# FFT study of Mode matching at LHO and LLO

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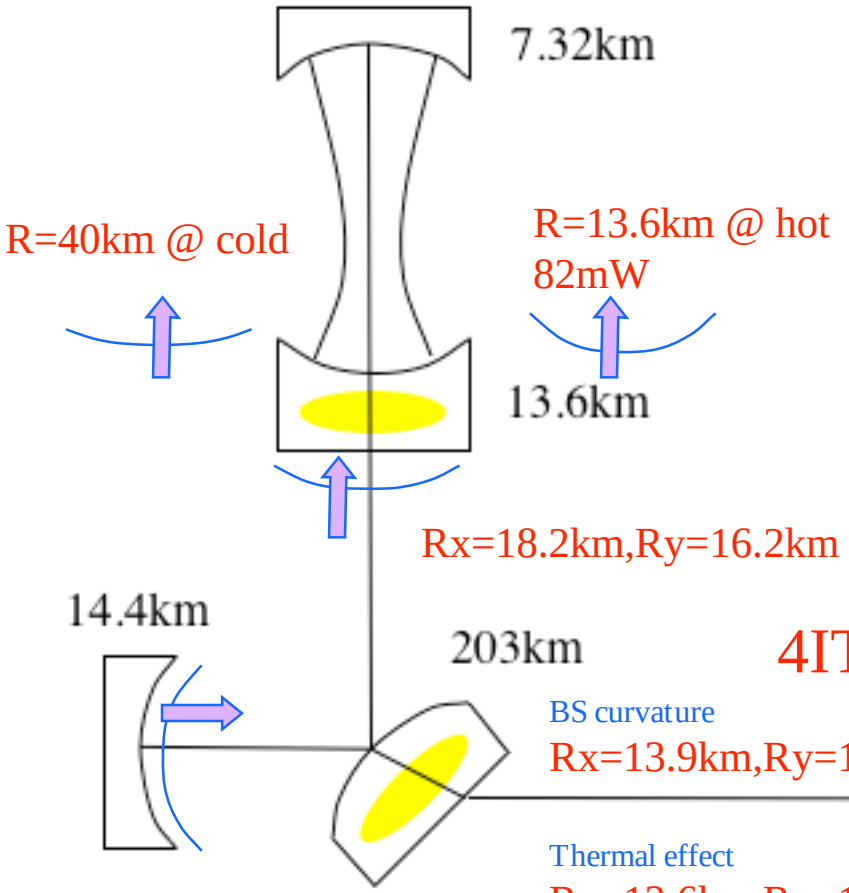
- LHO4k ITMX
  - »4ITM07 (14.24km) vs 4ITM05 (13.58km)
- Effect of thermal deformation
  - »Thermal model vs simple lens
- Input beam mode matching with arm
  - »CR & SB in COC is insensitive to input beam mode
  - »Reflected CR is sensitive to input beam mode

# Mode matching in LHO4k

## beam and mirror curvature




Reflection by BS

$$\frac{R_{in}}{R_{out}} = 1 - \frac{2}{R_{BS}} \frac{R_{in}}{C_{x/y}} \qquad C_x = 1/\sqrt{2},\ C_y = \sqrt{2}$$

Transmission through BS

$$\frac{R_{in}}{R_{out}} = 1 + \left(\frac{n_0 - 1}{R_{BS}} - \frac{1}{f_{thermal}^{BS}}\right) \frac{R_{in}}{C_{x/y}}$$

Transmission through ITM

$$\frac{R_{in}}{R_{out}} = 1 + \left(\frac{n_0 - 1}{R_{ITM}} - \frac{1}{f_{thermal}^{ITM}}\right) R_{in}$$

