Cavity Enhanced Sum Frequency Generation

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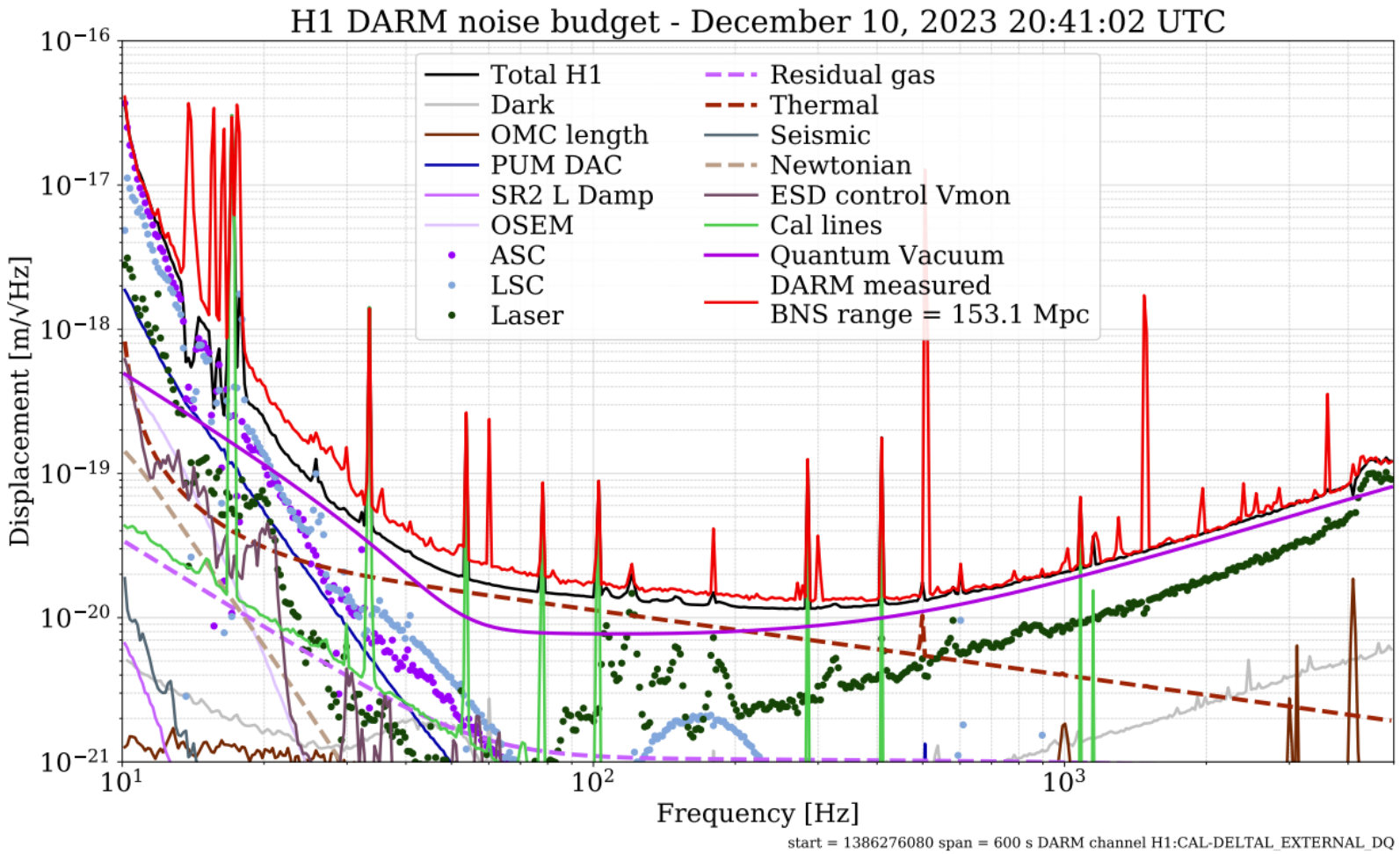
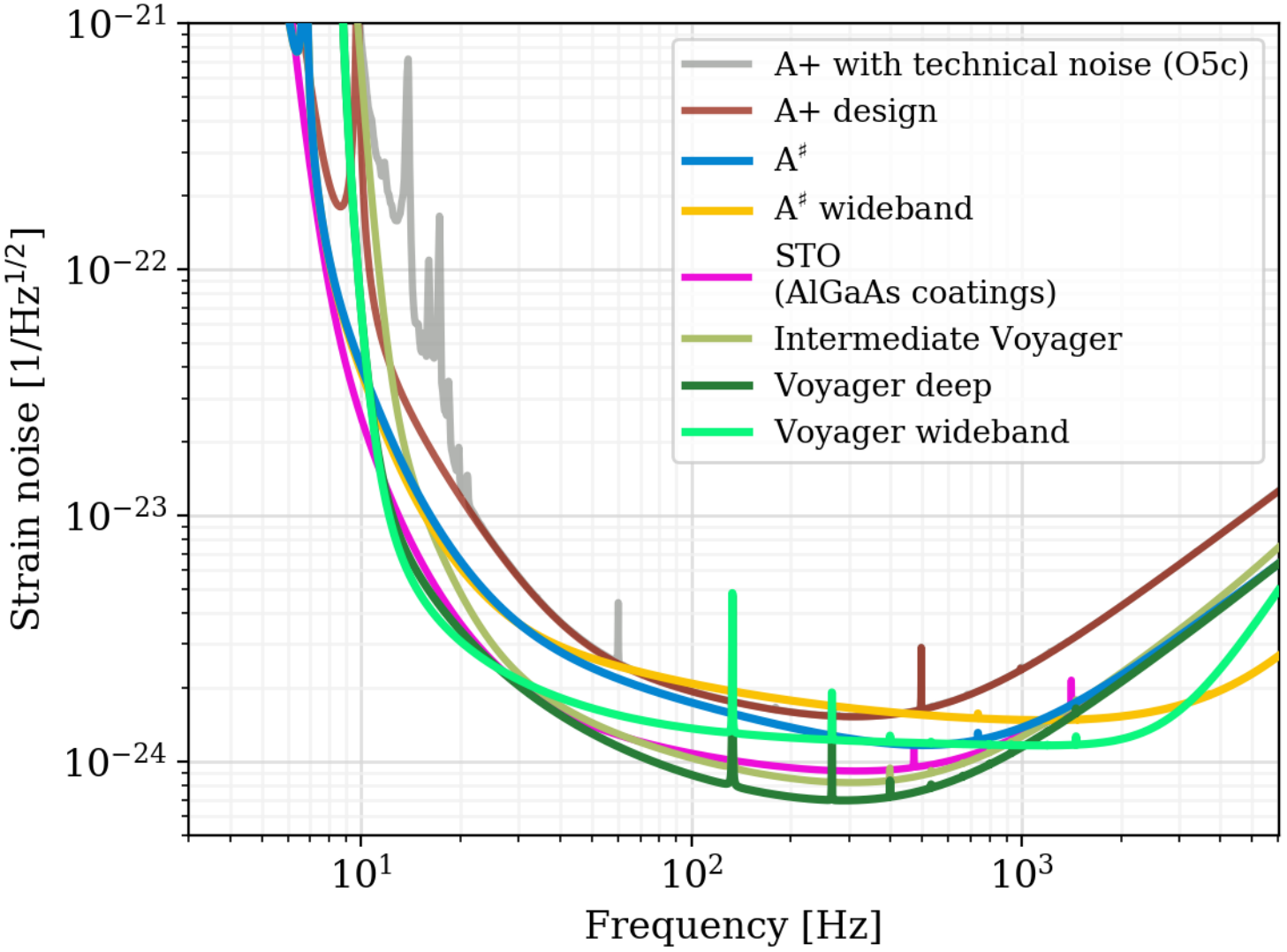
Mentors: Francisco Salces Carcoba, Rana Adhikari

