Arm Cavity as Squeezing Filter via Entanglement Swapping

Intra-Cavity Squeezing for White-Light Cavities

Yanbei Chen

on behalf of

Yiqiu Ma, Haixing Miao, Jan Harms, Matt Evans, Roman Schnabel

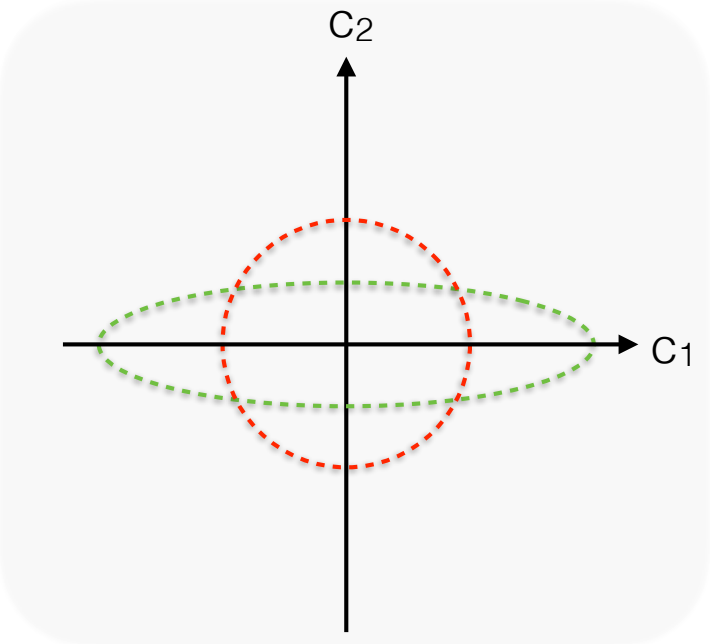
Degenerate vs Non-Degenerate OPA

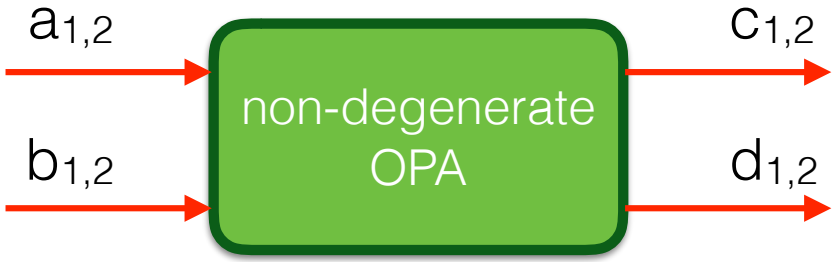
$$c_1 = e^{+r} a_1$$

$$c_2 = e^{-r} a_2$$

phase-sensitive amplification

$$S_{c_1 c_1} = e^{+2r},\ S_{c_2 c_2} = e^{-2r},\ S_{c_1 c_2} = 0.$$





$$\begin{aligned} c_1 &= a_1 \cosh r + b_1 \sinh r \\ c_2 &= a_2 \cosh r - b_2 \sinh r \\ d_1 &= b_1 \cosh r + a_1 \sinh r \\ d_2 &= b_2 \cosh r - a_2 \sinh r \end{aligned}$$

phase-insensitive amplification

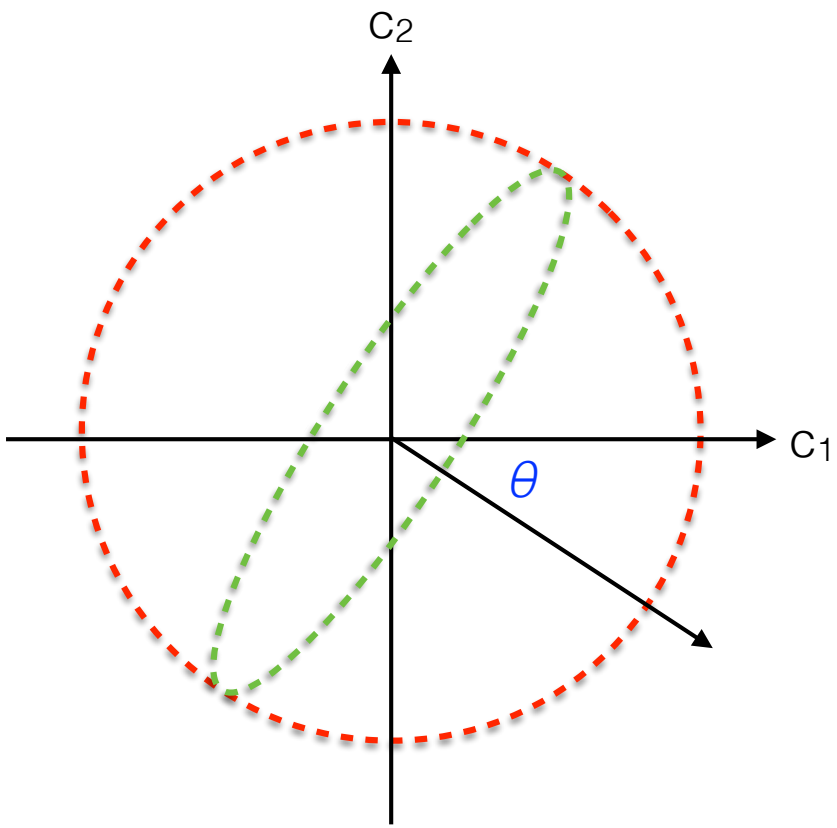
additional noise

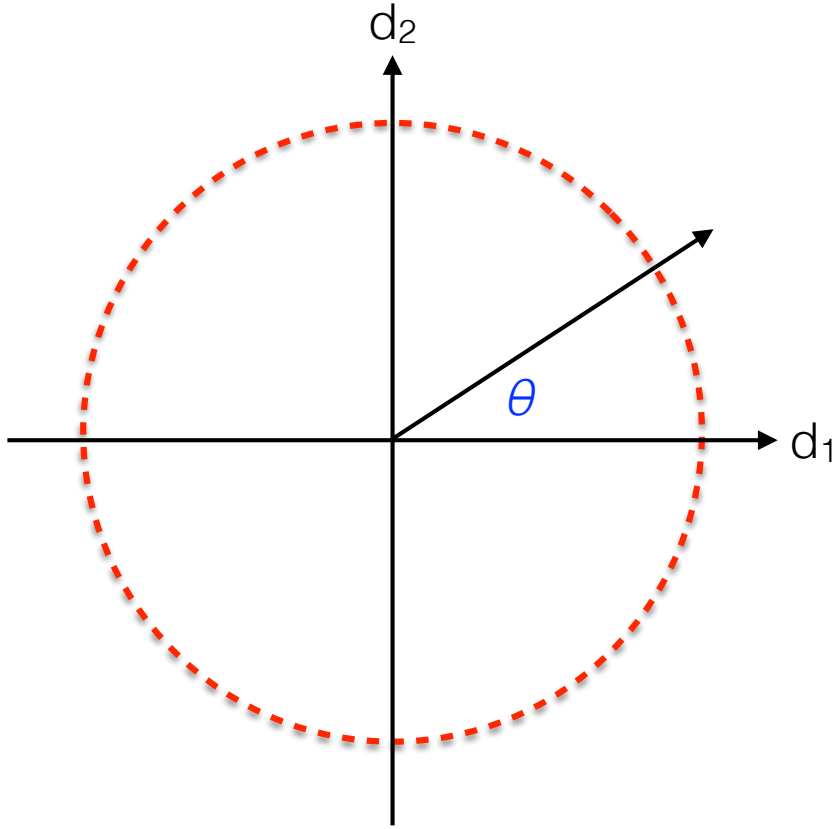
$$S_{c_1 c_1} = S_{c_2 c_2} = \cosh 2r, \quad S_{c_1, c_2} = 0$$

$$S_{d_1 d_1} = S_{d_2 d_2} = \cosh 2r, \quad S_{d_1, d_2} = 0$$

$$r \gg 1 : \ c_1 \sim d_1, \quad c_2 \sim -d_2$$

EPR Entanglement!