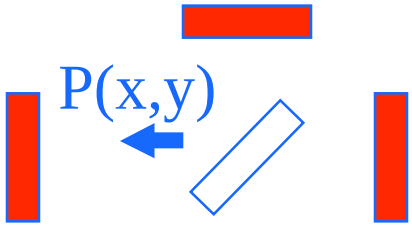
$$\frac{1}{f_{thermal}^{BS}} = \frac{1}{2}\frac{1}{2}\frac{4}{10}\frac{1}{f_{thermal}^{ITM}(hot)}$$

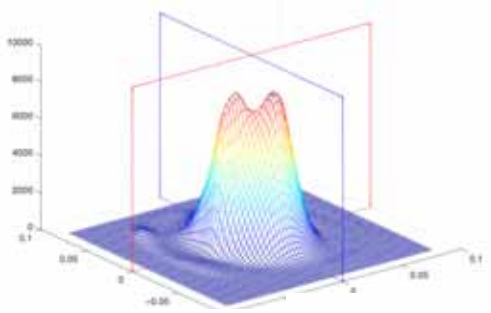
# Optimum power to correct static curvature errors

| | ITM, ROC (km) | Gaussian heat power (mw) | | |
|---|---|---|---|---|
| | | Data | FFT | Lens |
| LHO2k | ITMx 13.23 | 0 | | 57 |
| | ITMy 13.72 | 17 | | 110 |
| LHO4k 4ITM07 | ITMx 14.24 | 35 | 27 | 52 |
| | ITMy 13.60 | 60 | 60 | 82 |
| LHO4k 4ITM05 | ITMx 13.58 | | 40 | 63 |
| | ITMy 13.60 | | 60 | 82 |
| LLO | ITMx 14.76 | 22 | 30 | 53 |
| | ITMy 14.52 | 39 | 60 | 83 |