Introduction

- Sensitivity of LIGO
- **Thermal Noise**



Future LIGO Upgrades



LIGO Voyager Upgrade

Fused Silica → Crystalline Silicon

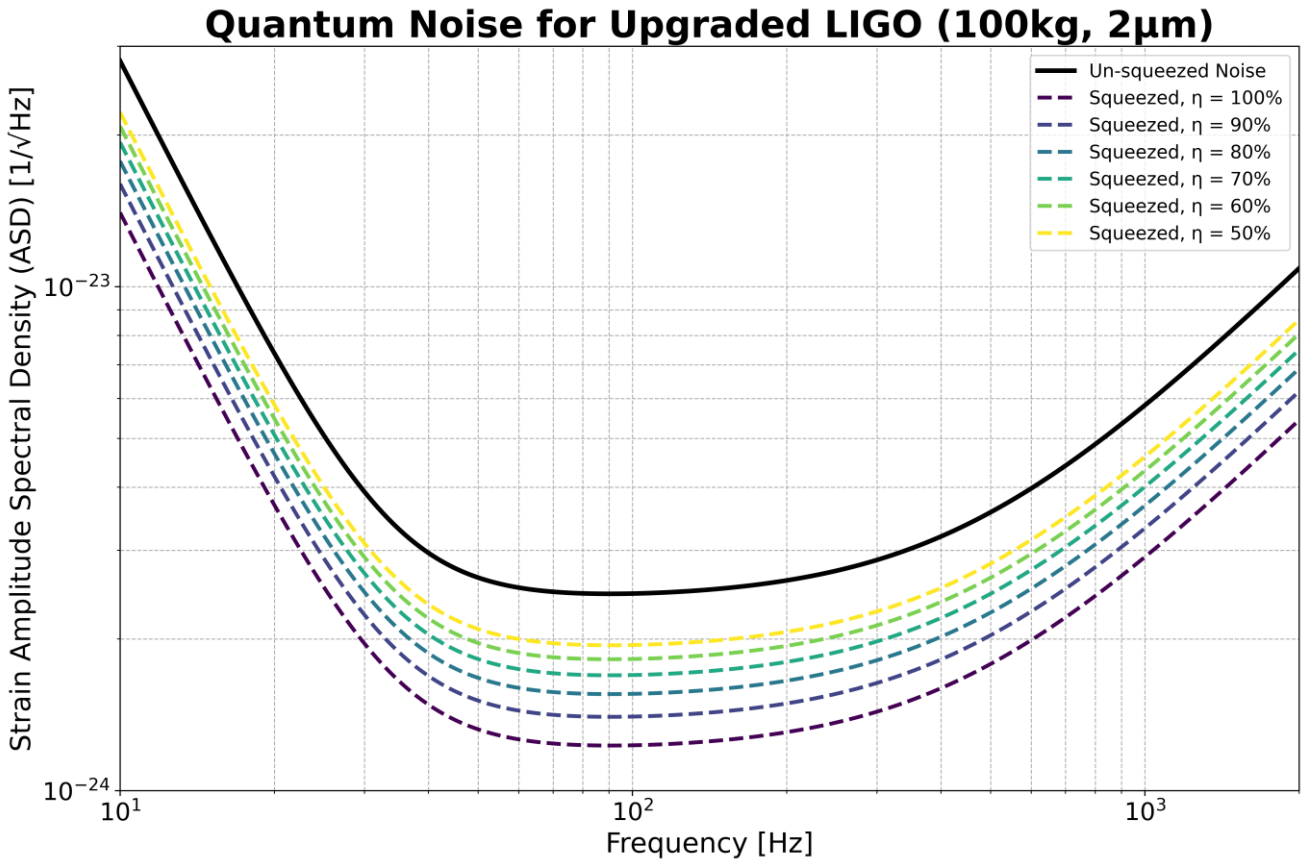
1064 nm → 2 Micron

Cryogenic cooling

Motivation

- Low **Quantum Efficiency** of Photo detectors at **2 micron**

- **Indirect Detection** of 2 um.
- Using Sum Frequency Generation



Sum Frequency Generation

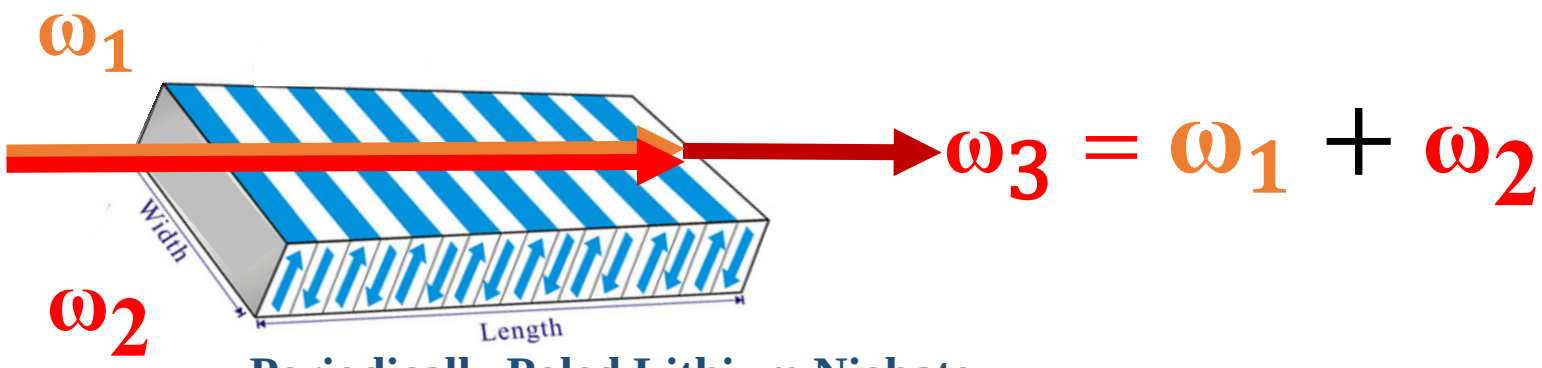
- In conventional Optics: Polarization depends linearly on Electric field. $\tilde{P}(t) = \epsilon_0 \chi^{(1)} \tilde{E}(t)$
- **Non-linear** materials: Higher order dependence are considerable.

$$\tilde{P}(t) = \epsilon_0 \left[\chi^{(1)} \tilde{E}(t) + \chi^{(2)} \tilde{E}^2(t) + \chi^{(3)} \tilde{E}^3(t) + \cdots \right]$$

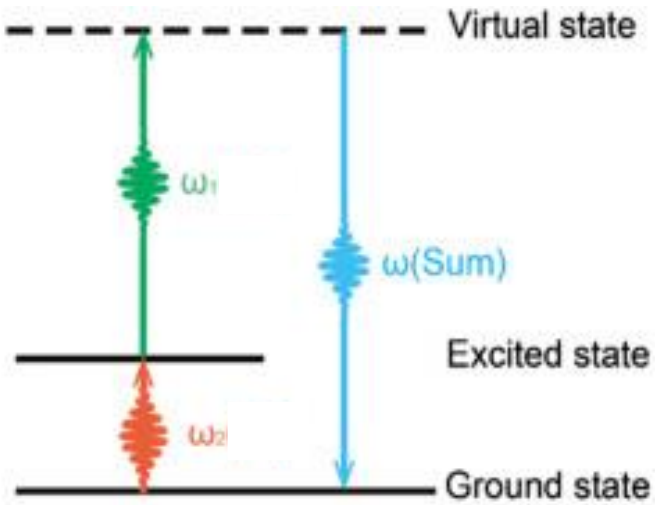
The quantities $\chi^{(2)}$ and $\chi^{(3)}$ are known as the second- and third-order non-linear optical susceptibilities, respectively.