can predict $c_{-\theta} = c_1\cos\theta - c_2\sin\theta$

after subtraction: conditionally squeezed!

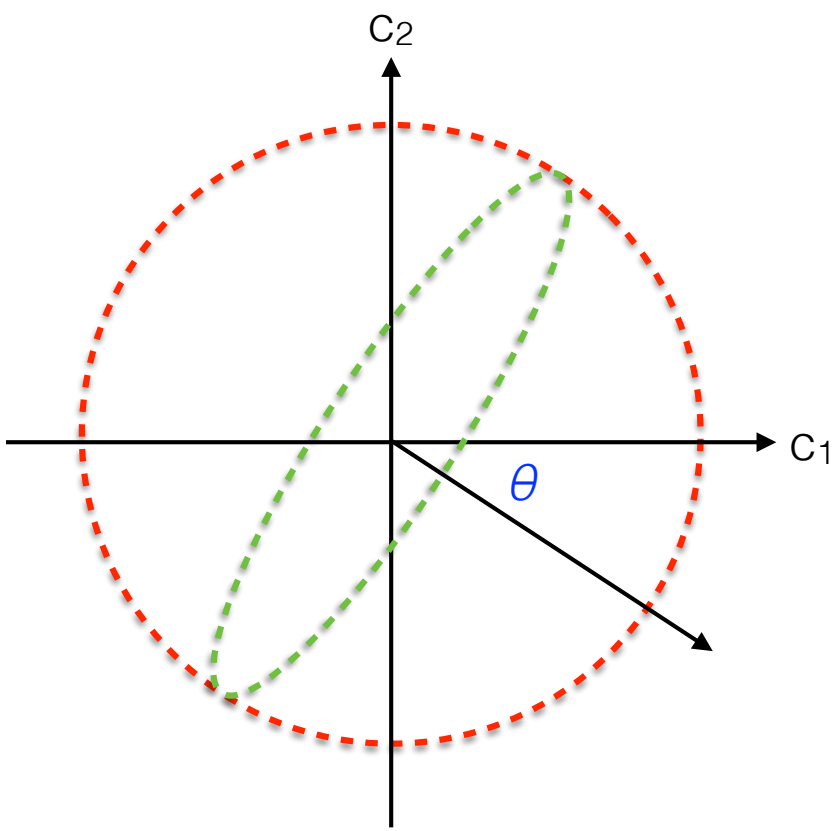
$$S_{c_{-\theta}c_{-\theta}} = \frac{1}{\cosh 2r}, \quad S_{c_{\pi/2-\theta}c_{\pi/2-\theta}} = \cosh 2r$$

~3dB less than single squeezer

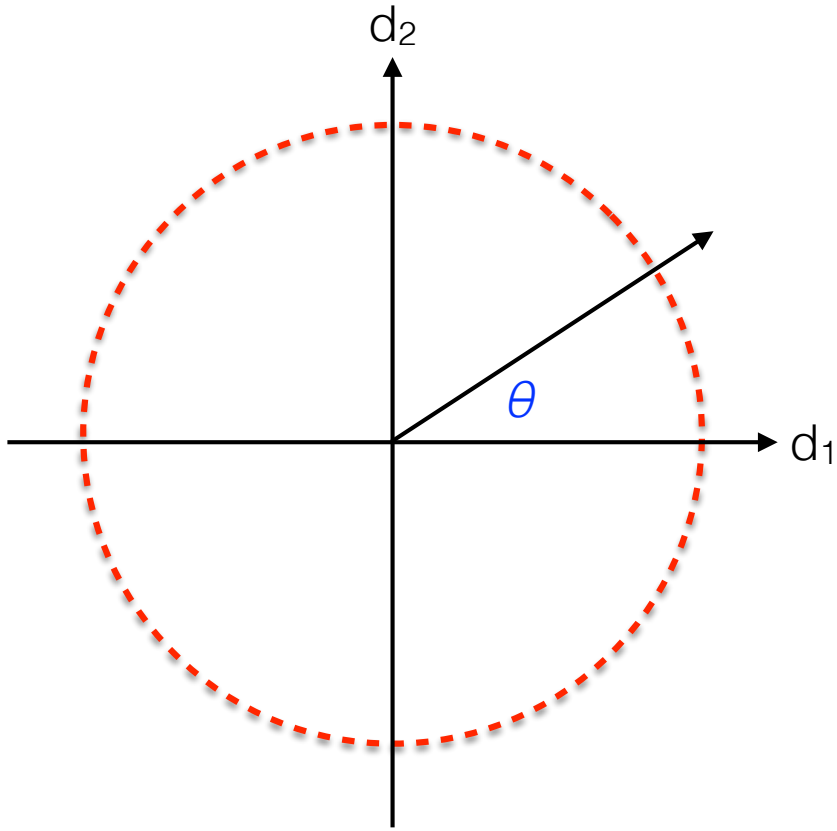
measuring $d_\theta = d_1\cos\theta + d_2\sin\theta$