FFT optimal : based on upper and lower SB gains and Spob

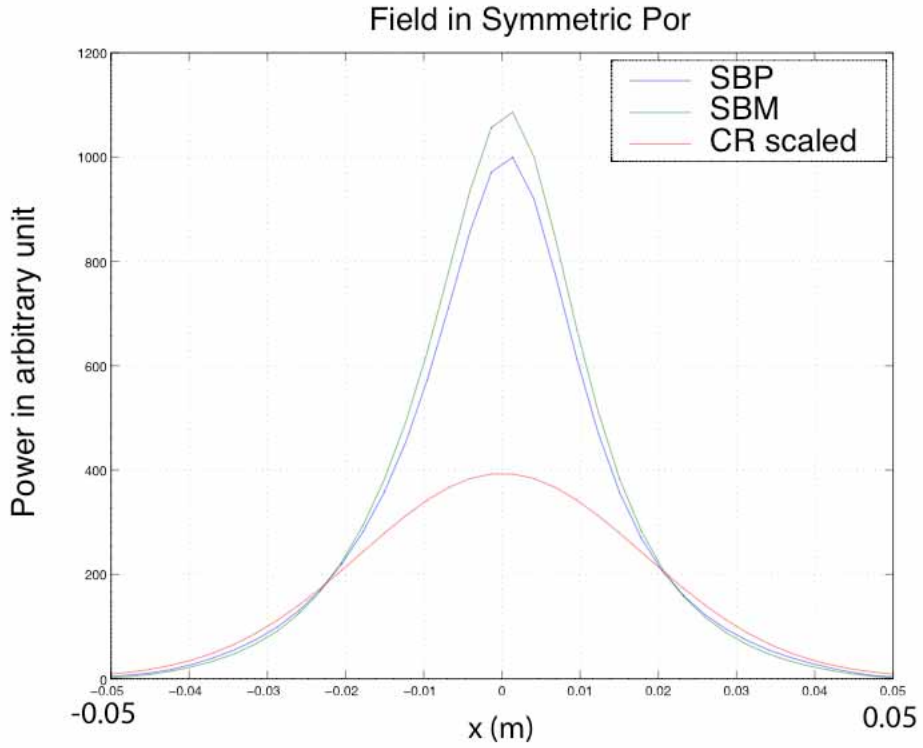
# CR and SB widths at optimal heating