- Second Harmonic Generation.
- Difference frequency Generation.
- Sum frequency generation.

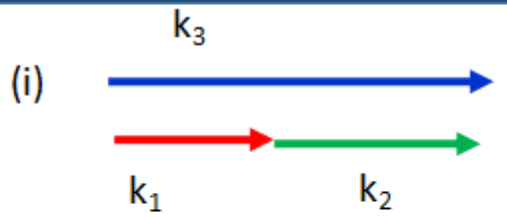
Sum Frequency Generation



Periodically Poled Lithium Niobate

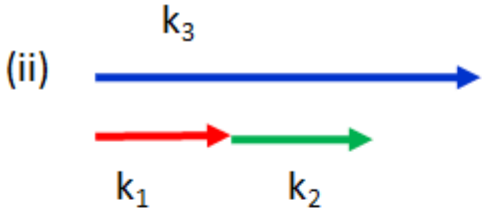


Sum Frequency Generation



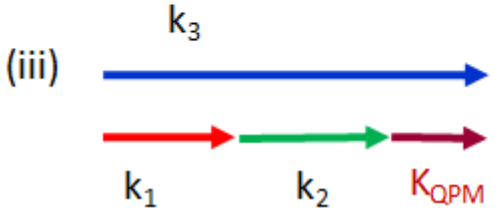
Phase-Matching

$\Delta\beta = k_3 - k_1 - k_2 = 0$



Non-Phase-Matching

$\Delta\beta = k_3 - k_1 - k_2 \neq 0$

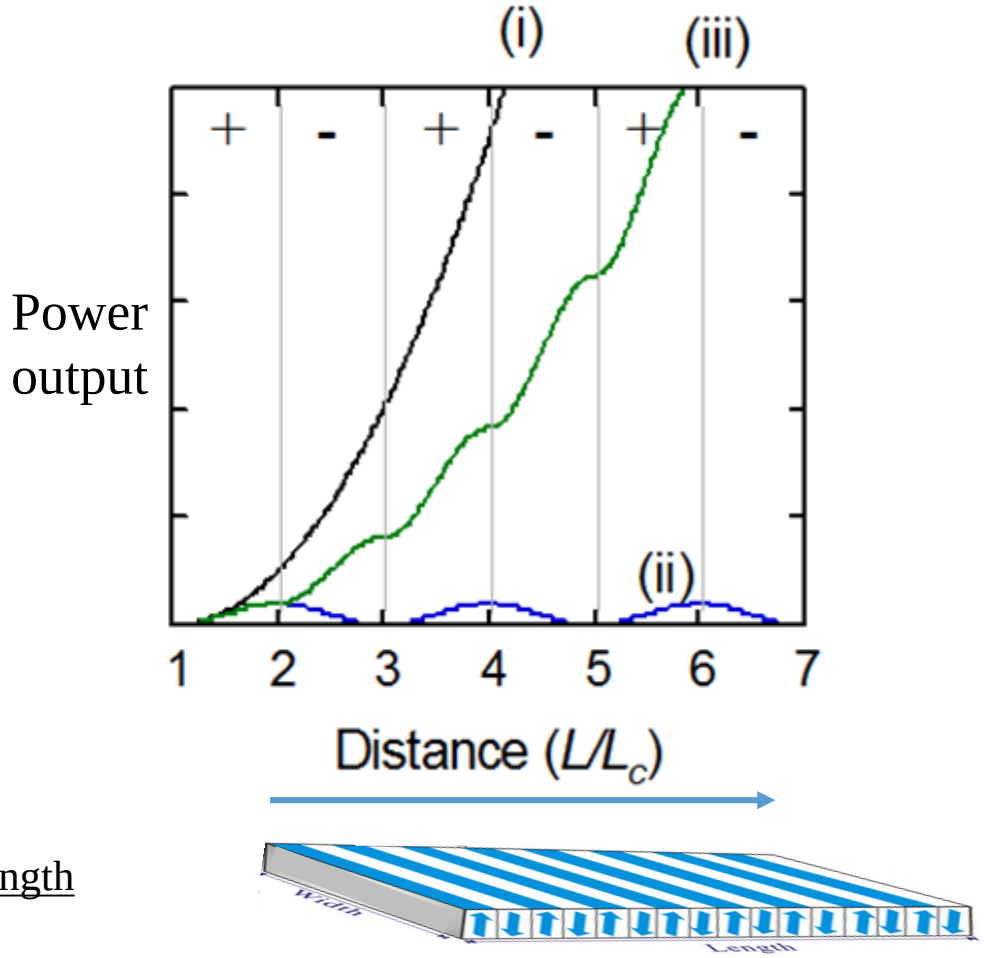


Quasi-Phase-Matching

Periodic poling

Flip in the sign of $\chi^{(2)}$

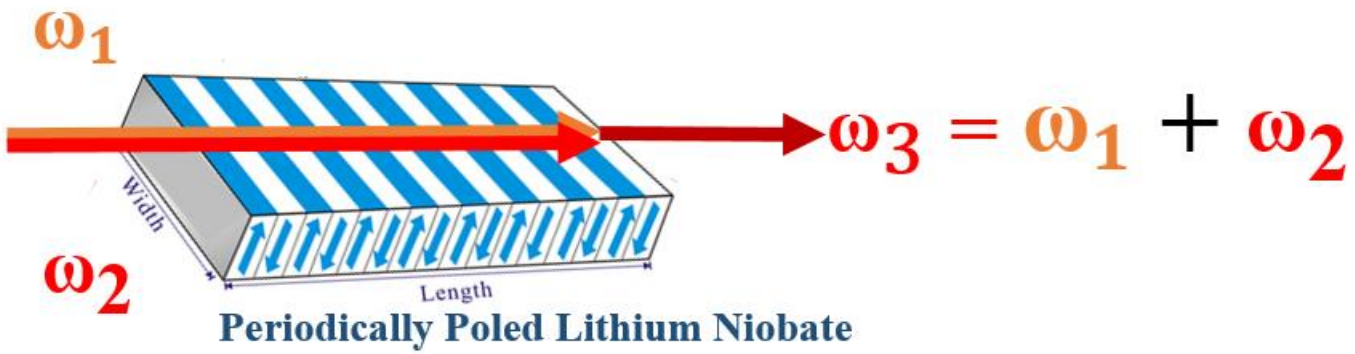
After every coherence length



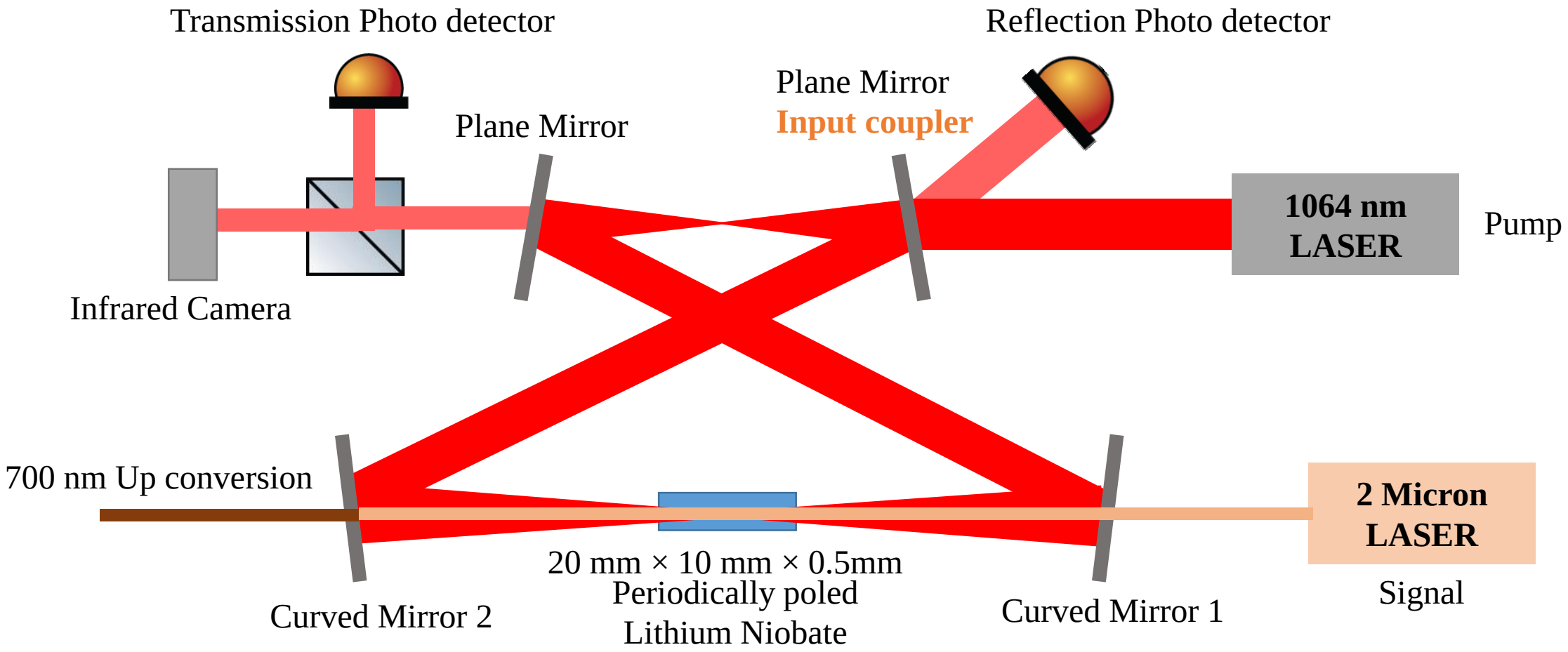
The distance over which the accumulated phase difference of mixing waves reaches π is the "coherence length" L_c

Recap

- Low Quantum Efficiency of Photo detectors at 2 micron
- **Indirect Detection** of 2 um.
- Setting up Sum Frequency Generation.