Measurement of entangled beam produces conditional squeezing

Using EPR



sent to dark-port of main IFO

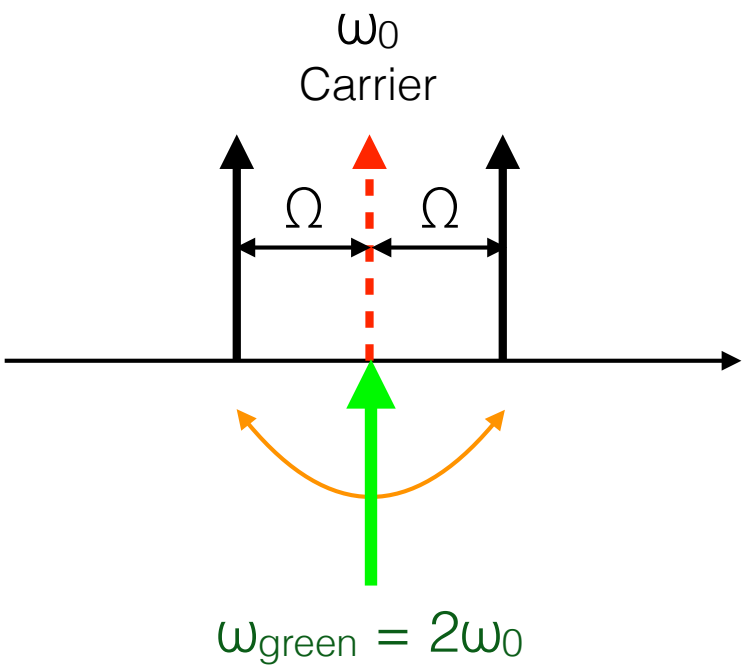


sent to filter cavity then detect

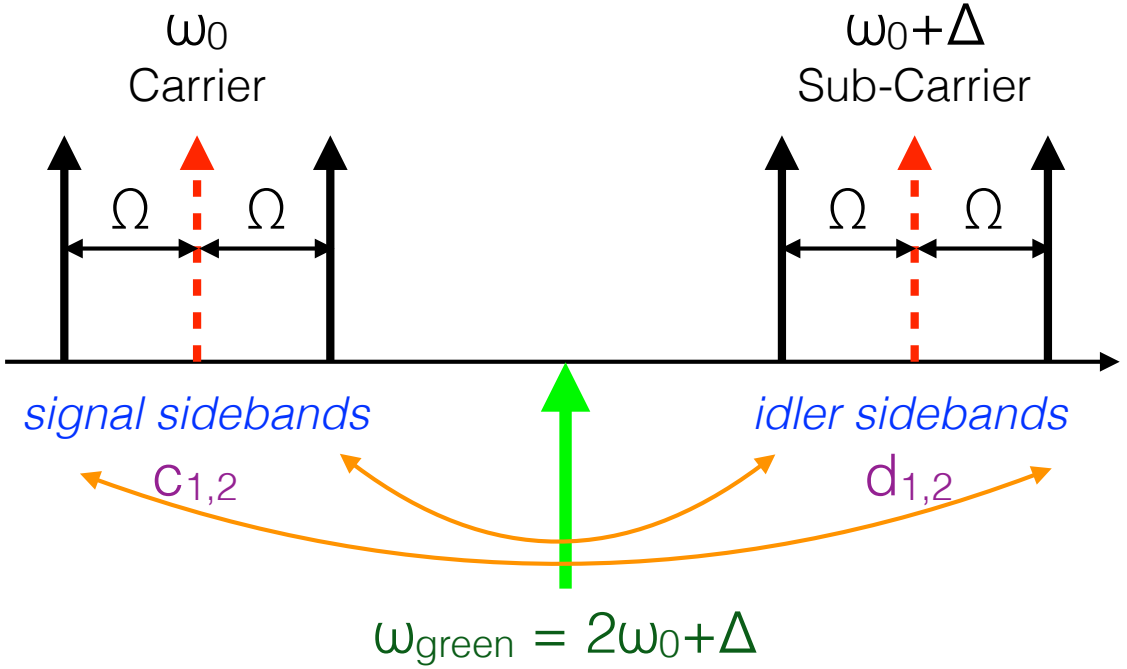
frequency-dependent measurement of **d**
[rotate by $\mathbf{\Phi}$=-θ, and measure 1st quadrature]

means frequency dependent squeezing for **c**

Generating EPR

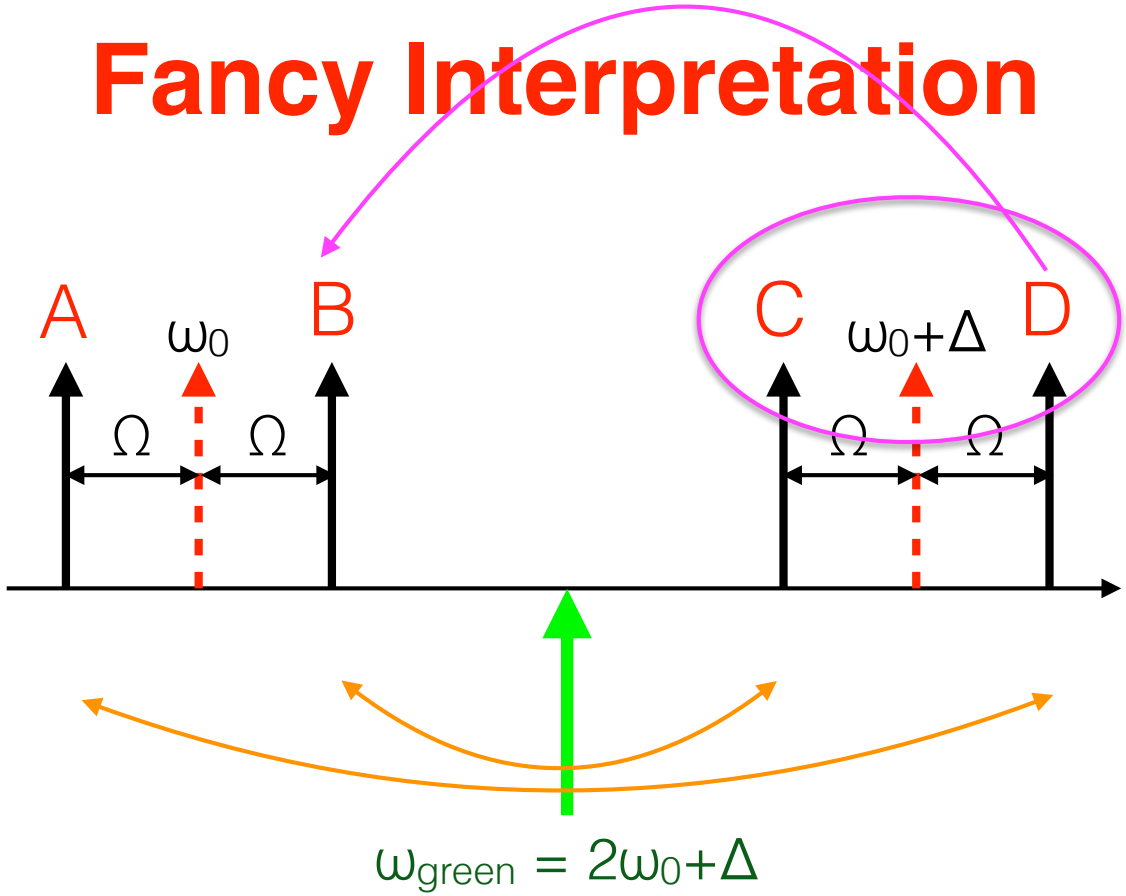


correlations between upper/ lower sideband fields



correlations between upper/ lower sideband fields

Fancy Interpretation



- **From squeezer:** B & C form EPR pair
- **Detection of sub-carrier:** Joint measurement of C & D
- **“Conditioning”:** Classical Operation on B
- D **teleported** to B, **carrier now squeezed**.

