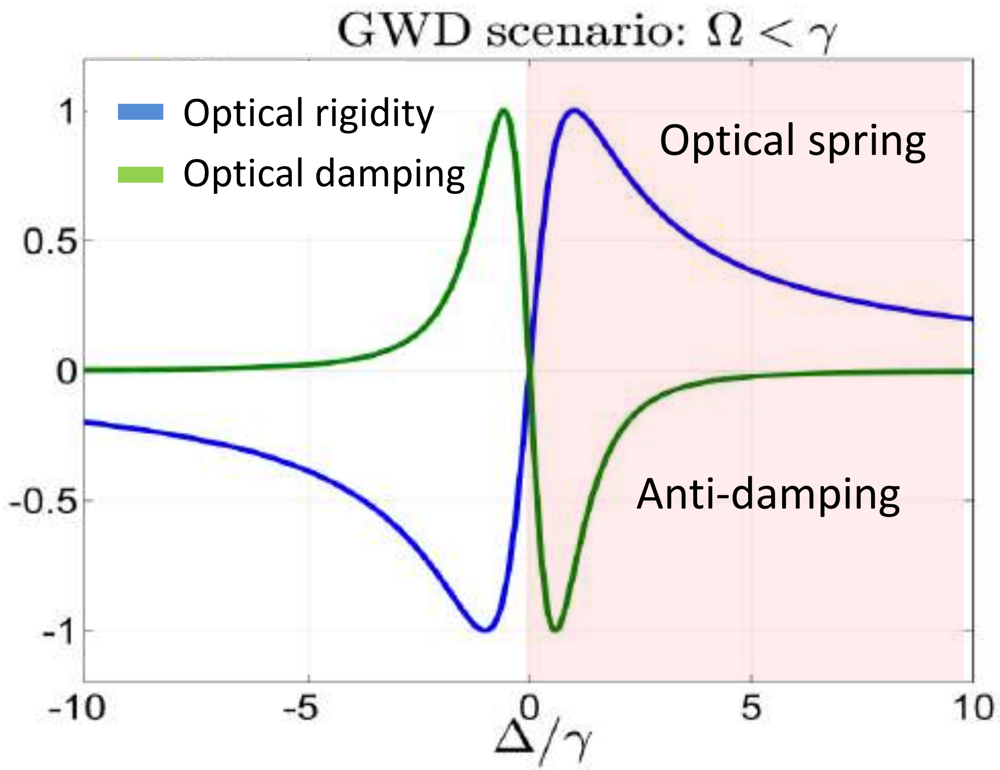
b/c) $\delta \neq 0$:

linear dependence

$P_{Cavity} \propto \delta x \Rightarrow F_{RP} \propto \delta x$

Optical spring

Dynamical Back-Action in GWD



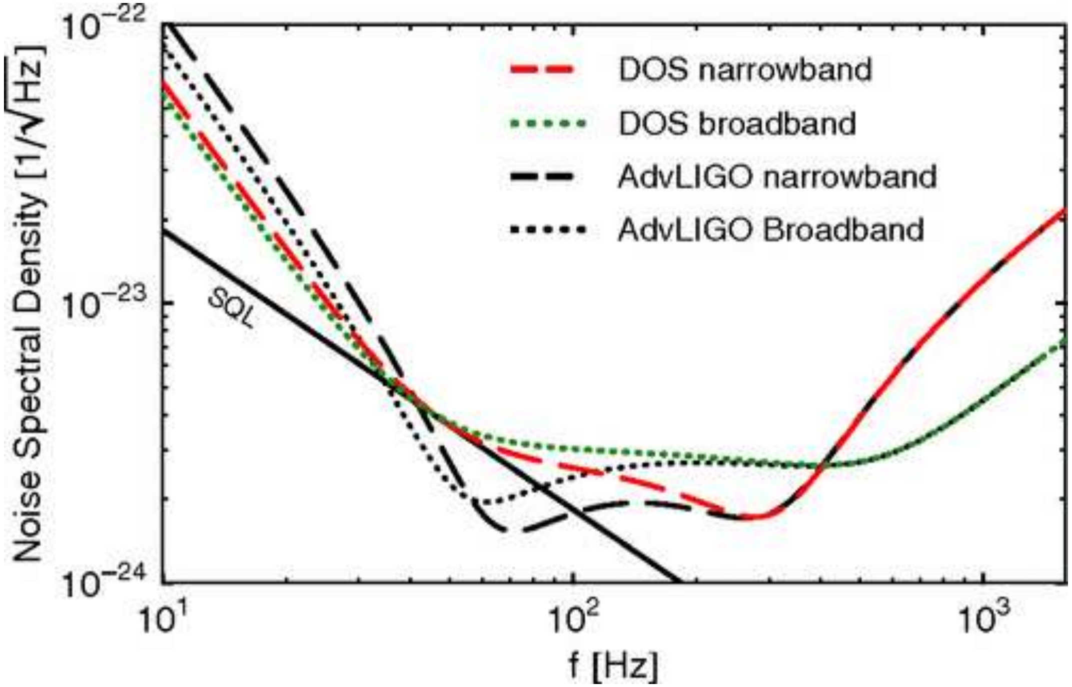
$$F(\Omega) = -\,\delta x\,[K(\Omega) - 2i\Omega\Gamma(\Omega)]$$

$K(\Omega)$: *optical rigidity*
$\Gamma(\Omega)$: *optical damping*

Optical Spring in GWD is unstable!

*V.B. Braginsky et al., Phys. Lett. A **232**, 340 (1997);*
*F.Ya. Khalili, Phys. Lett. A **288**, 251 (2001);*
*A. Buonanno, Y. Chen, Phys. Rev. D **65**, 042001 (2002)*

Dynamical Back-Action in GWD



*H. Rehbein et al., PRD **78**, 062003 (2008)*

Optical Spring in GWD is unstable!

- control/feedback needed for stabilization
- 2 Laser drives can create stable spring and sensitivity improvement

*H. Rehbein et al., PRD **78**, 062003 (2008)*
*T. Corbitt et al., PRL **98**, 150802 (2007)*

Dynamical Back-Action in GWD

Dynamical back-action on dark-port

- 2nd generation of GWD will operated slightly off dark-port

f [Hz]

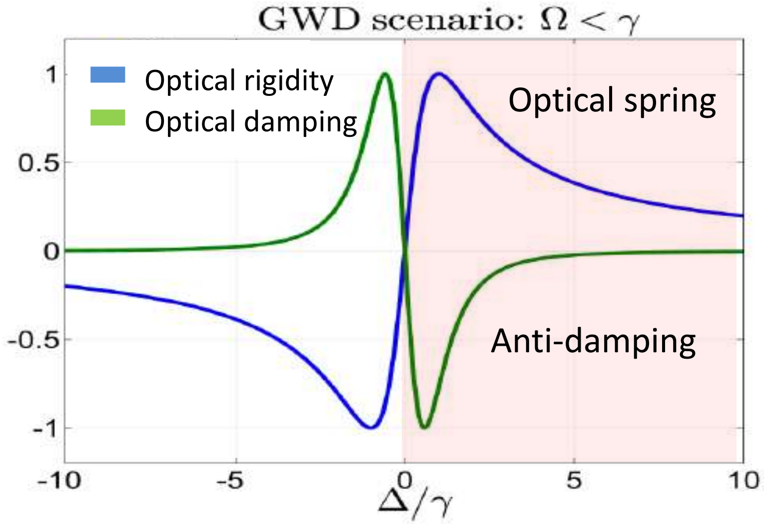
*H. Rehbein et al., PRD **78**, 062003 (2008)*

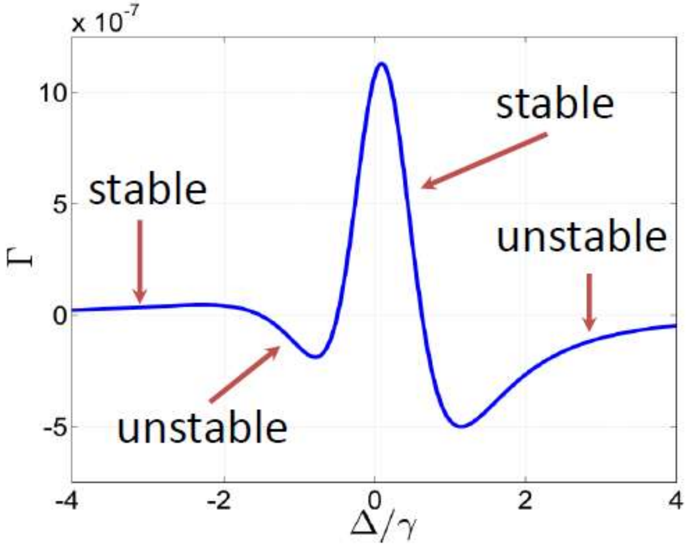
What about dynamic back-action off dark-port?