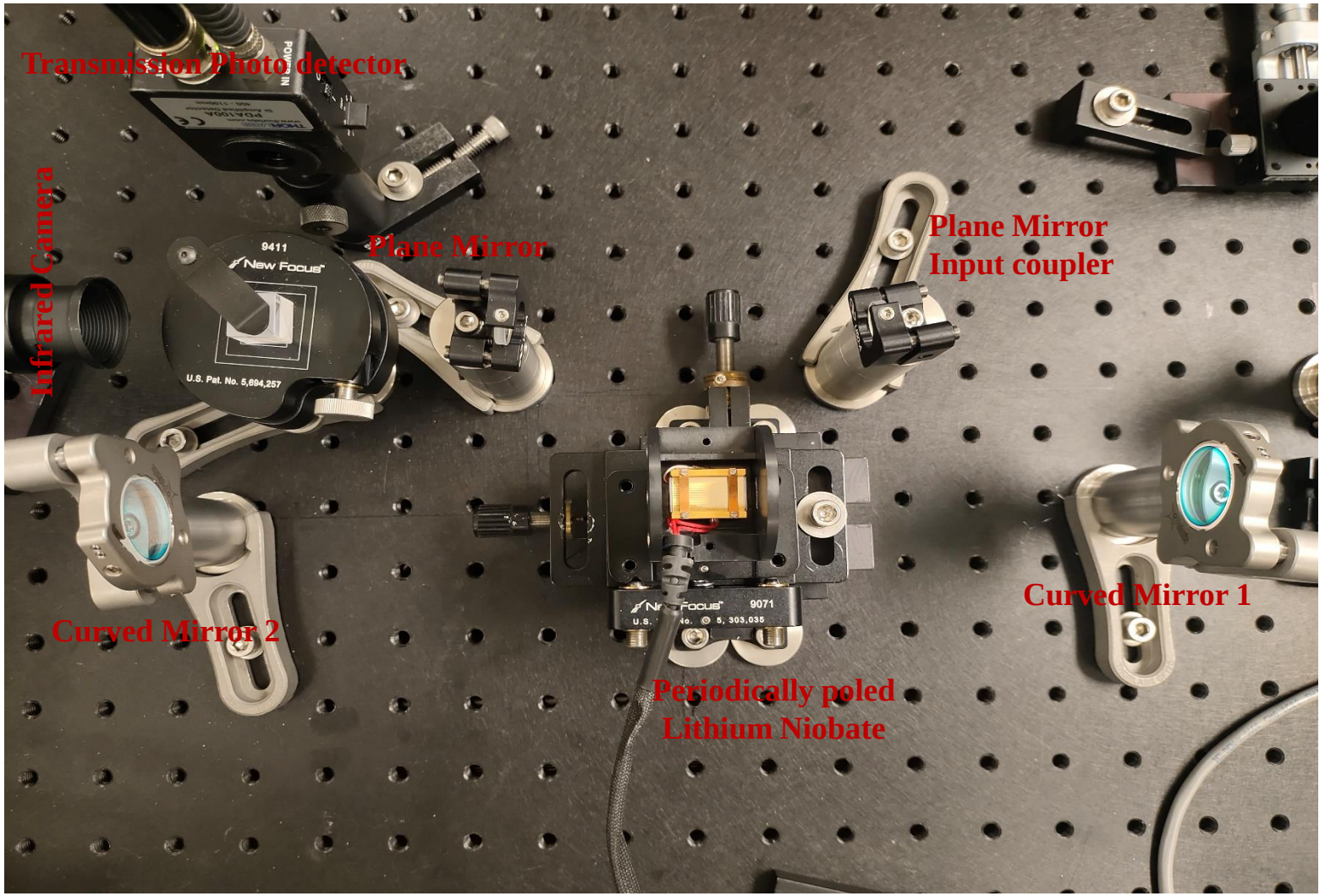


Bowtie Cavity Setup



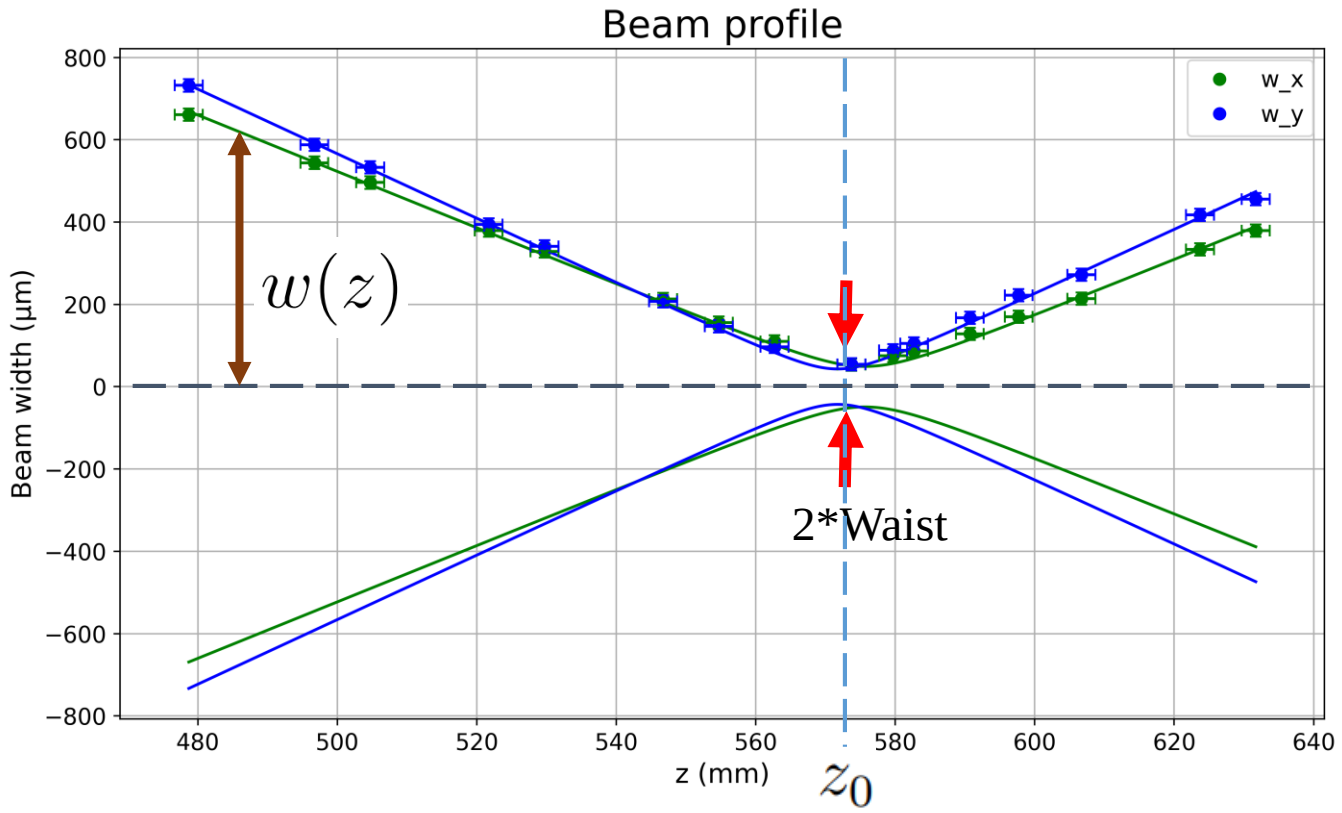
Mirror	Type	Radius of Curvature [m]	Transmission (T)	Reflection (R)
Input Coupler	Flat	∞	0.003	0.997
Plane Mirror	Flat	∞	0.001	0.999
Curved Mirror 1	Curved	0.2	0.001	0.999
Curved Mirror 2	Curved	0.2	0.001	0.999

Bowtie Cavity Setup



Gaussian beam propagation

- Beam complex “q” parameters
  - Measuring the **Beam Profile**
  - Fitting the data and obtaining **q parameters.**



$$w(z) = w_0\sqrt{1+\left(\frac{z-z_0}{z_R}\right)^2}, \quad z_R = \frac{\pi w_0^2}{\lambda}$$

w_0 is the beam waist(minimum width)