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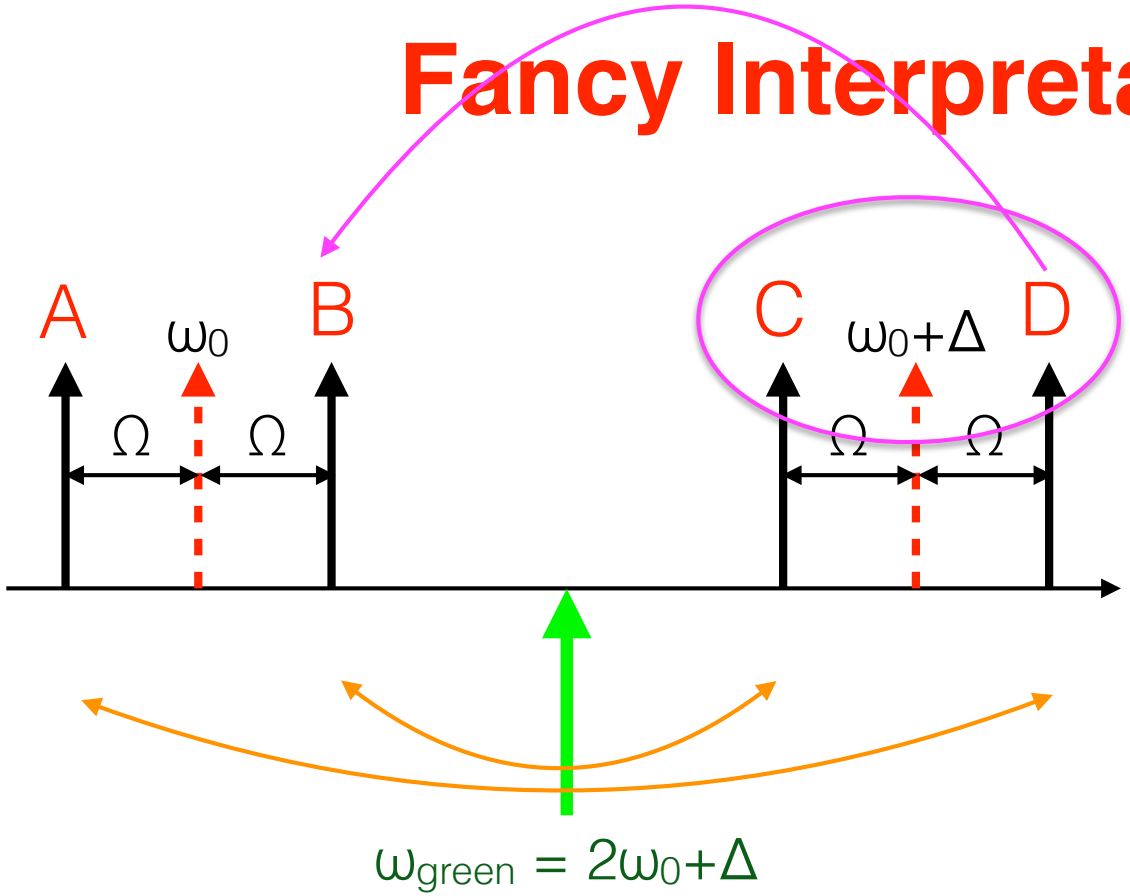

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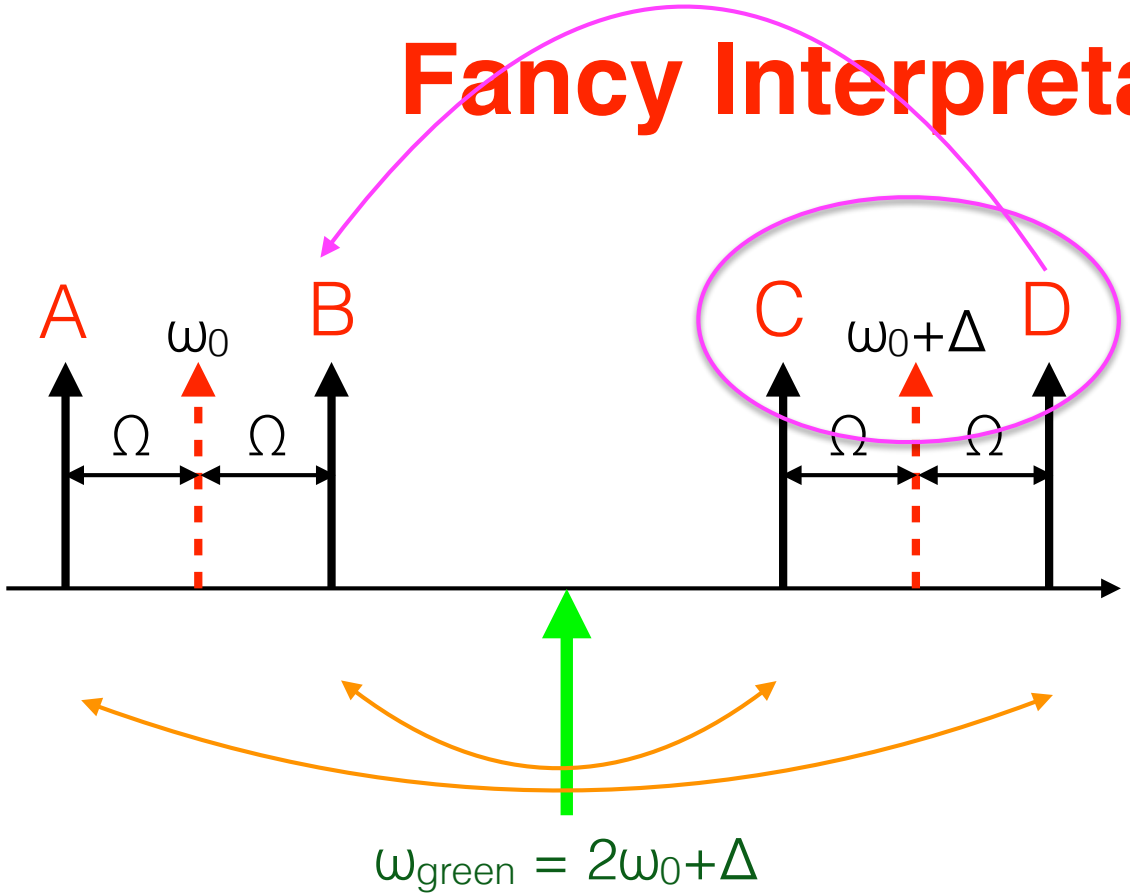