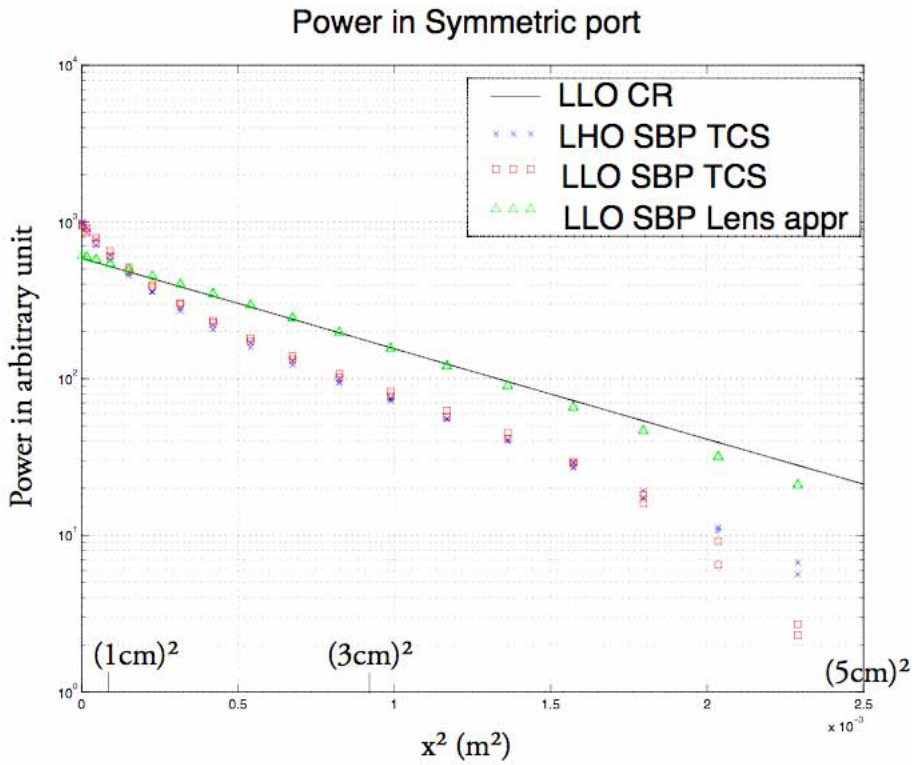


$$Power = P\mathrm{i}Exp(-\frac{2x^2}{w^2})$$

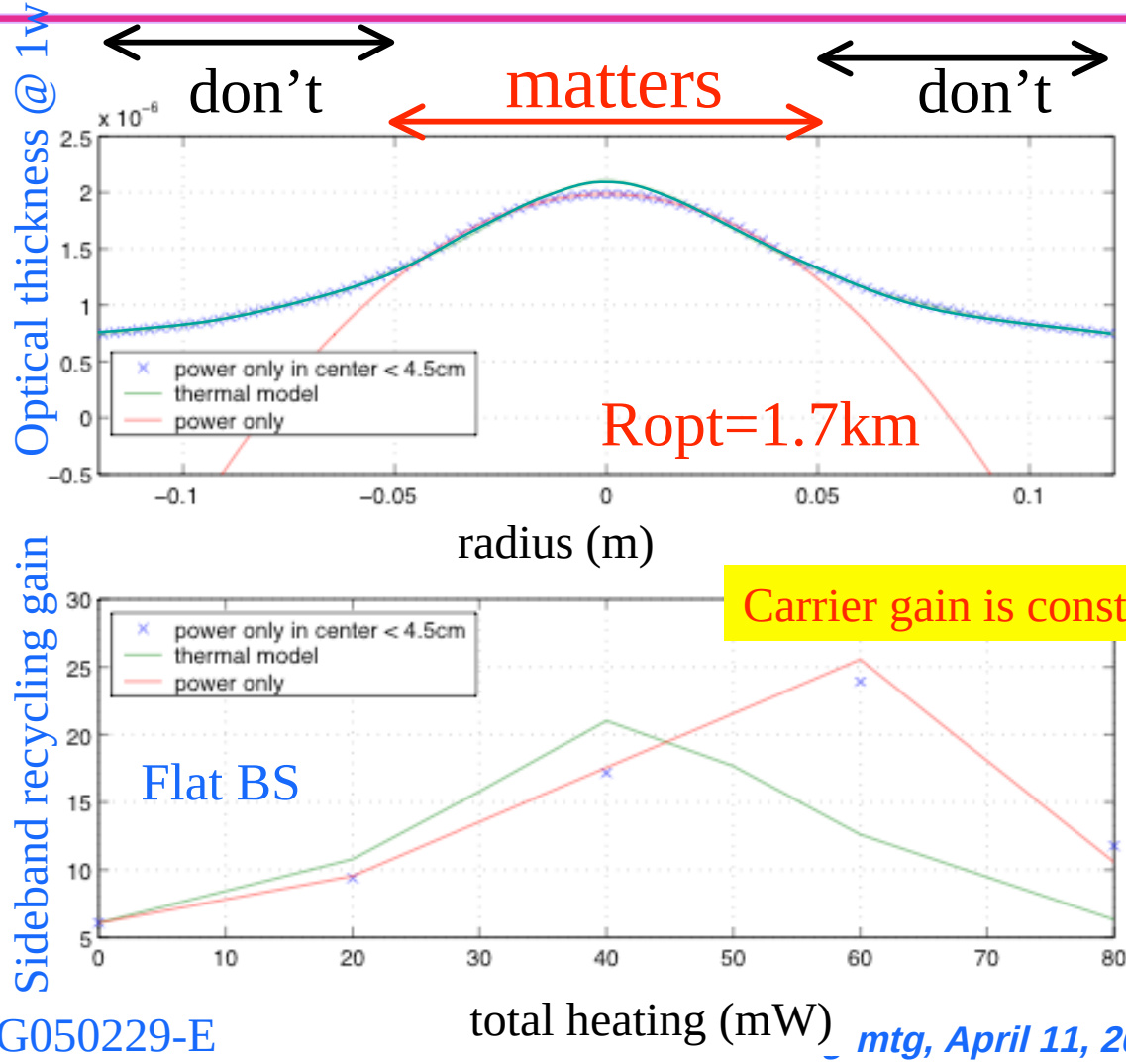
$$\ln(Power) = \ln(P) - \frac{2x^2}{w^2}$$