Additional instabilities

S. Tarabrin et al.,
Phys. Rev. A 88, 023809 (2013)

On dark-port → Far away Off dark-port





→ Not crucial for GWD!

LARGE SCALE to small scale experiment

Gravitational Wave Detector (GWD)

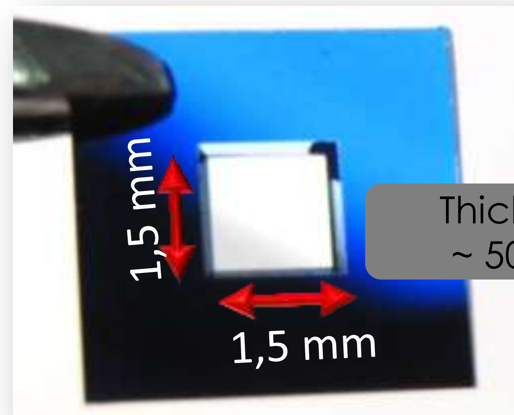
~ 200 W	high input power
~ 40 Kg	free test Masses
~ 100%	power reflectivity
~ 1 Hz	resonant frequency

Suspended fused silica mirror

Michelson interferometer + signal recycling

Table top experiment

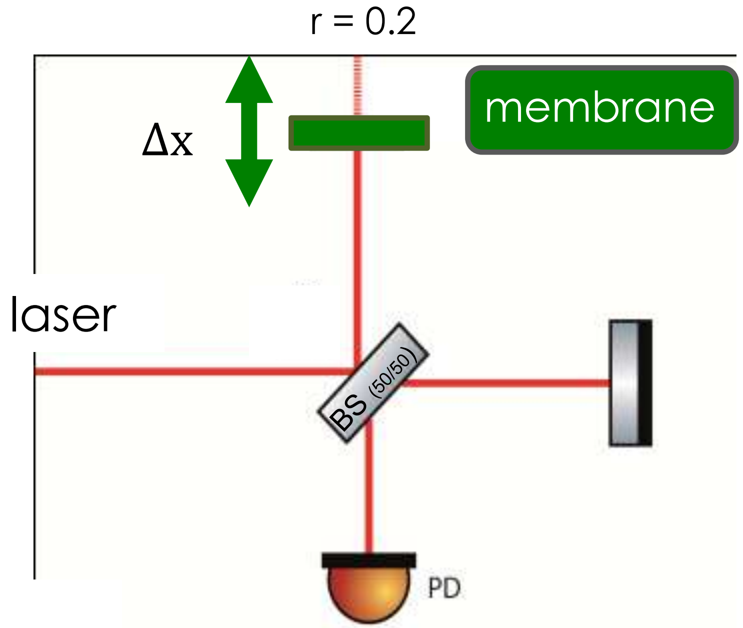
~ 1mW-1W	input power
~ 100 ng	test mass
~ 20 %	power reflectivity
~100 kHz	resonant frequency