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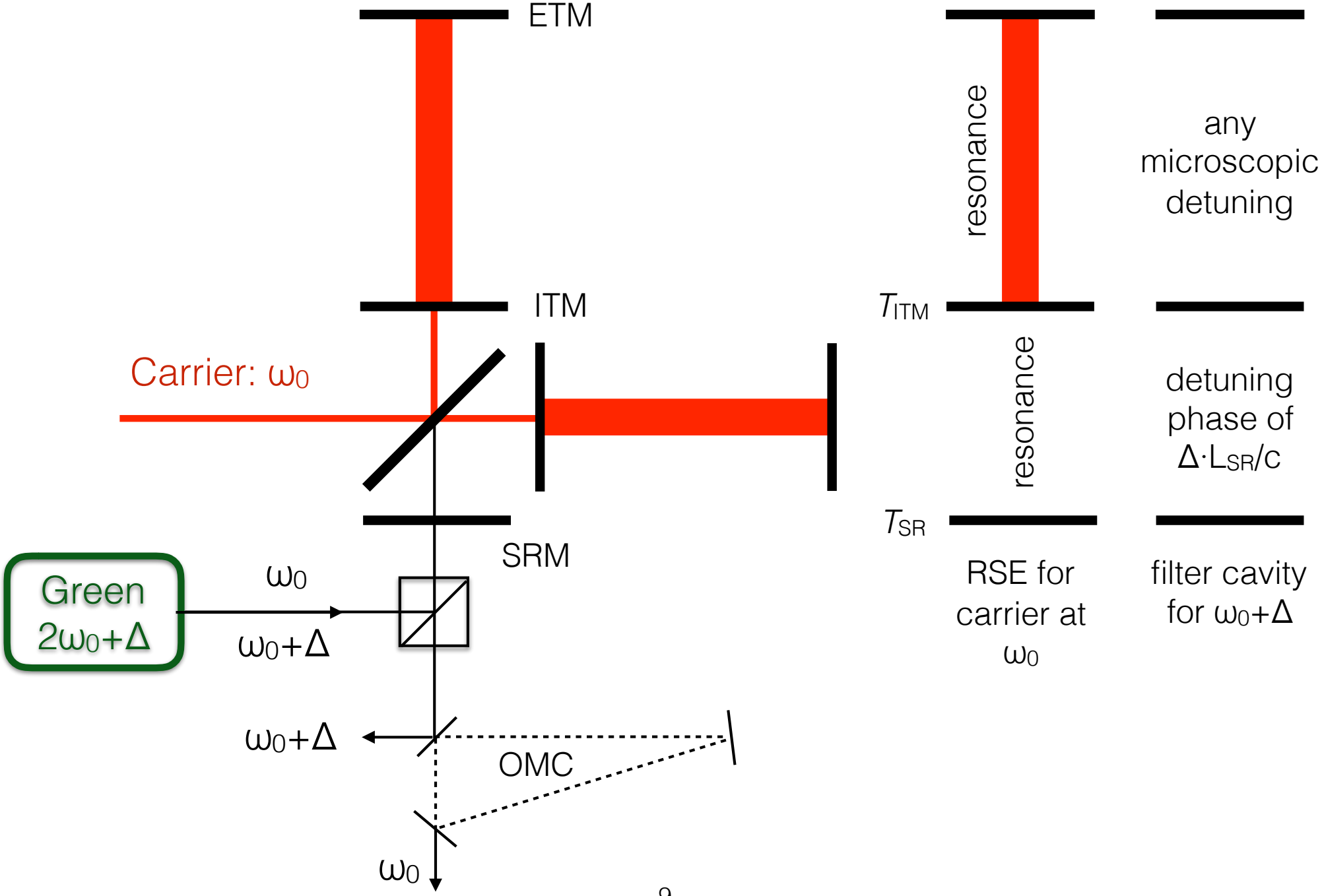
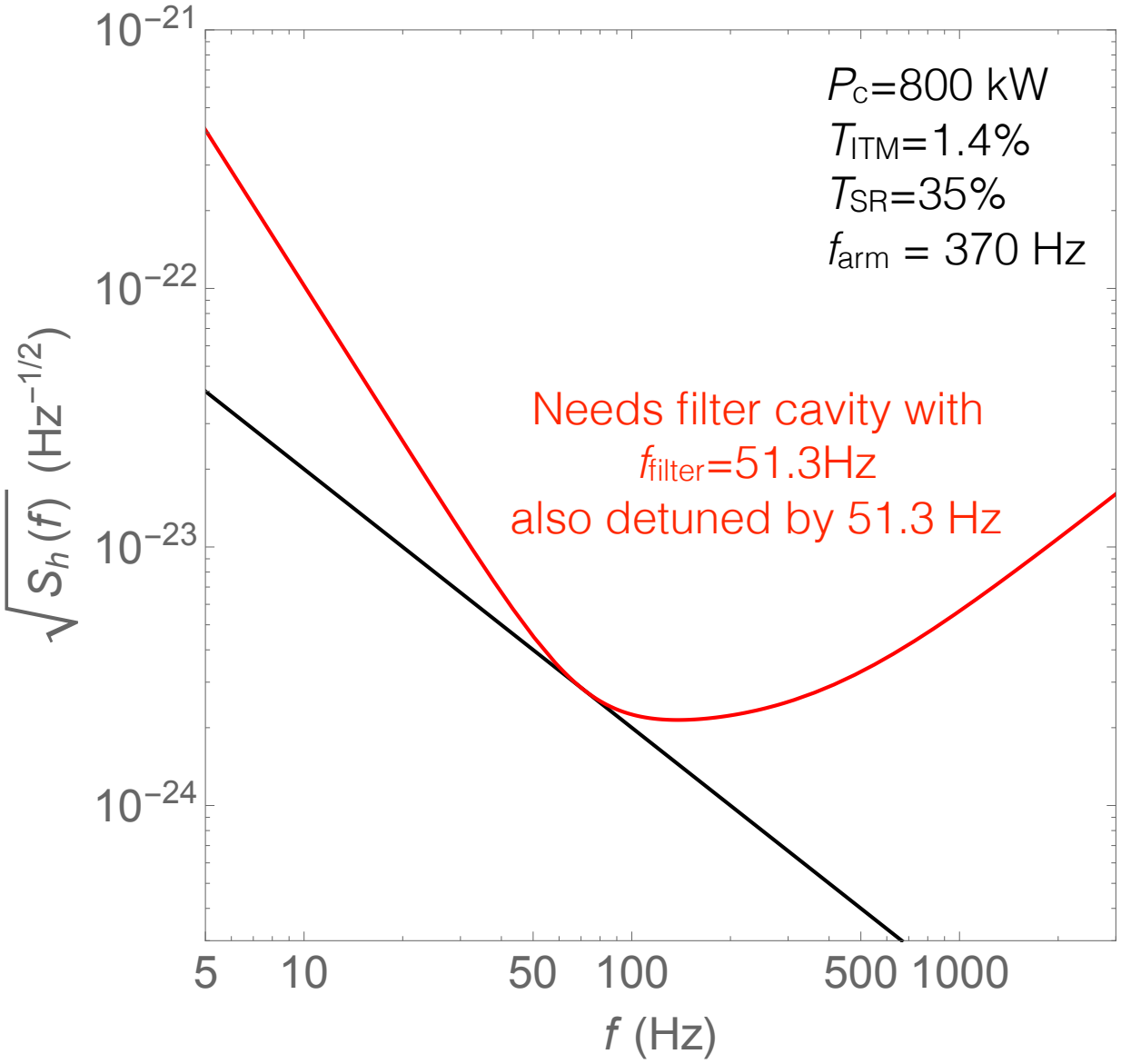
Arm as filter cavity