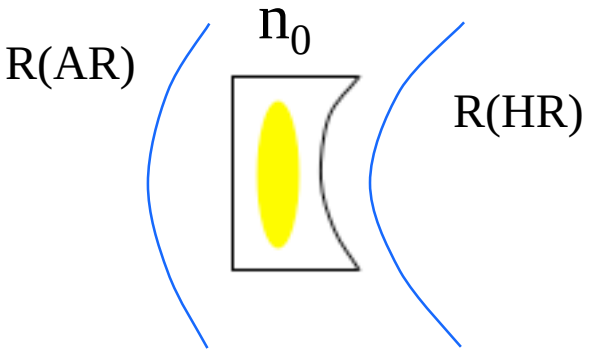


# Thermal lensing and $n_{effective}$

## - P. Willems calculated based on MIT model -




$$\frac{1}{f} = -\frac{n_0 - 1}{Rm} + \frac{Power}{Ropt}$$

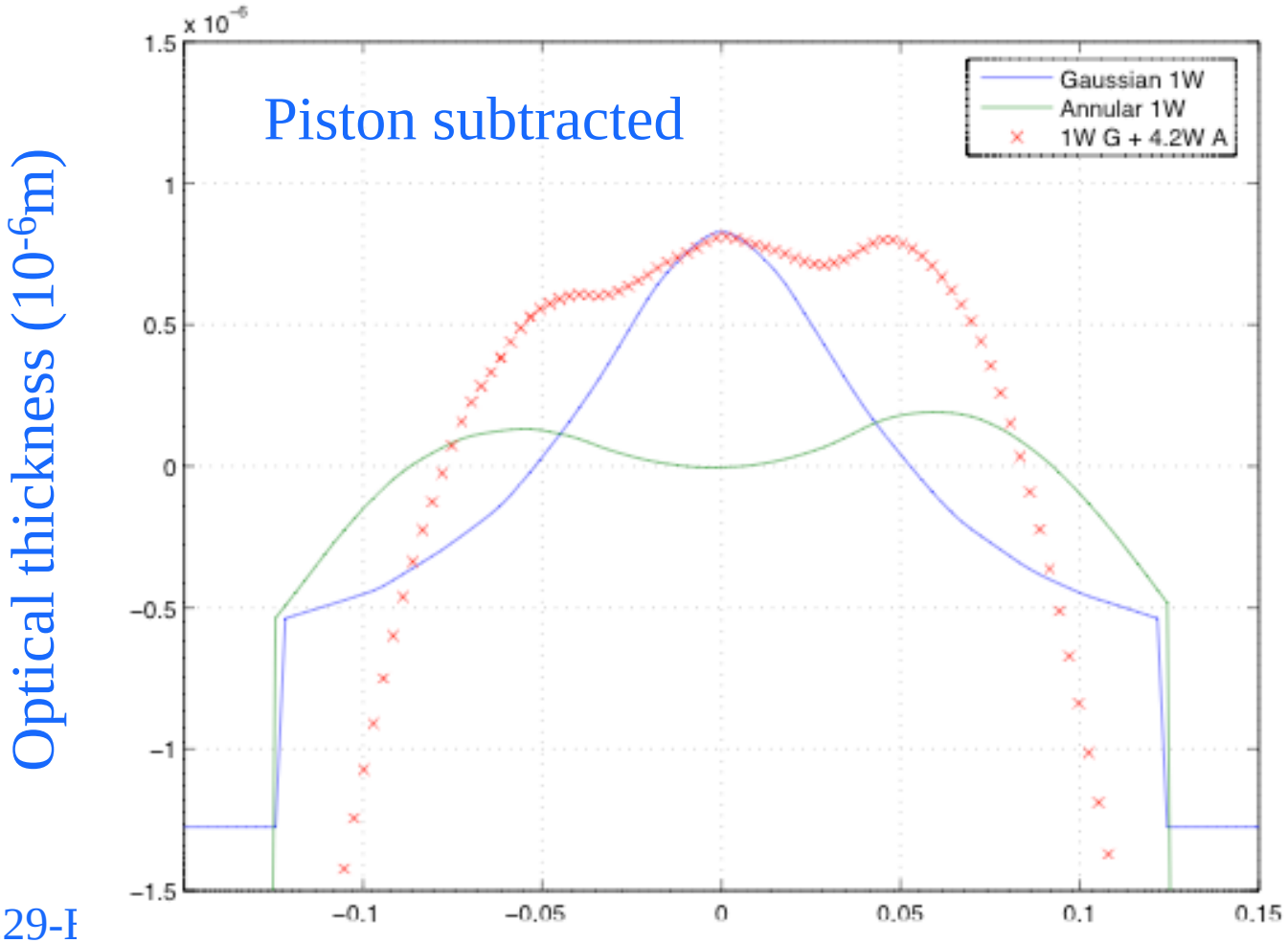
$$= -\frac{n_{effective} - 1}{Rm}$$

$$\frac{1}{R_f(HR)} = \frac{1}{R_f(AR)} - \frac{1}{f}$$

Power = 58mW

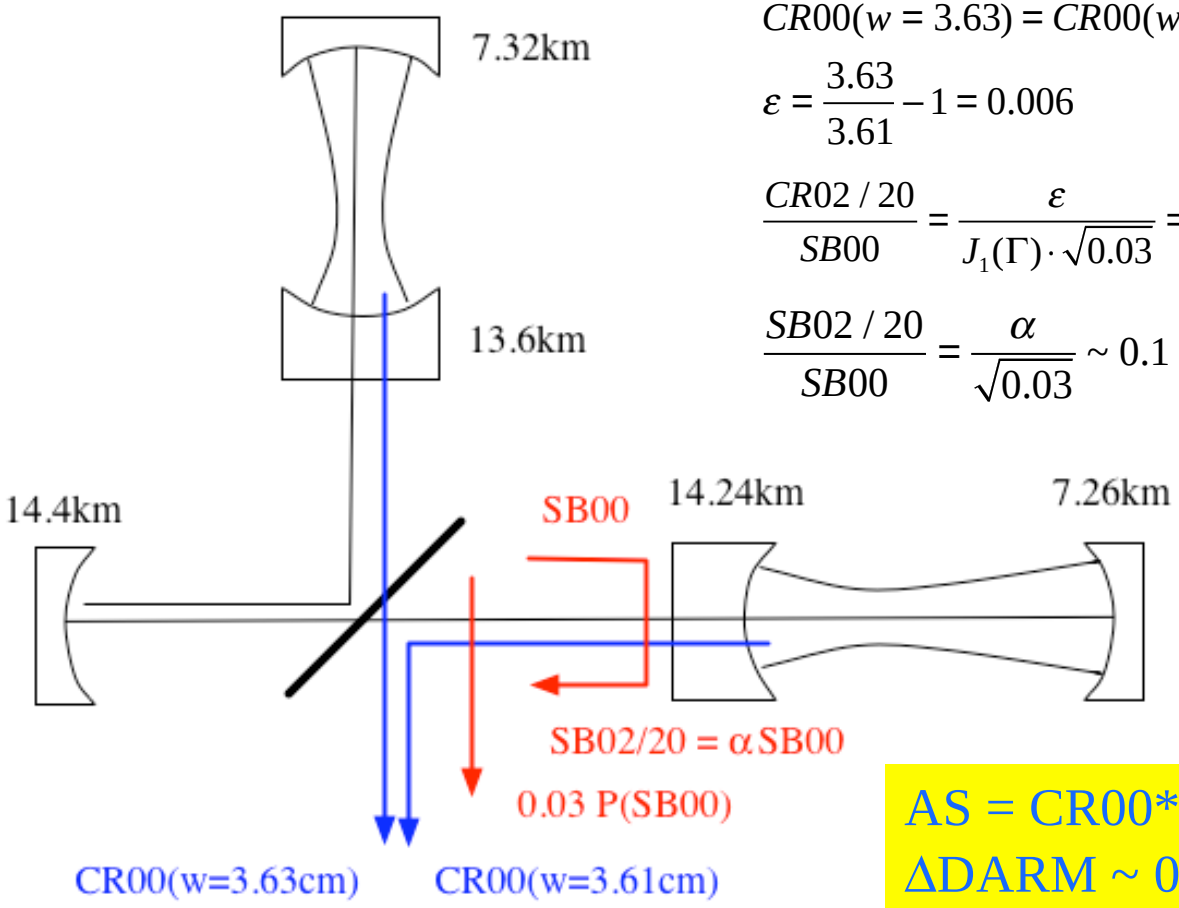
# Gaussian and Annular

## no annular heating, smoother deformation



# modes in the dark port

## - back on the envelope -




$$CR00(w = 3.63) = CR00(w = 3.61) + \varepsilon \cdot CR02/20(w = 3.63)$$

$$\varepsilon = \frac{3.63}{3.61} - 1 = 0.006$$

$$\frac{CR02/20}{SB00} = \frac{\varepsilon}{J_1(\Gamma)\cdot\sqrt{0.03}} = 0.15$$

$$\frac{SB02/20}{SB00} = \frac{\alpha}{\sqrt{0.03}} \sim 0.1$$

| | ϵ |
|---|---|
| LHO4k 4ITM07 | 0.6% |
| LHO4k 4ITM05 | 0.4% |
| LLO4k | 0.013% |