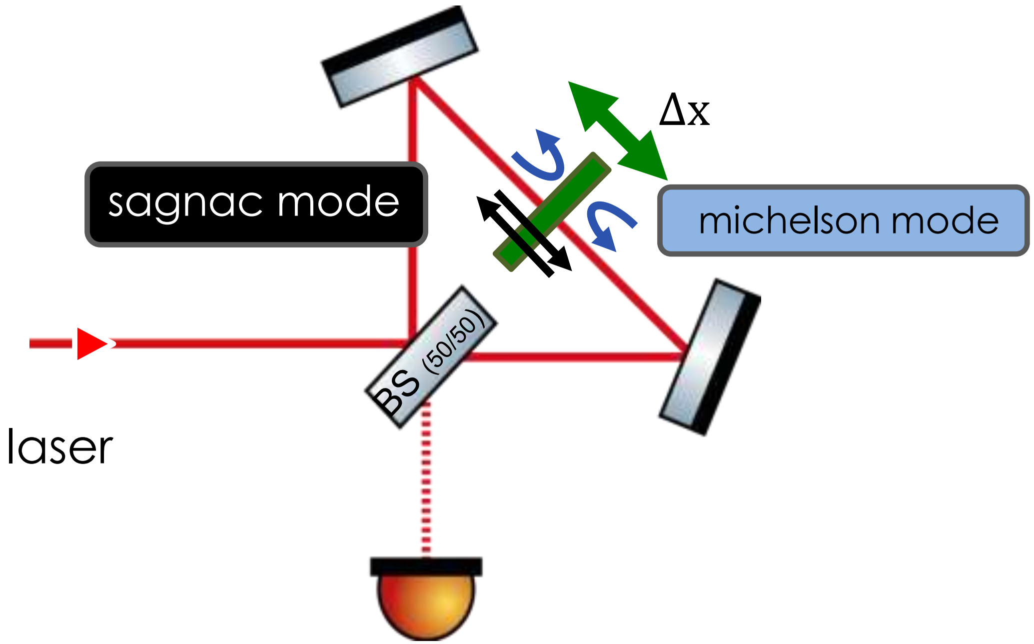


Thickness ~ 50 nm

SiN – Silicon Nitride membrane

Michelson – Sagnac Interferometer



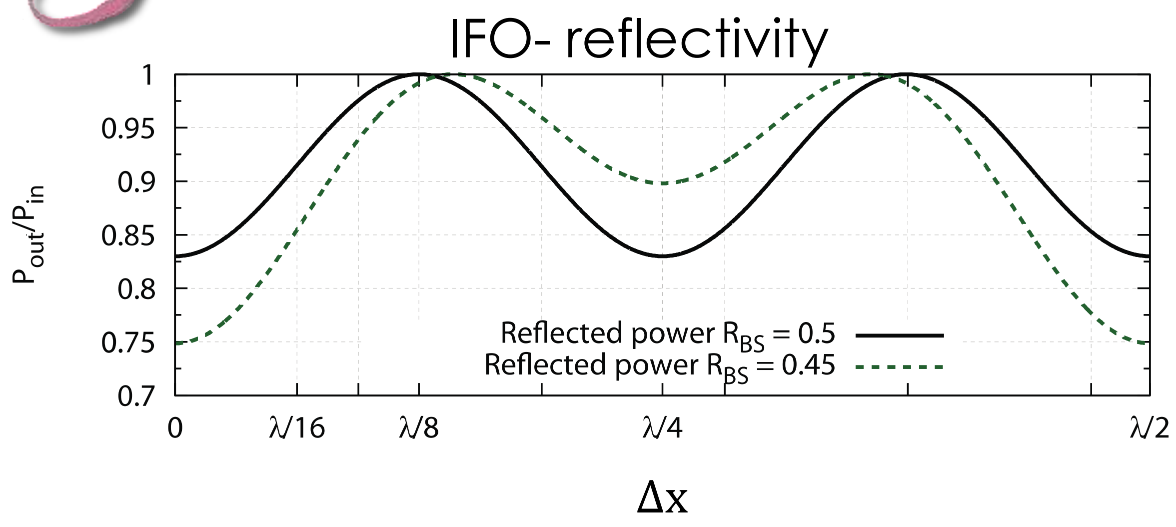


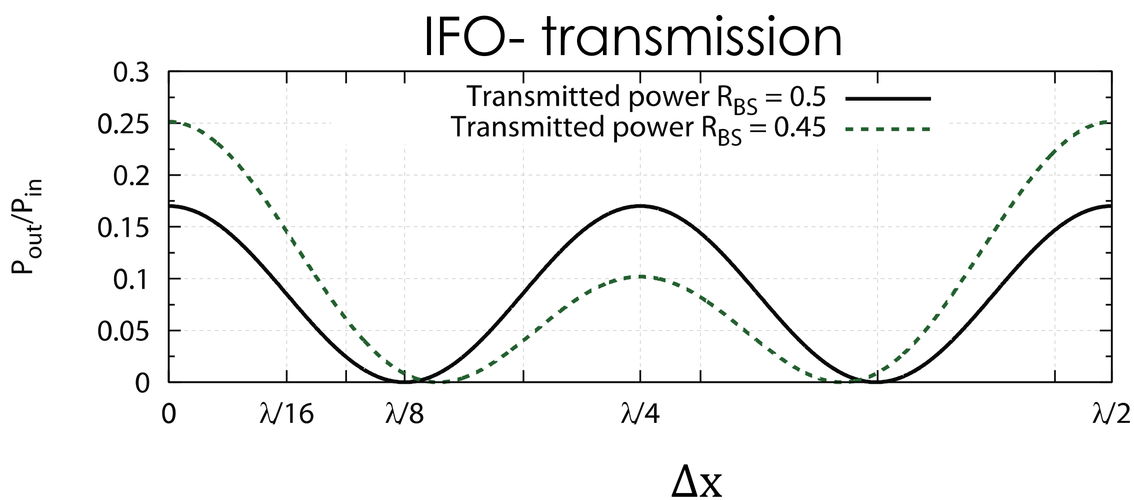
K. Yamamoto et al., Phys. Rev. A ***81****, 033849 (2010)*

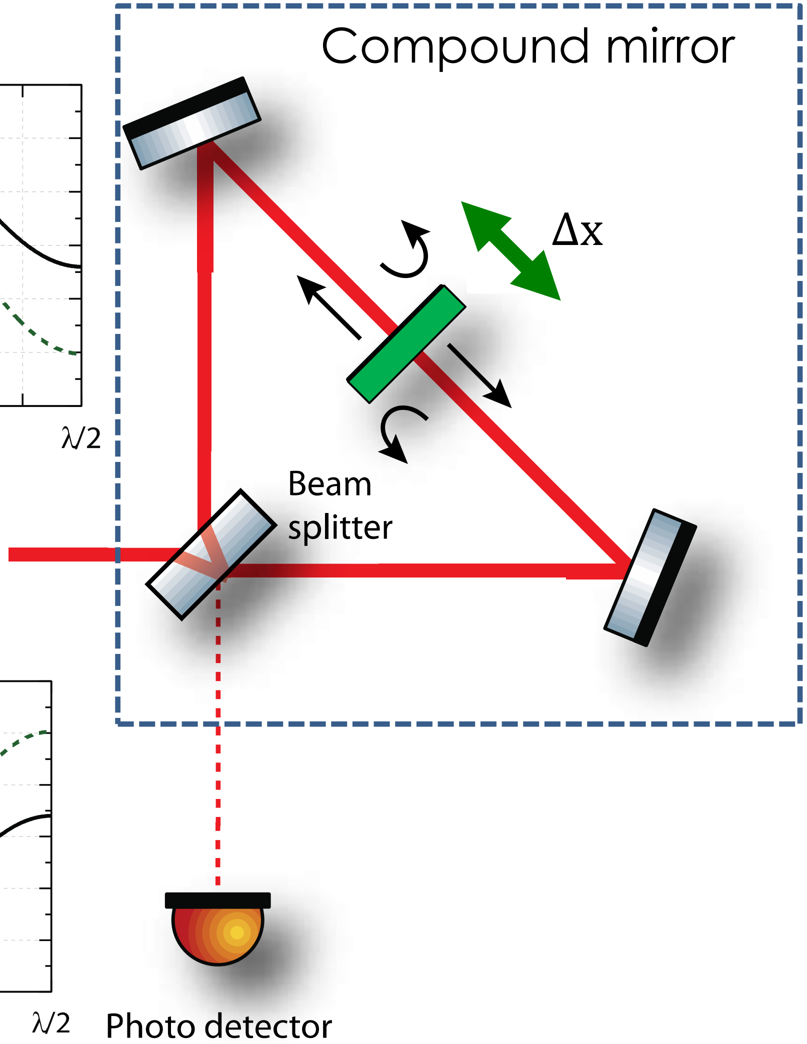
D. Friedrich et al., New J. Phys. ***13****, 093017 (2011)*