z is the axial distance

z_0 is the location of the beam waist

Z_R is the Rayleigh range

λ is the laser wavelength.

$$q(z) = (z - z_0) + iZ_R$$

Gaussian beam propagation

- ABCD Matrices

  Matrices to **model** propagation

  Paraxial assumption

  Thin lenses assumption

$$q(z) = (z - z_0) + iZ_R$$

Free space $\begin{pmatrix} 1 & d \\ 0 & 1 \end{pmatrix}$

Thin lens $\begin{pmatrix} 1 & 0 \\ -\frac{1}{f} & 1 \end{pmatrix}$

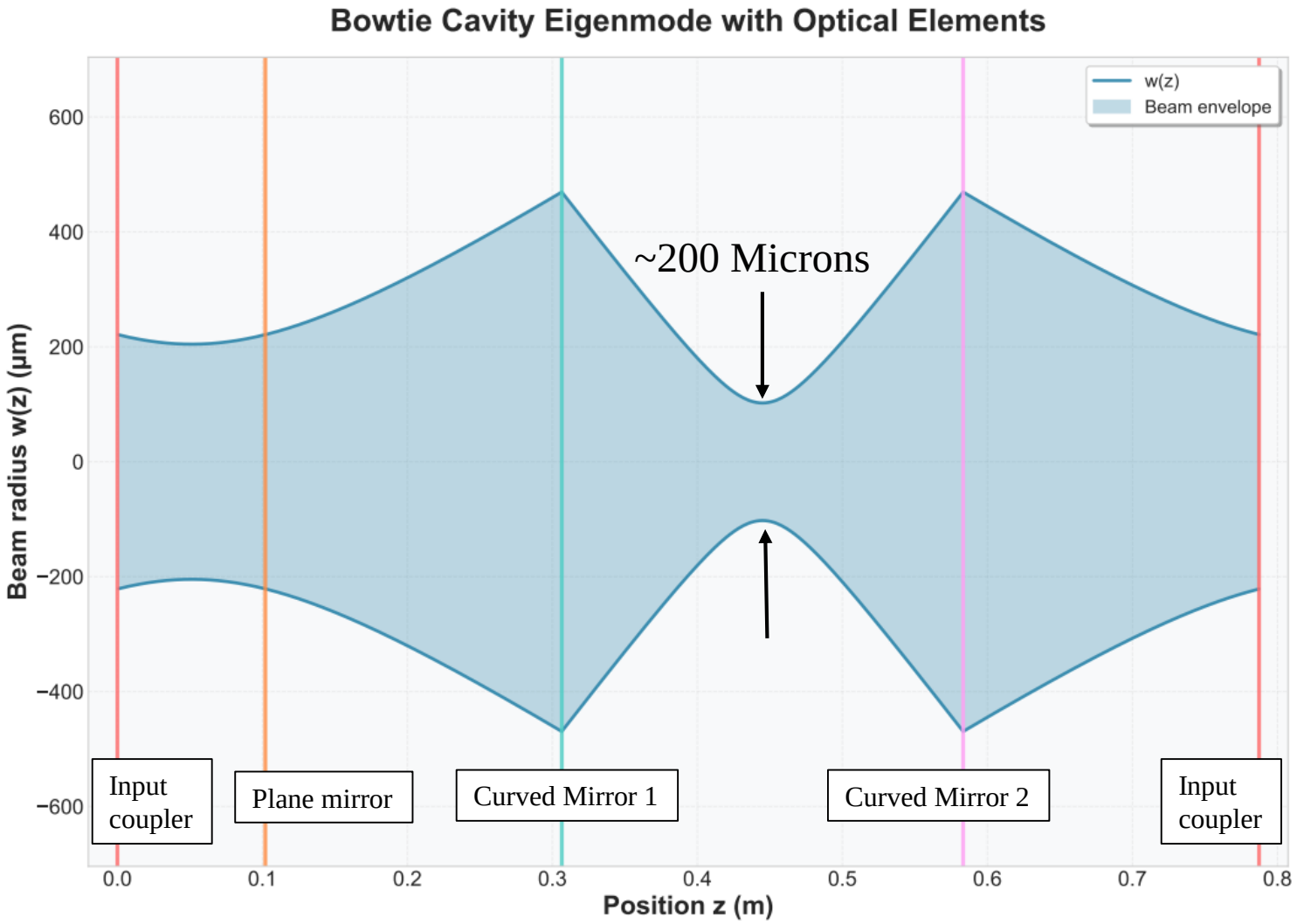
$$M_{\text{total}} = M_N \times M_{N-1} \times \cdots \times M_2 \times M_1 = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$$