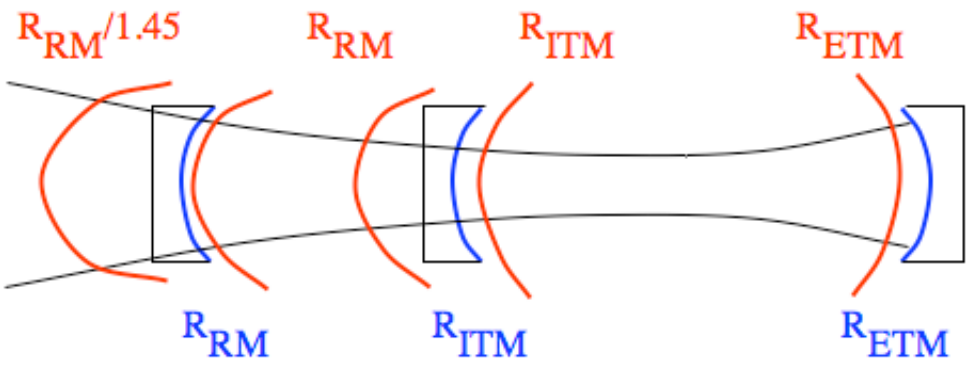
AS = CR00*SB00+CR02/20*SB02/20

ΔDARM ~ 0.5 pm, ASI

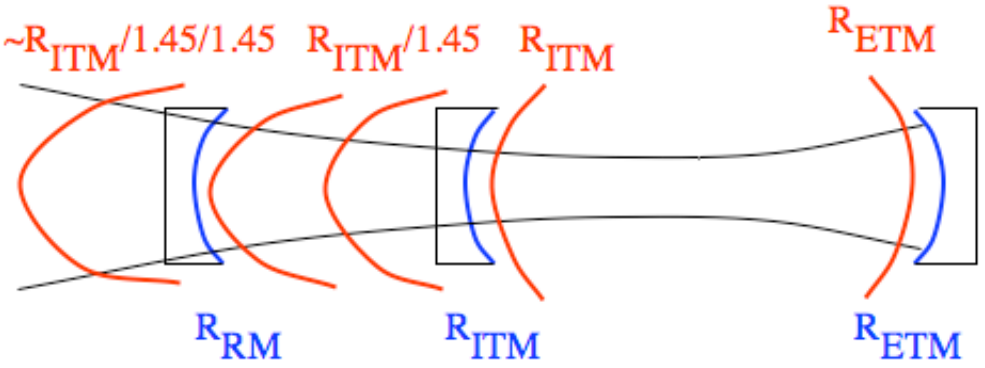
# Mode matching of input beam to COC

- Dependence on
  - » input beam mode
  - » ITM heating
- Cold beam can never fully mode match with arm