H. Kaufer et al. New J. Phys. **14** 095018 (2012)

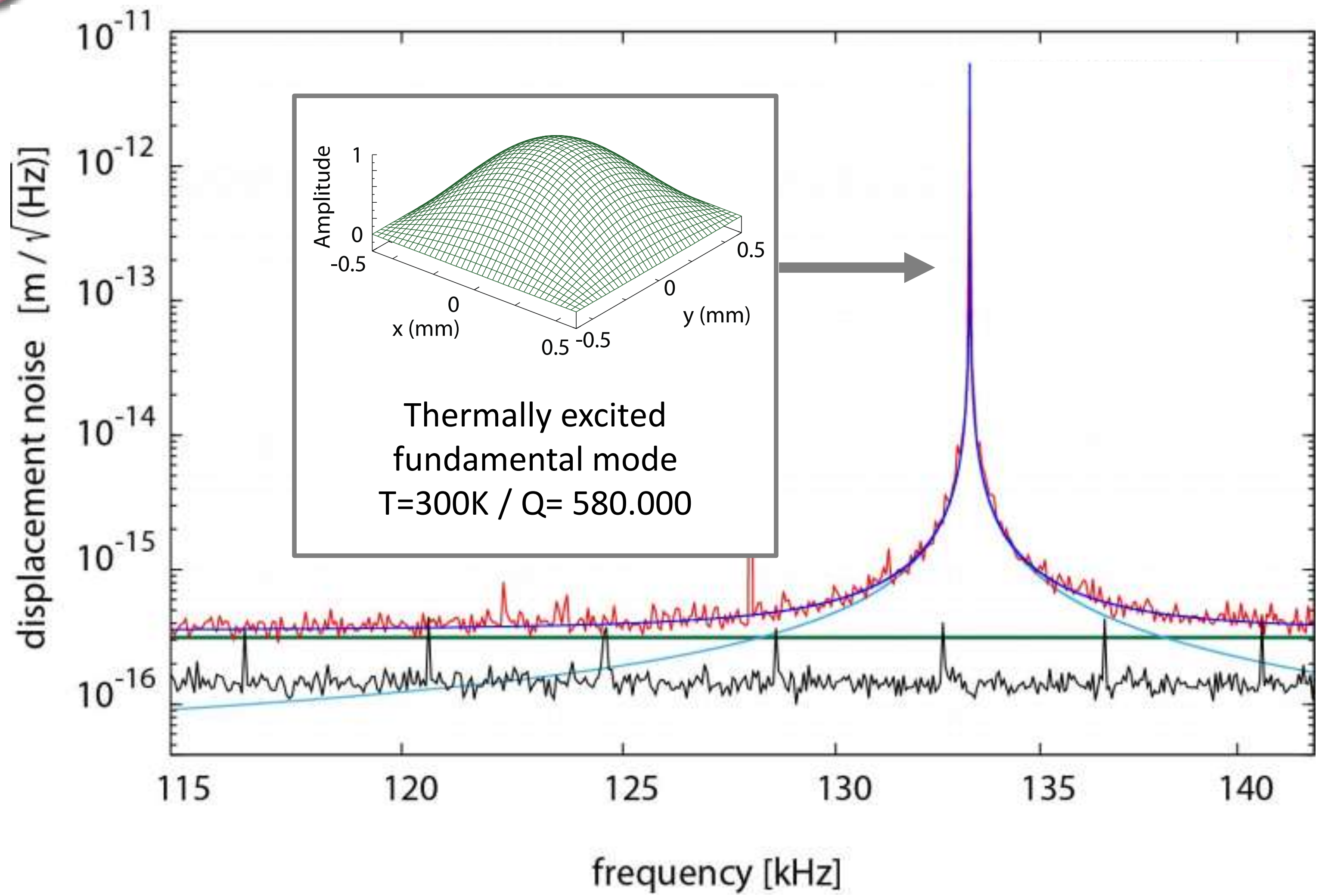
MiSa-Interferometer as a mirror



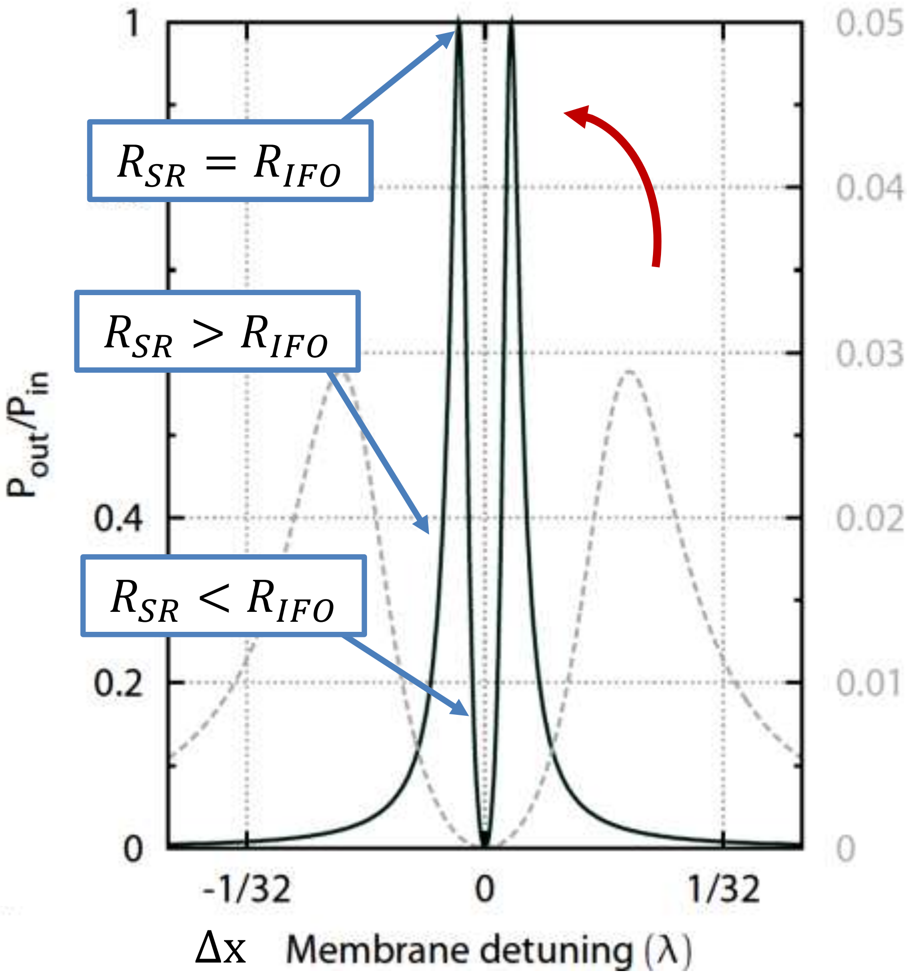


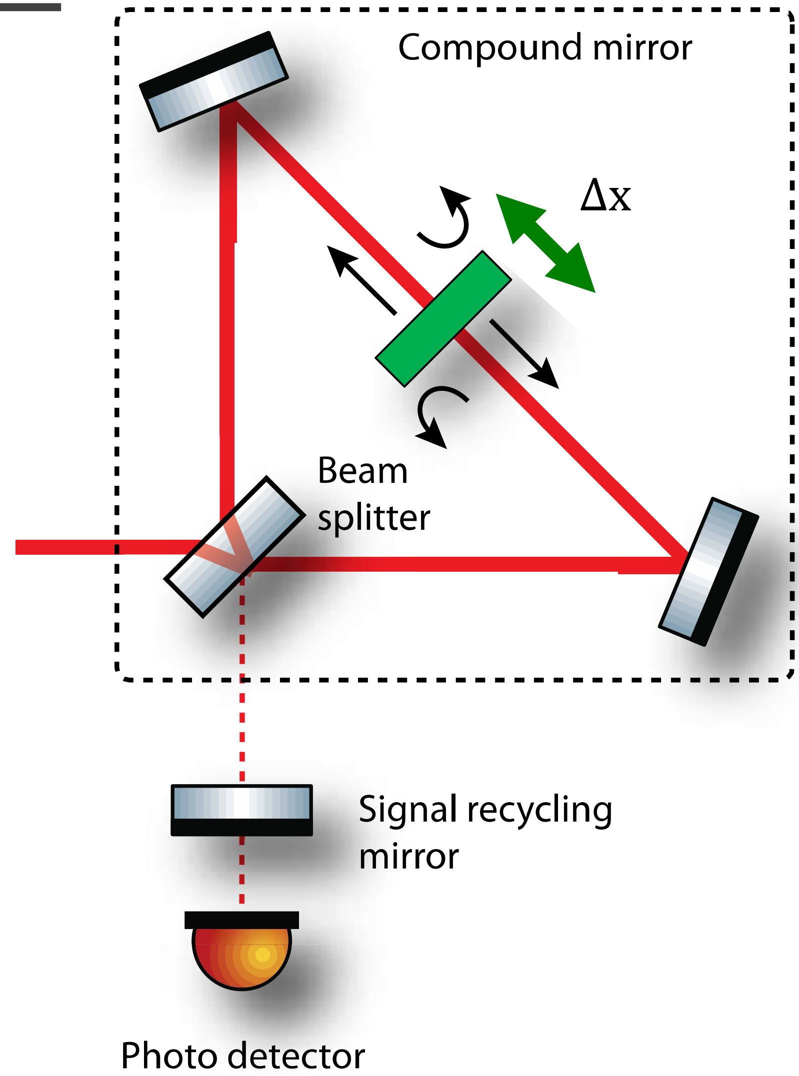


MiSa-Interferometer Output Spectrum

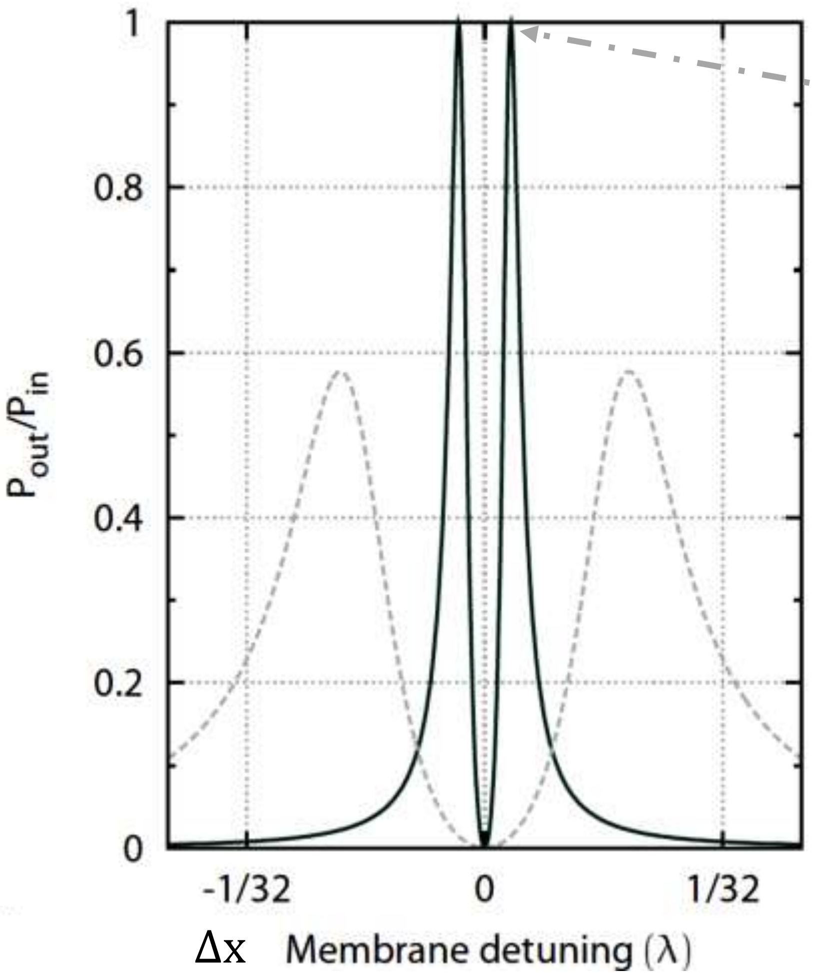


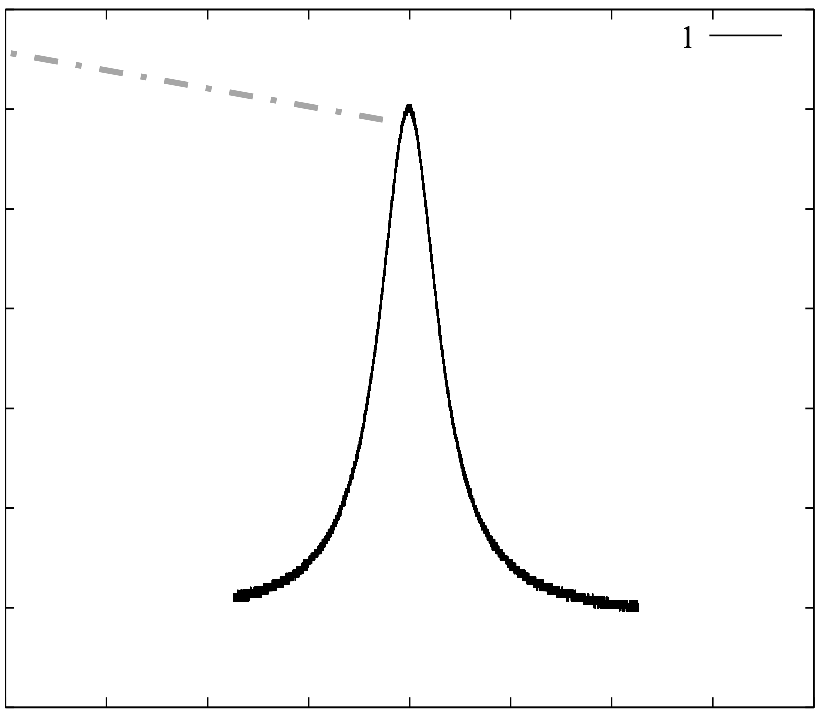
Signal Recycling Cavity





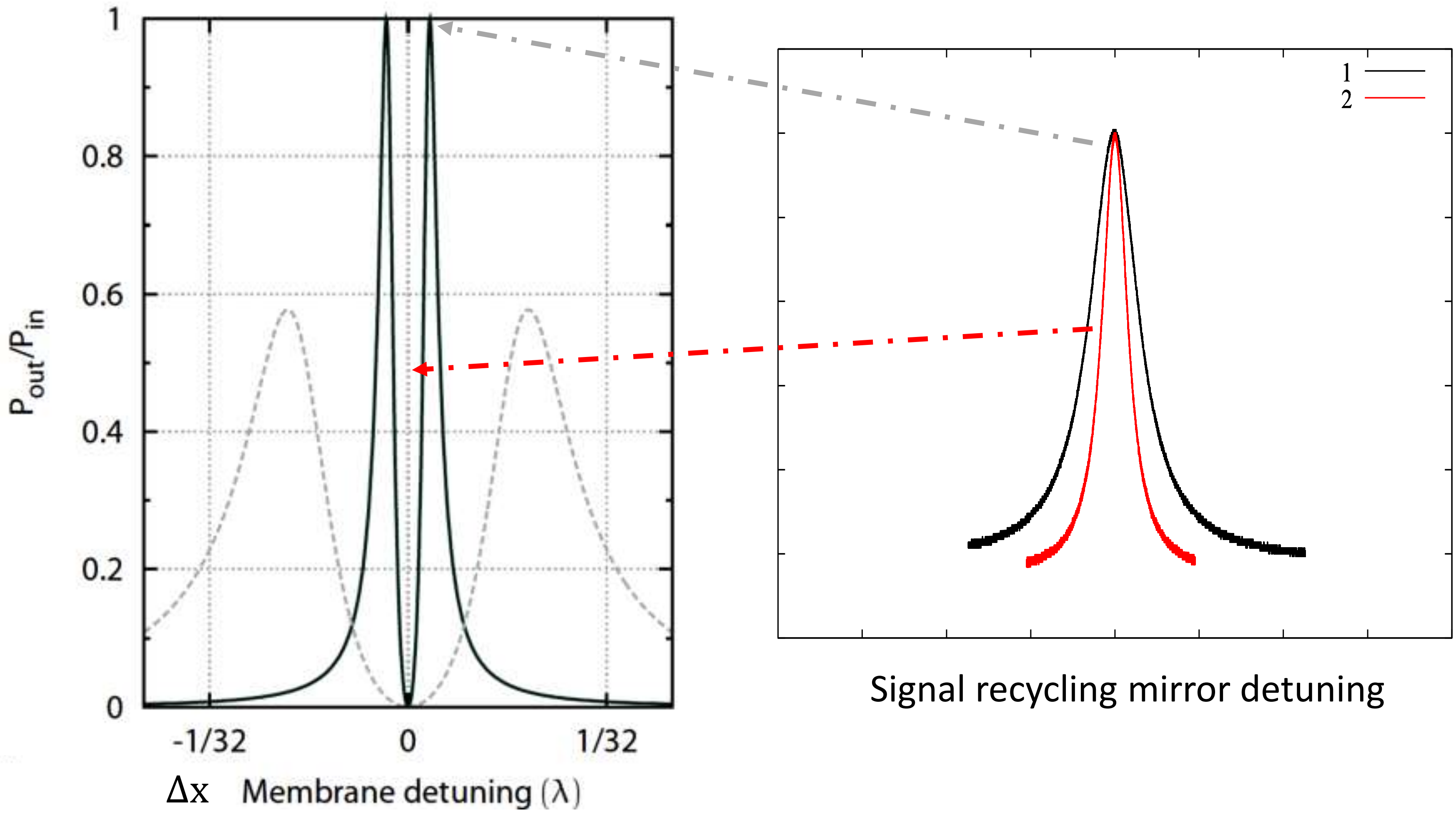
Linewidth depends on membrane position