$$q_f = \frac{Aq_i + B}{Cq_i + D}.$$

Cavity Eigen mode

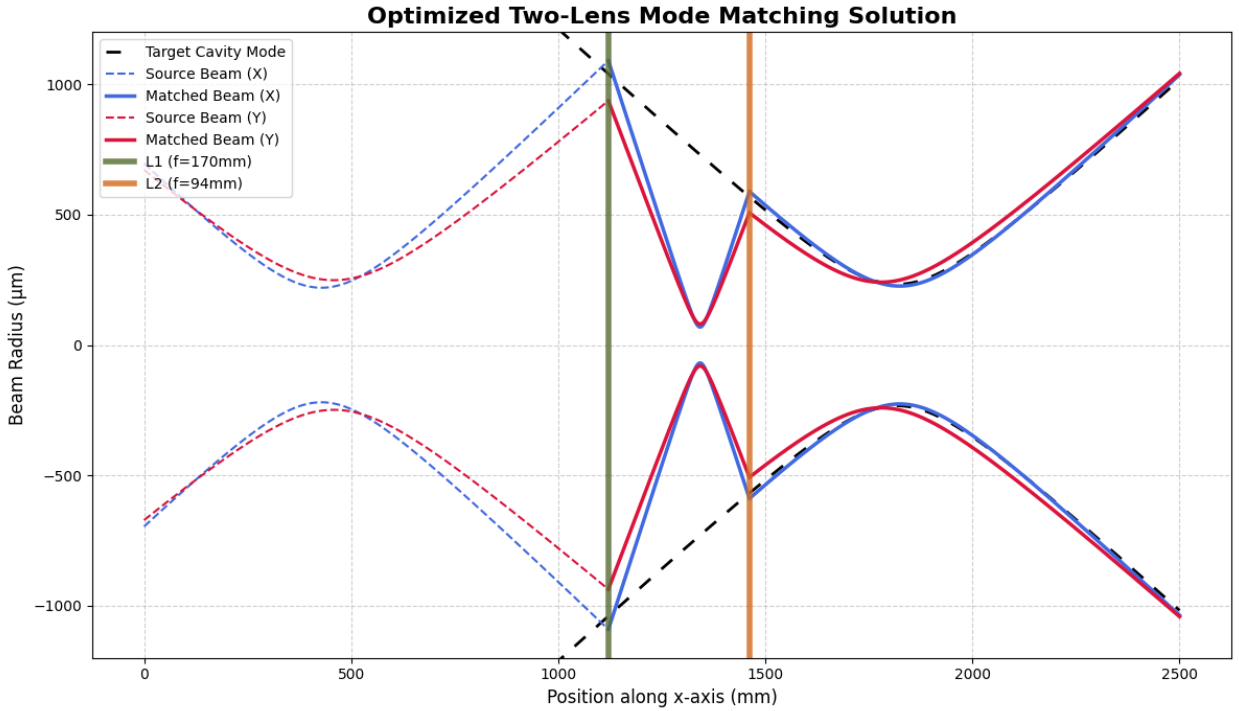
- **Pump-resonant** (1064 nm)
- Cavity **Eigen mode** Calculation
- Gaussian beam propagation

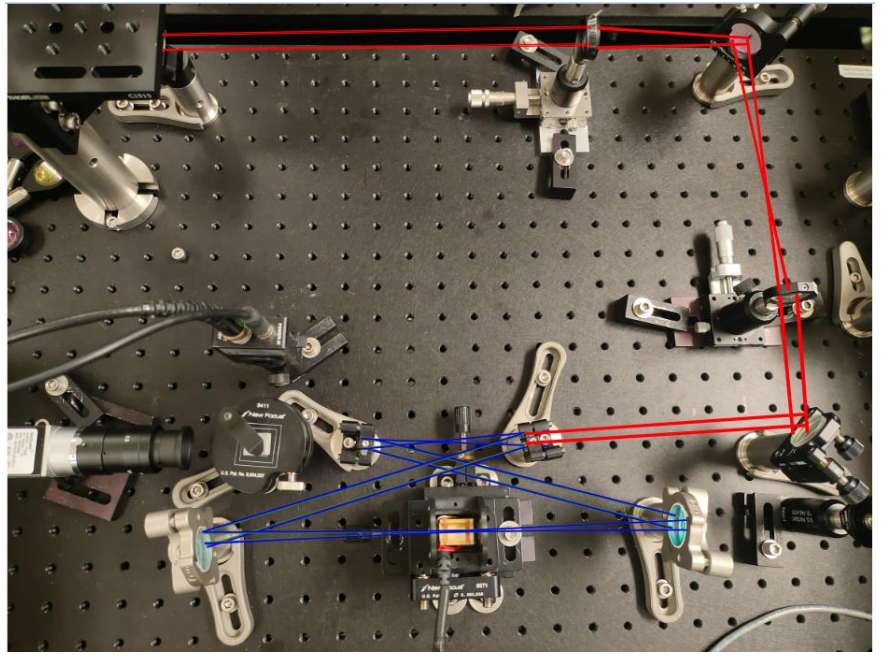
$$q_{\text{input coupler}} = \frac{A \cdot q_{\text{input coupler}} + B}{C \cdot q_{\text{input coupler}} + D}$$