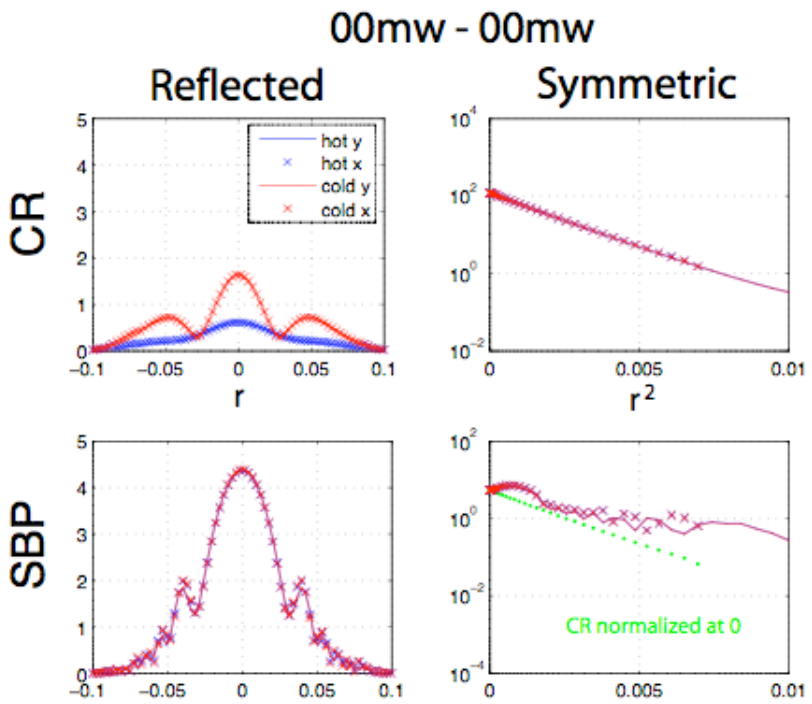
Beam matching with HOT arm

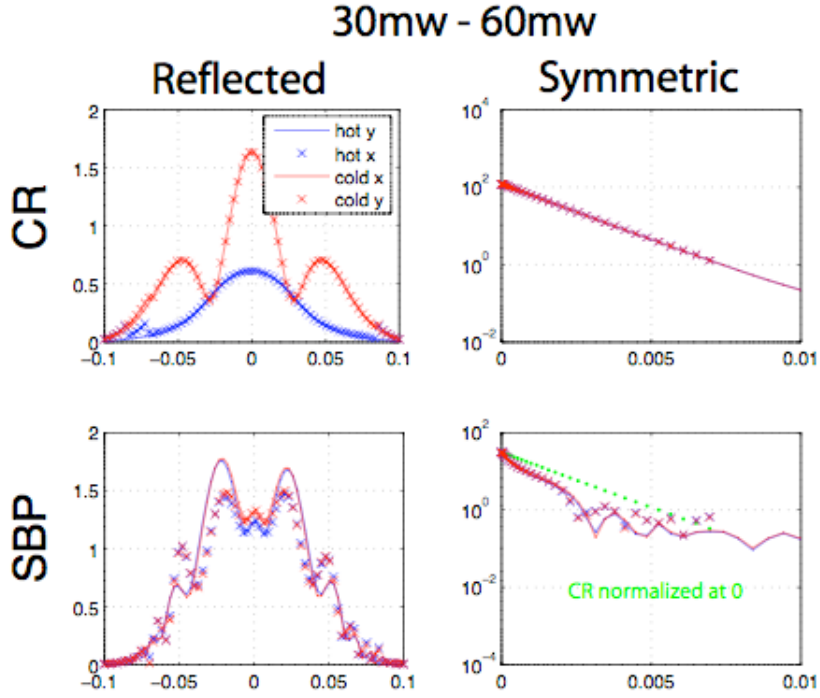


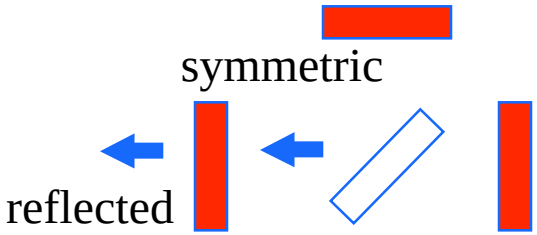

Beam matching with COLD arm



# Input beam mode matching
# LLO : cold and hot




- Field in COC is insensitive to input beam mode
- Reflected CR is most affected by mode mismatching
- CR in COC is determined by R(RM),R(ITM)s,R(ETM)s
- SB in COC is dependent on TCS