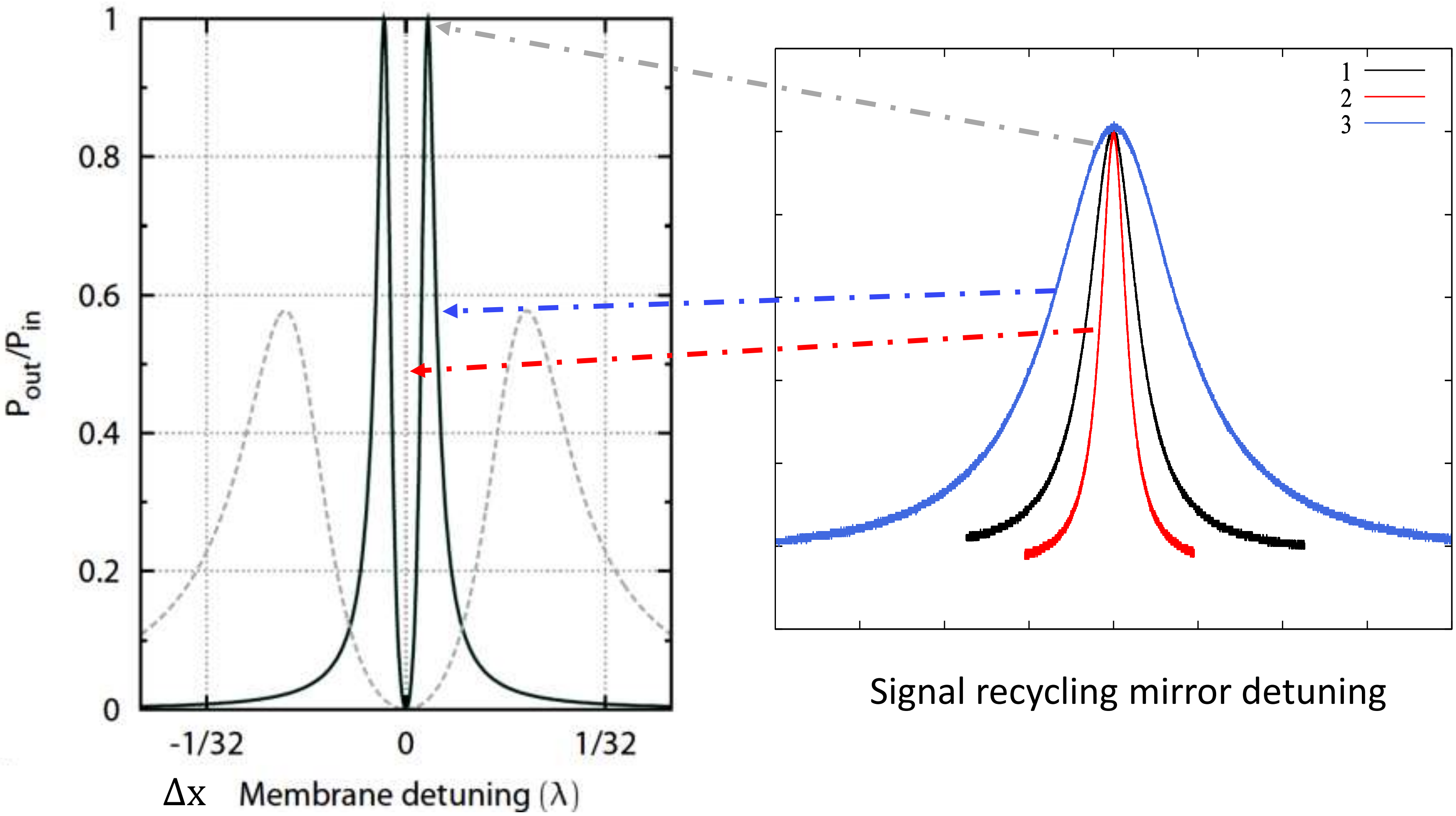
Signal recycling mirror detuning

Linewidth depends on membrane position



Signal recycling mirror detuning

Linewidth depends on membrane position



Dissipative Coupling

Modulation of the cavity linewidth → Changing the coupling of the optical system to the "thermal bath"

Interaction Hamiltonian:

$$\mathcal{H}_{int} = g_\omega \hat{x}\hat{a}^+\hat{a} + g_\gamma \hat{x} \ldots$$

dispersive coupling (modulation of cavity frequency)