Example: Advanced LIGO



any microscopic detuning

T_{ITM}=1.4%

detuning phase of $\Delta \cdot L_{SR}/c$

$\phi = 0.28 + n\pi$

T_{SR}=35%

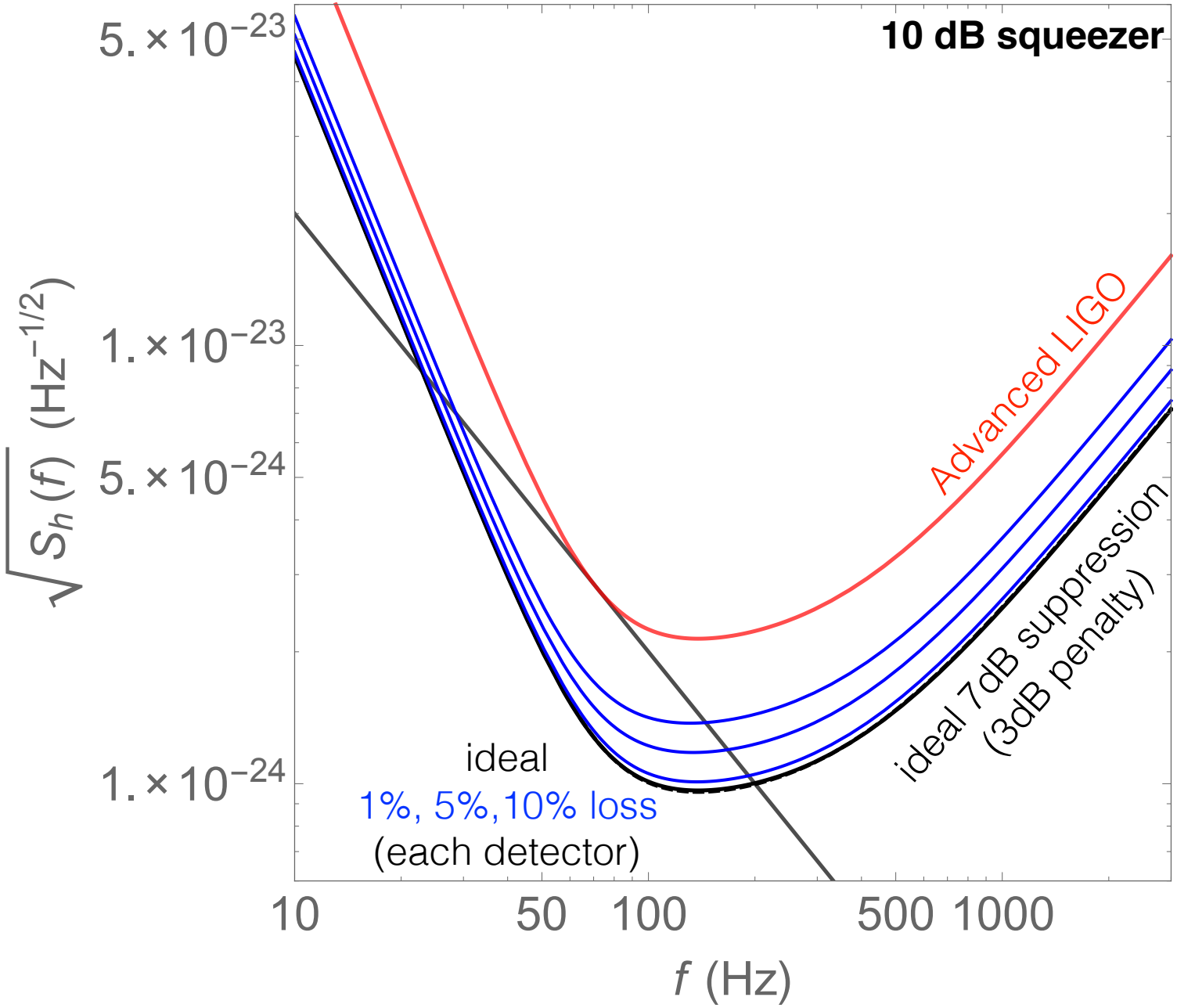
filter cavity for $\omega_0+\Delta$

for L_{SR}=15 meter

Δ = *891* kHz+*10*·*n* MHz

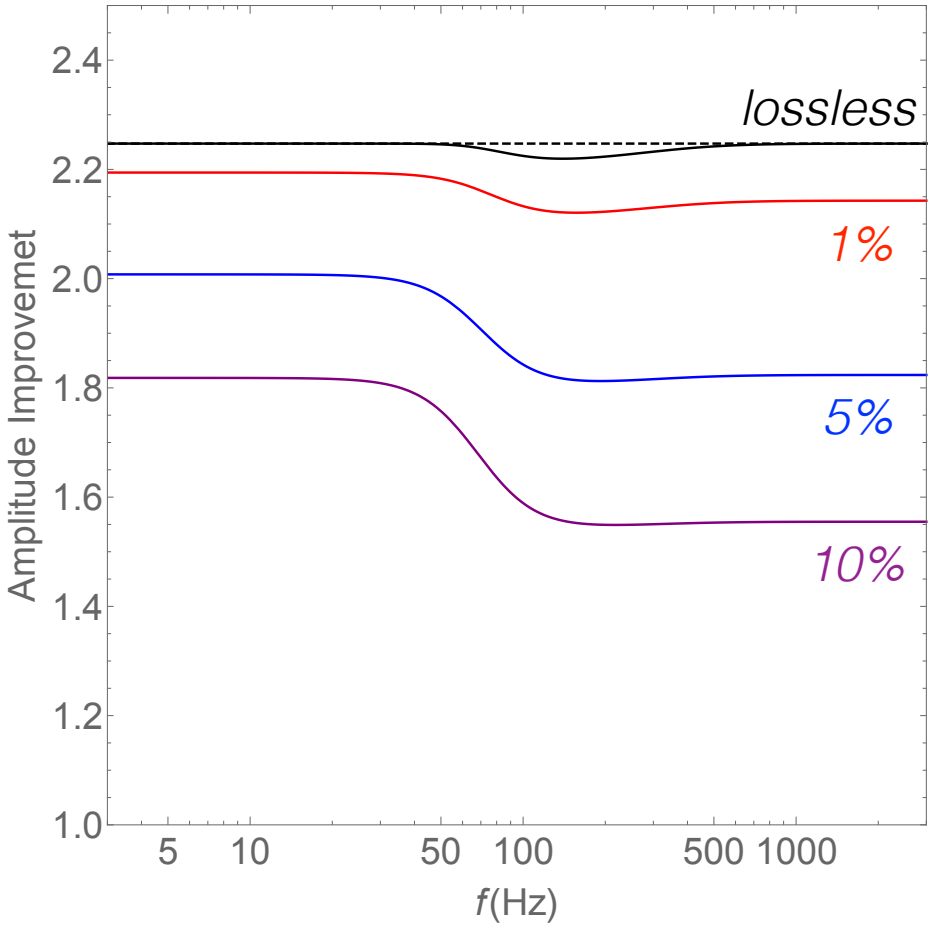
n=0,1,2,…

Noise Spectrum

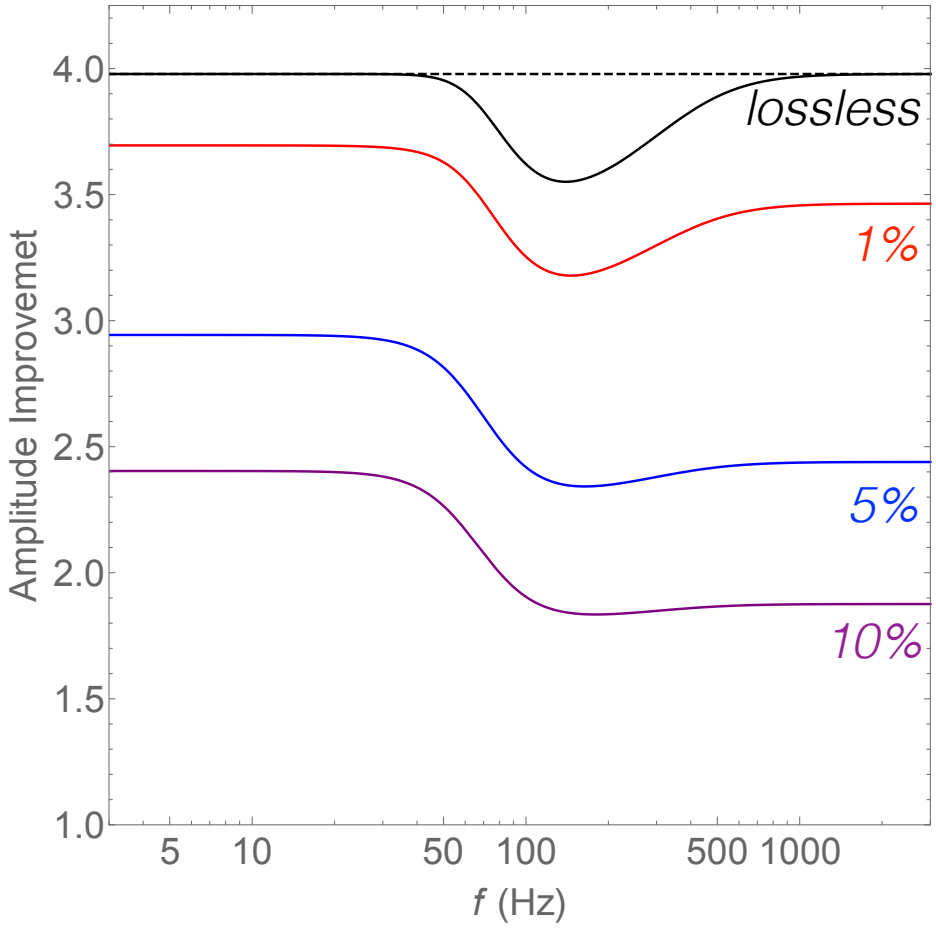


Improvement Factor

10 dB squeezer