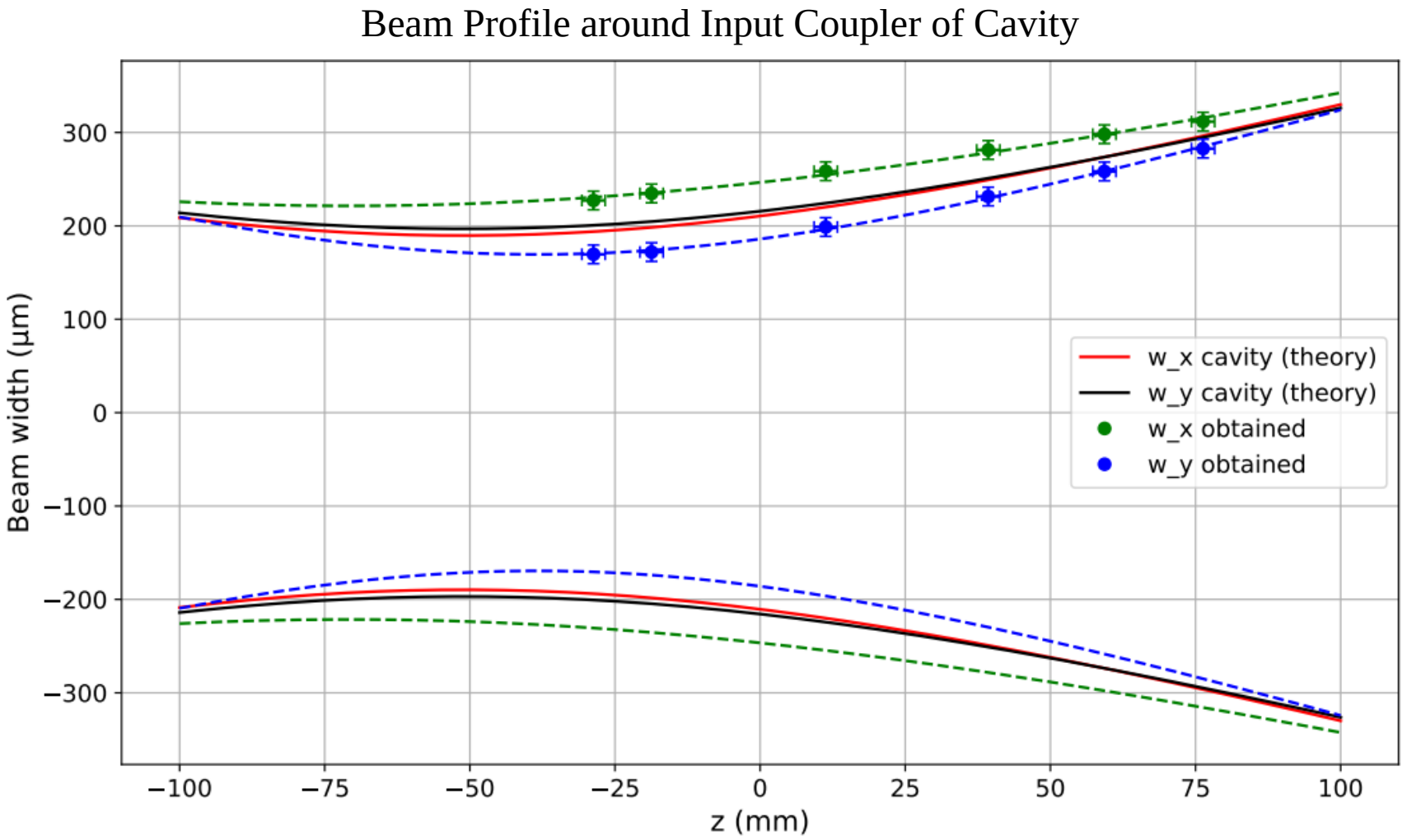
Mode matching

To summarize:



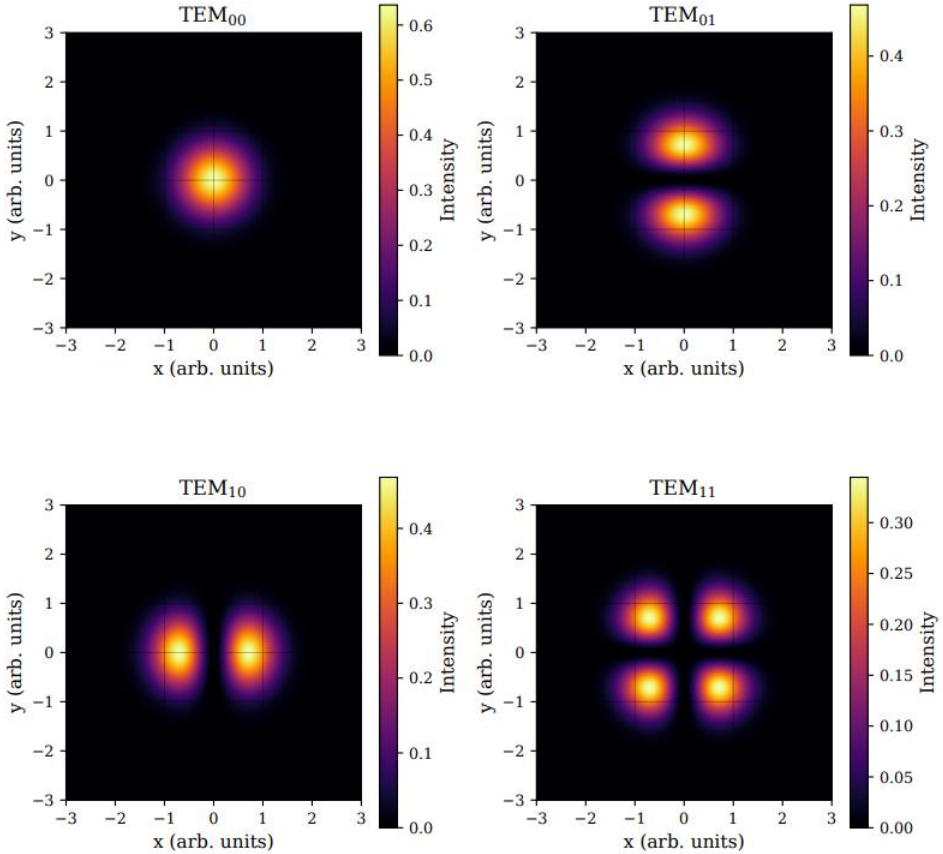


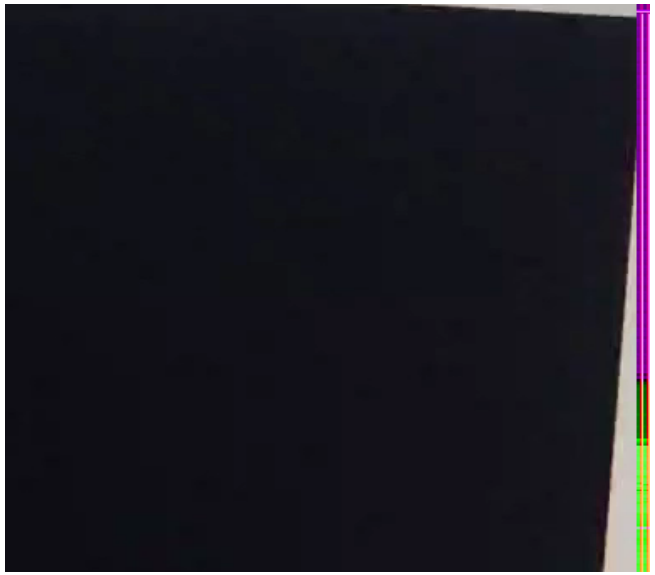
Mode matching



Cavity flashing

- Higher order modes of light
- Cavity flashing
- Transmission Signal

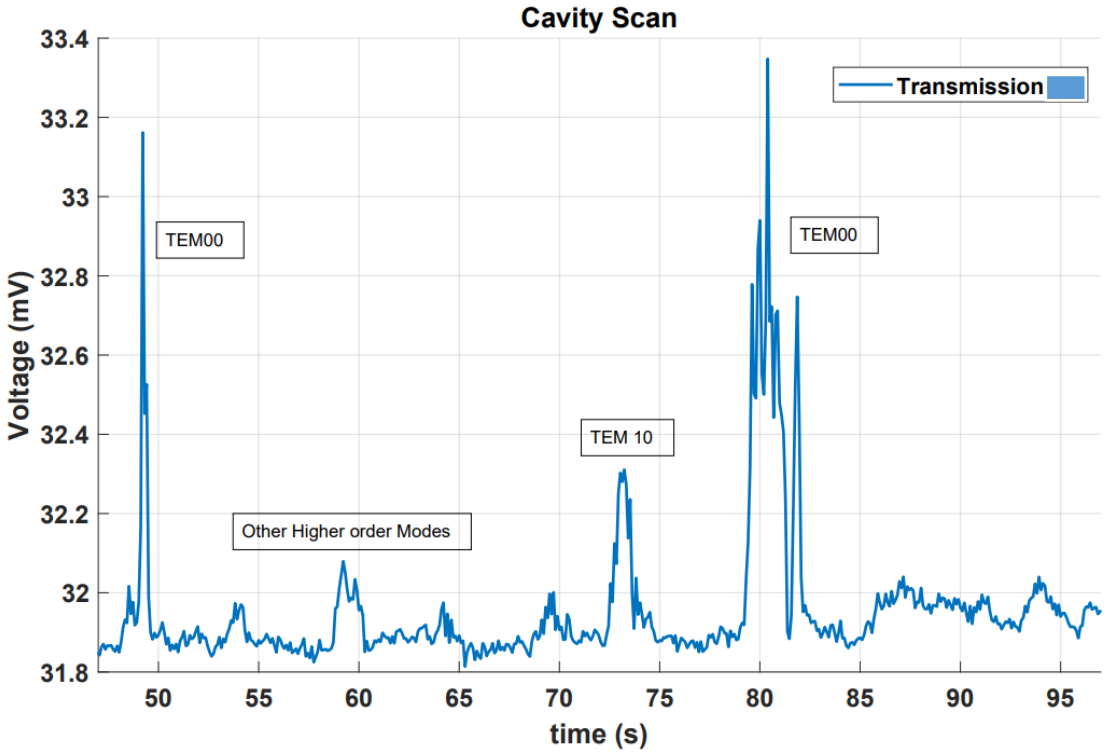




Measurements for the Bowtie Cavity

- Cavity flashing
- Transmission Signal
  - Measuring mode matching efficiency ~60%

$$\eta = \frac{\sum(V_{\mathrm{TEM}_{00}} - V_{\mathrm{offset}})}{\sum(V_{\mathrm{TEM}_{00}} - V_{\mathrm{offset}}) + \sum(V_{\mathrm{HOM}} - V_{\mathrm{offset}})}$$

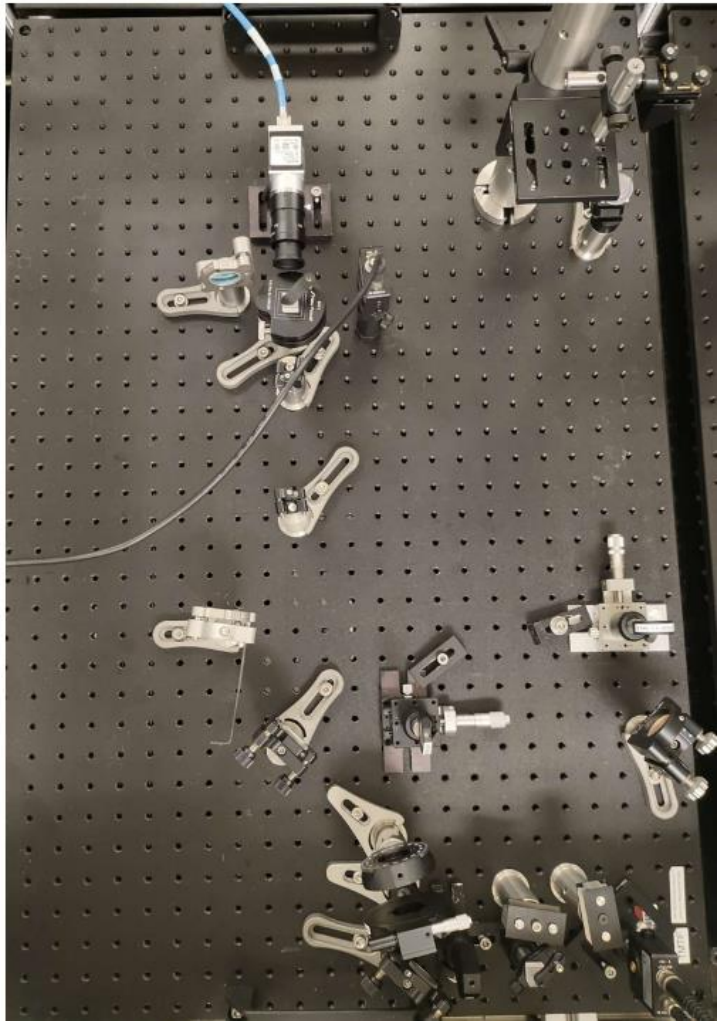


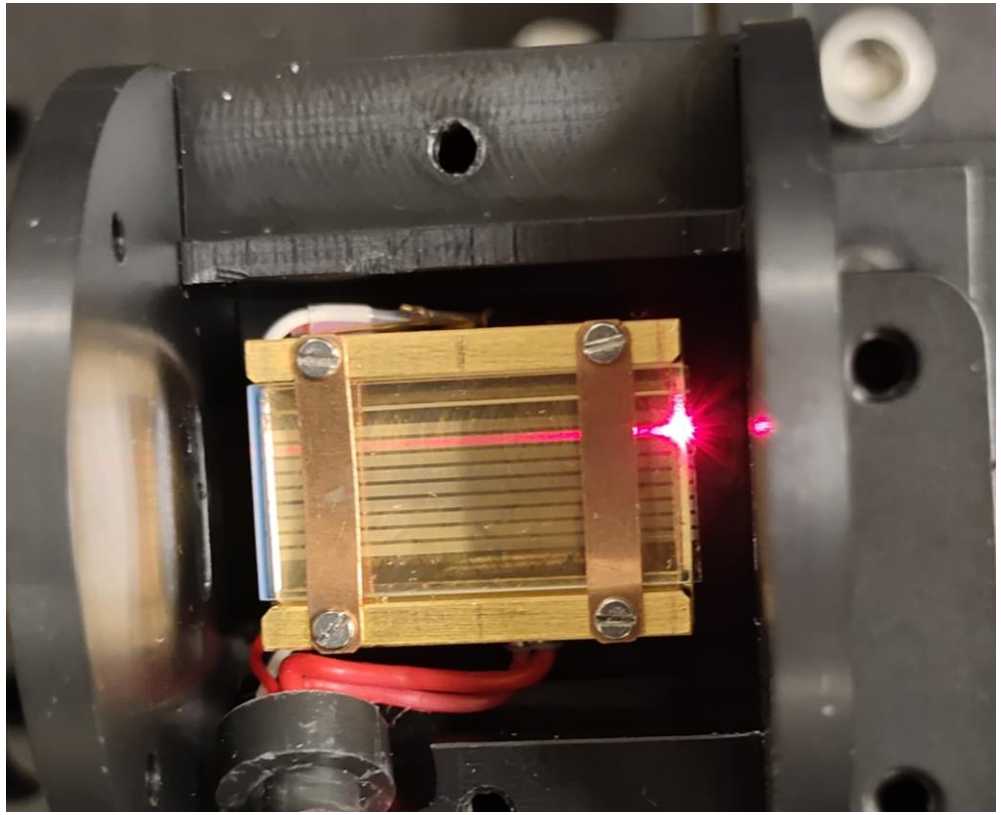
- $V_{\mathrm{TEM}_{00}}$ is the peak voltage corresponding to the fundamental mode,
- V_{HOM} are the peak voltages of the higher-order modes (HOMs),

Future plans:

- Characterizing the Cavity.
- Pound-Drever-Hall Locking the cavity
- Two mode squeezing from the bowtie cavity ?

Few pics





Acknowledgements and Sources

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- All the 40 meter and west bridge folks

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