$$g_\omega = \frac{\delta\omega}{\delta x}$$

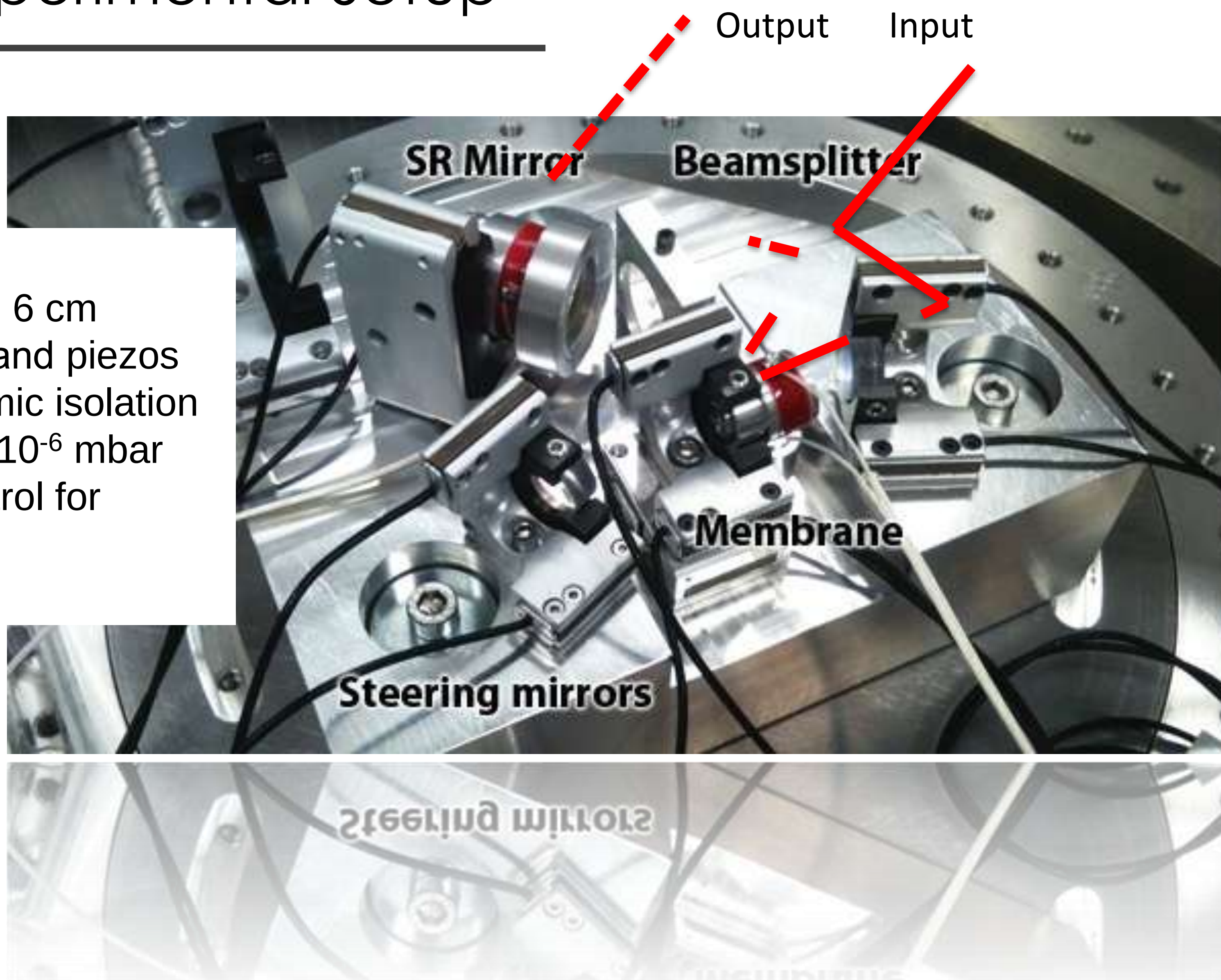
dissipative coupling (modulation linewidth)

$$g_\gamma = \frac{\delta\gamma}{\delta x}$$

F. Elste, S. Girvin, A. Clerk, PRL ***102****, 207209, 2009*

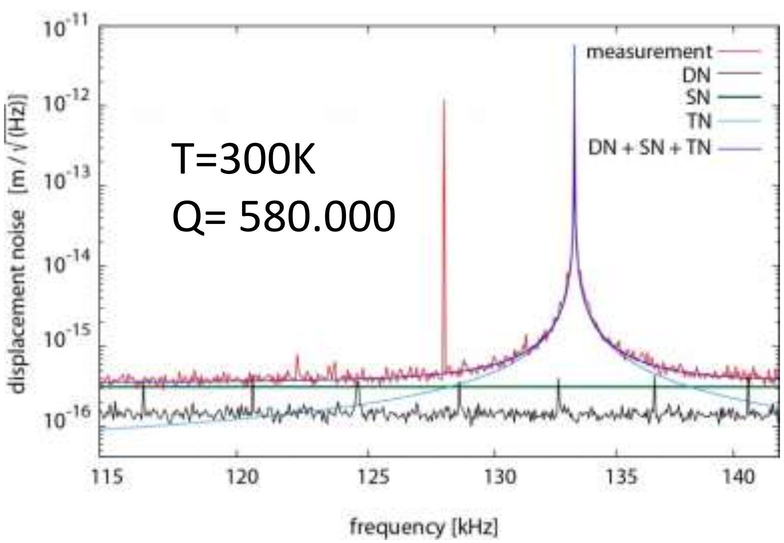
Experimental Setup

Setup features
- Arm length = 6 cm
- 0.5 “ Optics and piezos
- Double seismic isolation
- Operated at 10^{-6} mbar
- Remote control for alignment