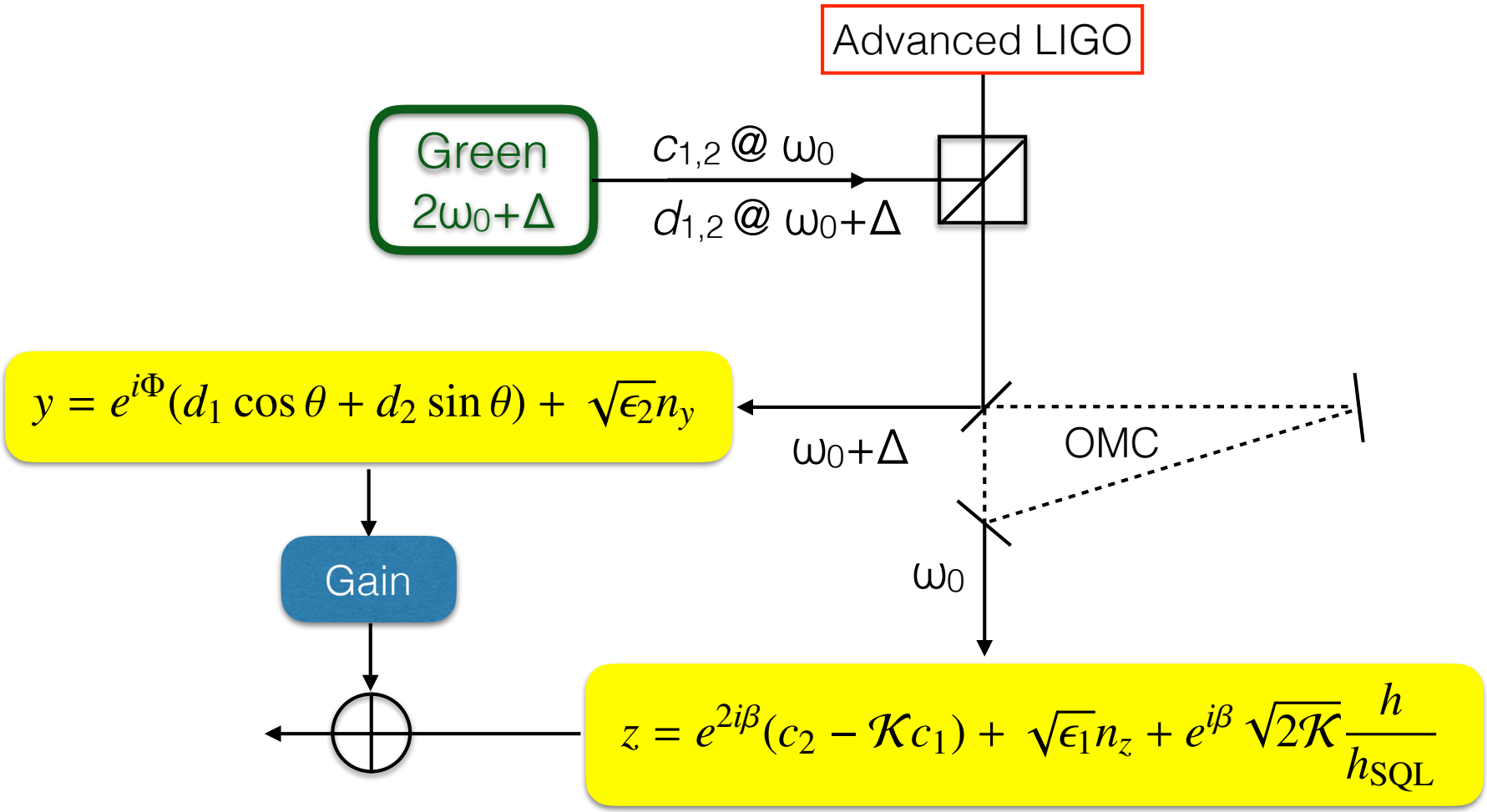


15 dB squeezer



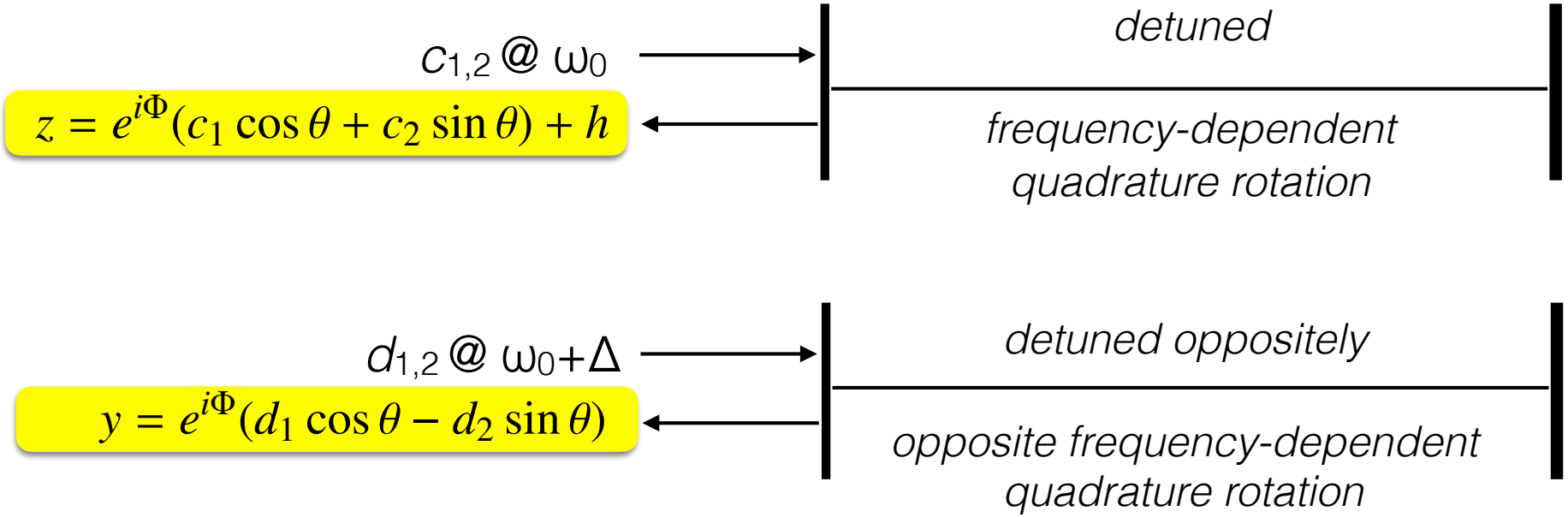
loss is the same for both photodetectors

Details



- **Ideal**: 3dB less than single squeezer
- **Losses:**
  - Filter loss much suppressed; other losses remain
  - Only sub-carrier loss important @ low frequencies

GEO 600: Detuned SR without RadiationPressure



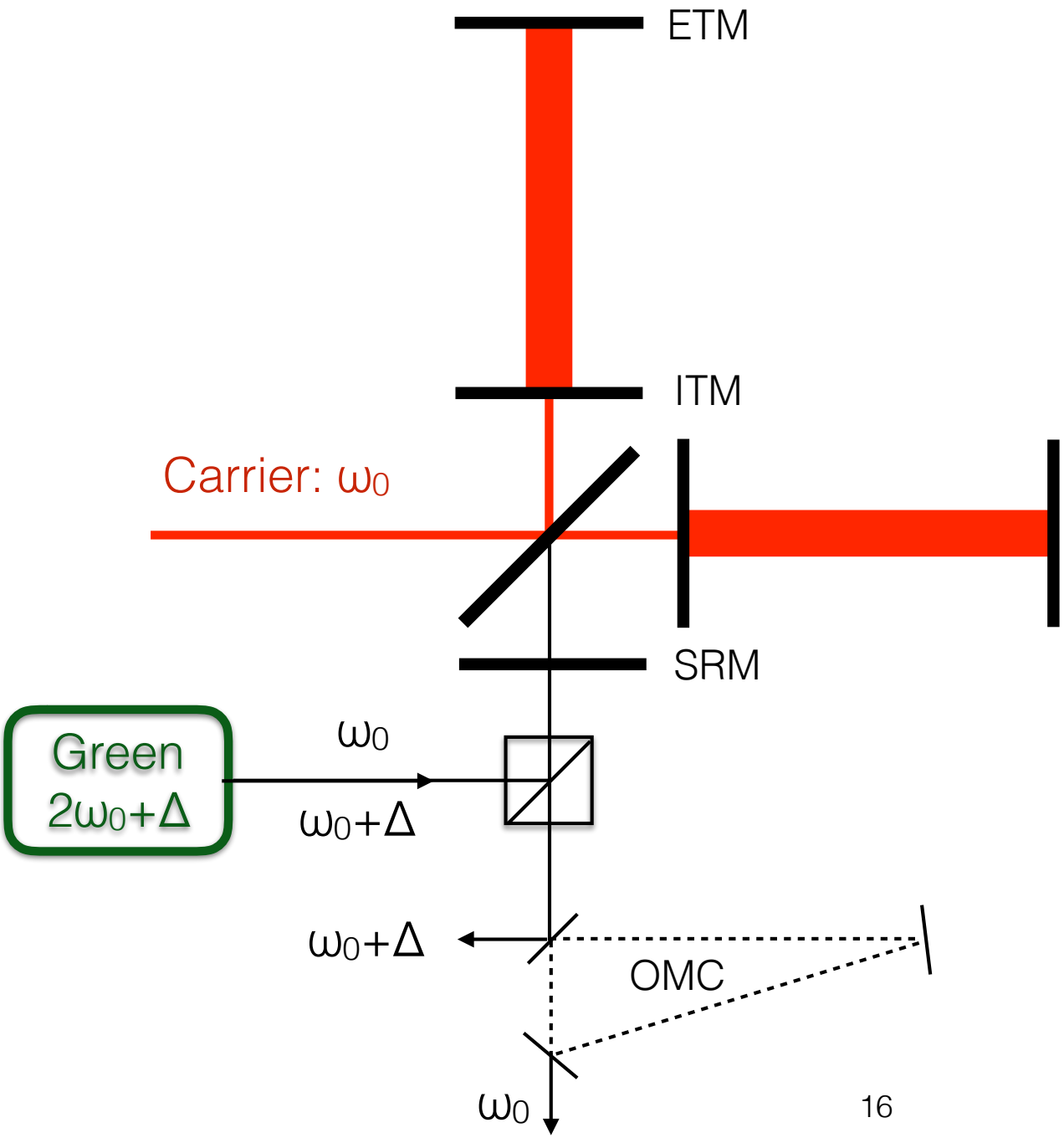
Direct subtraction achieves desired squeezing!!

Intra-Cavity Squeezing

- Optomechancail Filter for White-Light Cavity can also be realized this way

- Question: how to deal with optical instabilities?

Summary



- Squeezer pumped at an *offset frequency* produces entangled beams
- Arm cavity can be used as squeezing filter. *Examples:*
  - Advanced LIGO
  - GEO 600
- Filter for White-Light Cavity