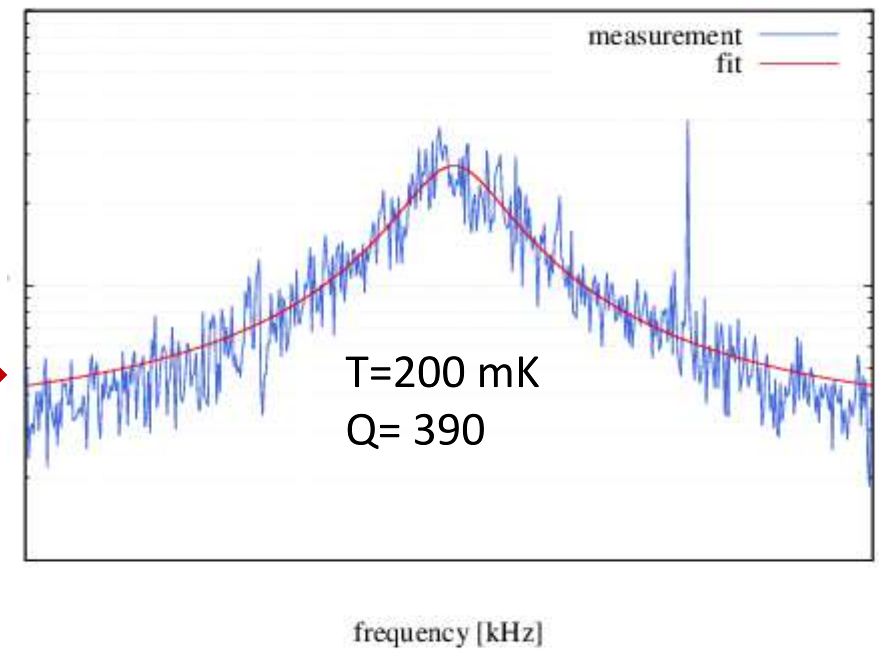


Cooling of the membrane

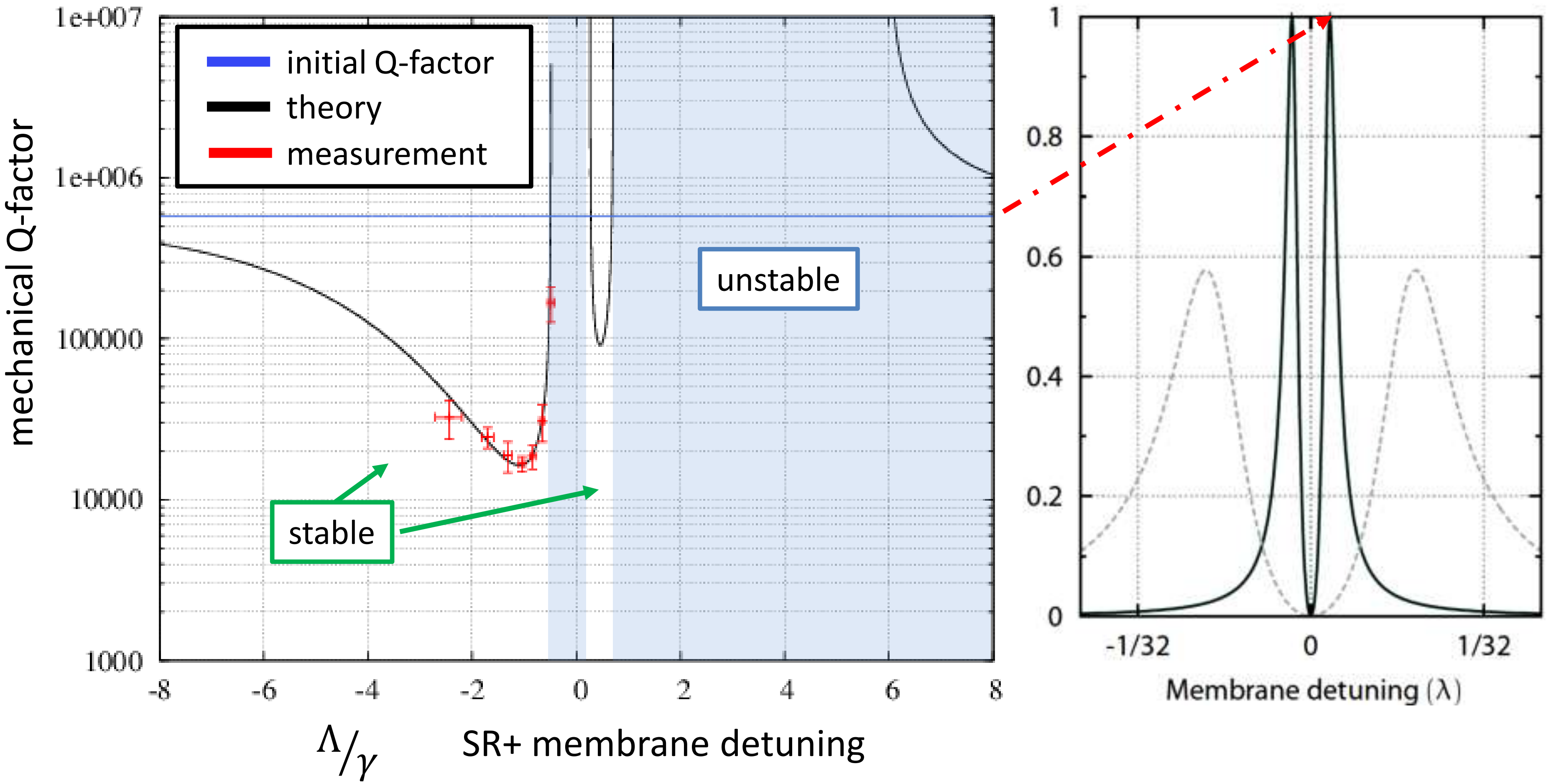
without signal- recycling



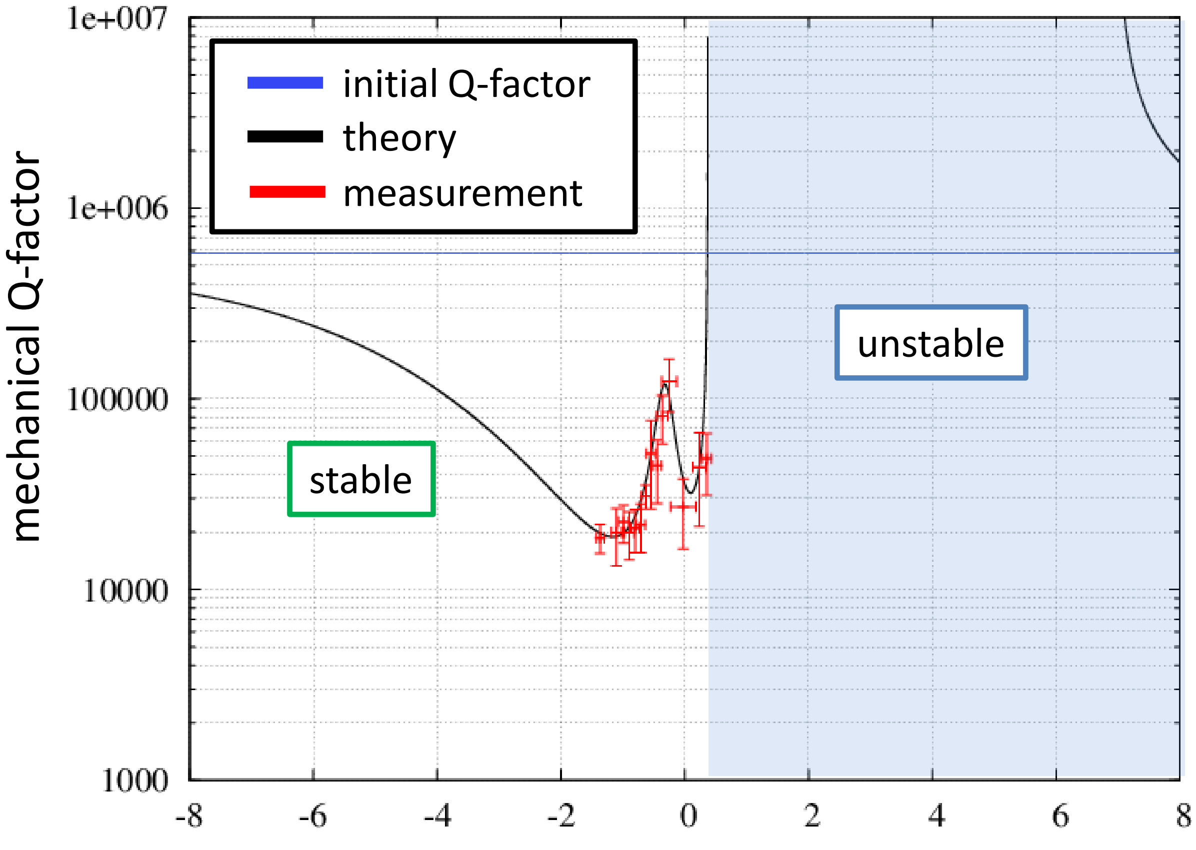
with signal- recycling

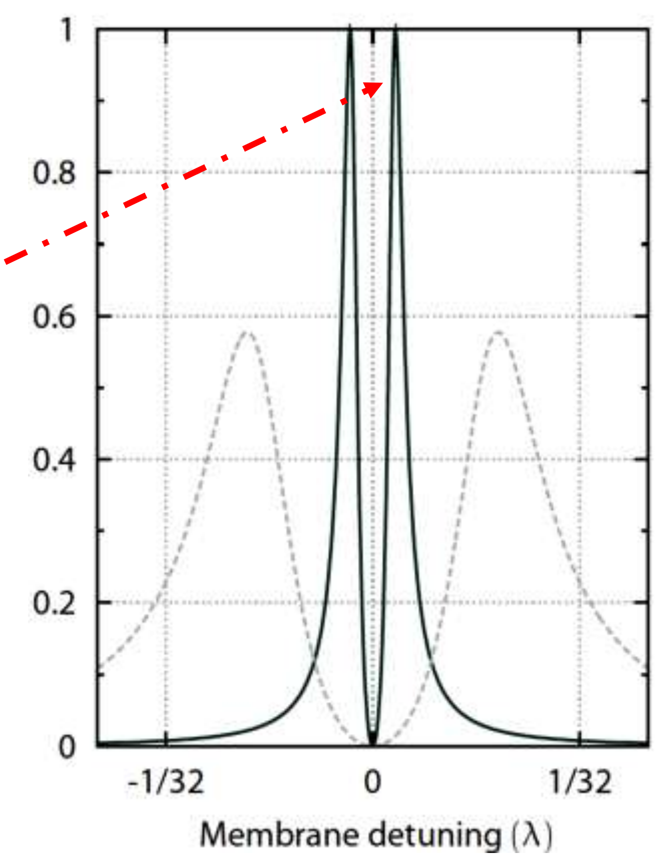


Stable + unstable regime measurments



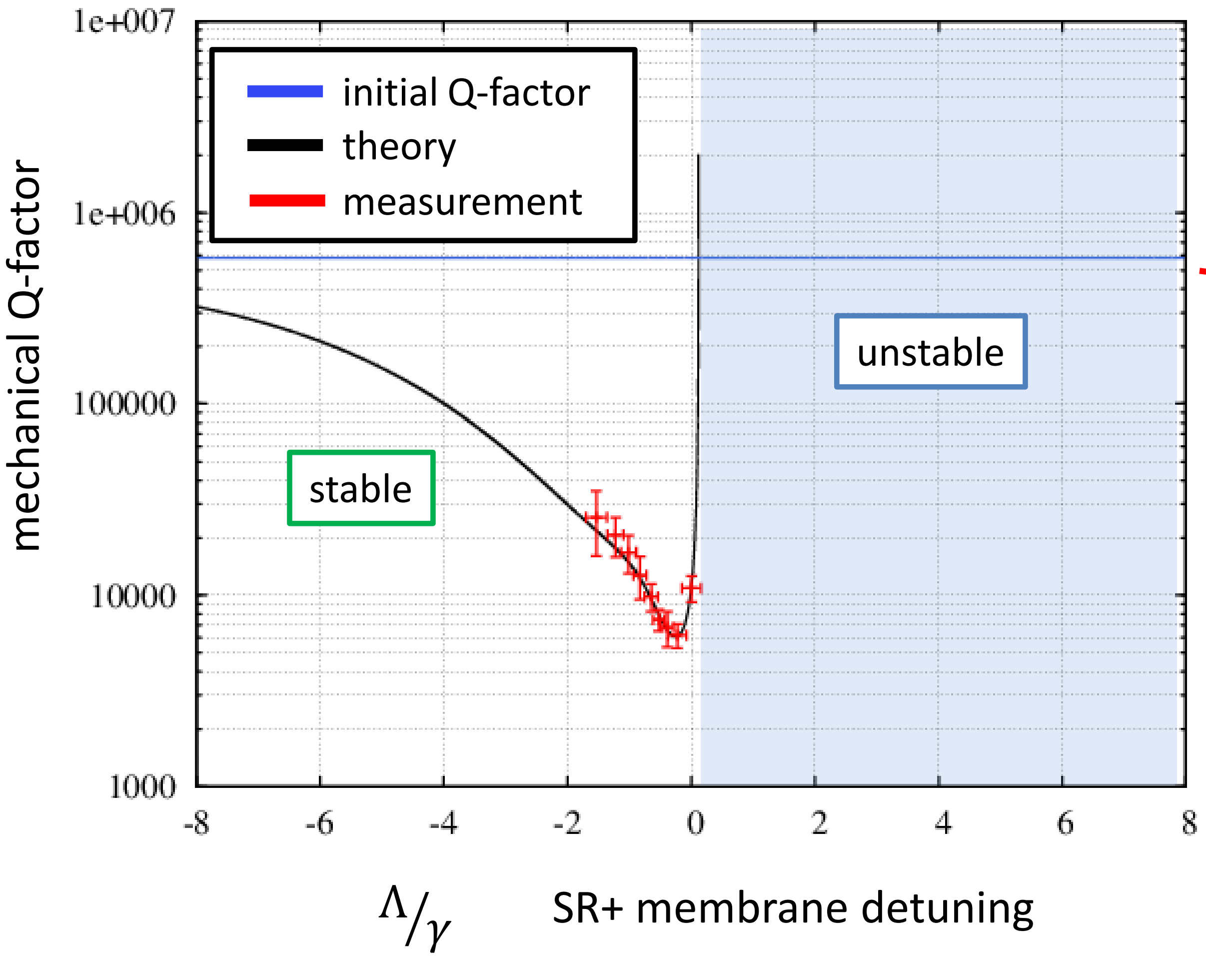
Stable + unstable regime measurments

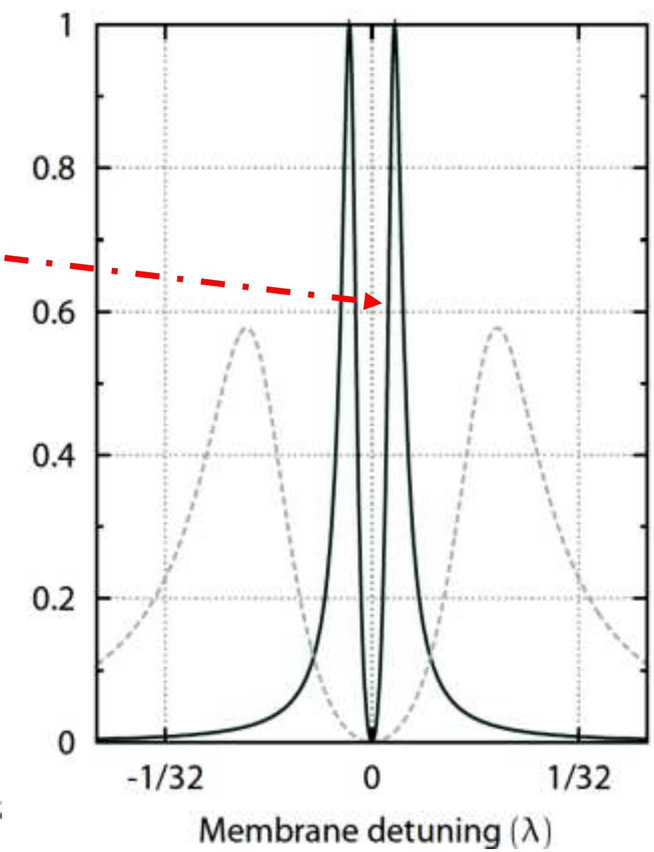




Λ/γ SR+ membrane detuning

Stable + unstable regime measurments





Conclusion

- Dynamical back-action off dark-port investigated and theory by Tarabrin confirmed
- Optical spring have some stable regions.
  Stable optical spring in GWD with single carrier. Usefull?
- Operation off dark-port leads to new type of dynamical back-action: dissipative coupling

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$\tau\hbar\alpha\eta\kappa\ \gamma o\mu$!