H1 Signal Recycling Cavity
8/12/13

wavelength, mm $\lambda := 1.064 \cdot 10^{-3}$

1 ppm beam radius multiple $m_{1ppm} := \sqrt{3 \cdot ln(10)}$ $m_{1ppm} = 2.628$

index of refraction of fused silica $n := 1.458464$

off-axis angle, deg $\theta := \frac{1}{2}$ $\theta = 0.5$

beam waist in IFO, mm $w_{01} := 12.0$

radius1 of ITM mm $R1_{ITM} := -1934000$

thickness of ITM mm $t_{ITM} := 200$

radius2 of ITM mm $R2_{ITM} := 10^{64}$

radius1 of BS mm $R1_{BS} := 10^{64}$

thickness of BS, mm $t_{BS} := 65.8$

radius2 of BS mm $R2_{BS} := 10^{64}$

radius of SR3 mm $R_{SR3} := -36000$

radius1 of SR2 mm $R1_{SR2} := 6430$

thickness of SR2 mm $t_{SR2} := 75$

radius2 of SR2 mm $R2_{SR2} := 10^{64}$

radius1 of SRM mm $R1_{SRM} := 5690$

thickness of SRM mm $t_{SRM} := 75$

radius2 of SRM mm $R2_{SRM} := 10^{64}$

distance from IFO waist to ITM, mm $l_{ifo\_ITM} := 1835000$

distance from ITM to BS Ellip Baf, mm $l_{ITM\_bsellip} := 4890$

distance from ITM to BS, mm $l_{ITM\_BS} := 20 + 100 \cdot n + 4817.4$

$l_{ITM\_BS} = 4.983 \cdot 10^{3}$

distance from BS to BS Ellip Baf, mm $l_{BS\_bsellip} := l_{ITM\_BS} - l_{ITM\_bsellip}$

$l_{BS\_bsellip} = 93.246$

distance from BS Ellip Baf to SR3, mm $l_{BSellipbaf\_SR3} := 19368 + (65.8 + 65.7) \cdot n + l_{BS\_bsellip}$

$l_{BSellipbaf\_SR3} = 1.9653 \cdot 10^{4}$

distance from SR3 TO SR2, mm $l_{SR3\_SR2} := 15461.2$

distance from SR2 TO SRM, mm $l_{SR2\_SRM} := 15740.9$

HARTMANN X

distance from SR3 TO SR2 SCRAPER BAF, mm $l_{SR3\_SR2scrapbaf} := 14888$

distance from SR3 TO HWSX M1 mm $l_{SR3\_HWSXM1} := 14888 + 367$

distance from SR3 TO HWSX M1 mm $l_{SR3\_HWSXM1} := 14888 + 367$

distance from SR3 TO HARTMAN SCRAPER BAF, mm $l_{SR3\_hartscrapbaf} := 14888 + 367 + 792.3$

distance from SR3 TO HWSX M2 mm $l_{SR3\_HWSXM2} := 14888 + 367 + 792.3 + 456.8$

distance from SR3 TO HWSY M3, mm $l_{SR3\_HWSYM3} := 14888 + 367 + 792.3 + 456.8 + 401.6$

distance from SR3 TO dcbs1 mm $l_{SR3\_dcbs1} := 14888 + 367 + 792.3 + 456.8 + 401.6 + 163.4$

distance from SR3 TO vac lens mm $l_{SR3\_vaclens} := 14888 + 367 + 792.3 + 456.8 + 401.6 + 163.4 + 324.9$

distance from VAC LENSX TO VP, mm $l_{vaclensx\_vp} := 688.1$

focal length VAC LENSX, mm $f_{vaclensx} := -700$

HARTMAN N Y

distance from SR2 AR TO SR2 scraper Baffle, mm $l_{SR2ar\_SR2arbaff} := 705$

distance from SR2 AR TO HWSY M1, mm $l_{SR2ar\_HWSYM1} := 705 + 189$

distance from SR2 AR TO Hartmann Scraper Baffle, mm $l_{SR2ar\_hartscraprbaff} := 705 + 189 + 741$

distance from SR2 AR TO HWSY M2, mm $l_{SR2ar\_HWSYM2} := 705 + 189 + 741 + 455$

distance from SR2 AR TO DCBS1, mm

$$l_{SR2ar\_DCBS1} := 705 + 189 + 741 + 455 + 68$$

distance from SR2 AR TO VAC LENS, mm

$$l_{SR2ar\_vaclens} := 705 + 189 + 741 + 455 + 68 + 152$$

distance from VAC LENS to HWSY M3 mm

$$l_{vaclens\_hwsym3} := 529$$

distance from VAC LENS to VP, mm

$$l_{vaclensy\_VP} := 1292$$

focal length VAC LENSY, mm

$$f_{vaclensy} := 60$$

signal recycling cavity length, mm

$$L_{src} := 200 \cdot n + l_{ITM\_BS} + l_{BS\_bsellip} + l_{BSellipbaf\_SR3} + l_{SR3\_SR2} + l_{SR2\_SRM} \qquad L_{src} = 5.622 \cdot 10^{4}$$

translation IFO waist to ITM

$$T_{ifo\_ITM} := \begin{bmatrix} 1 & l_{ifo\_ITM} \\ 0 & 1 \end{bmatrix} \qquad T_{ifo\_ITM} = \begin{bmatrix} 1 & 1.835 \cdot 10^{6} \\ 0 & 1 \end{bmatrix}$$

first surface ITM

$$M1_{ITM} := \begin{bmatrix} 1 & 0 \\ \dfrac{1-n}{n \cdot R1_{ITM}} & \dfrac{1}{n} \end{bmatrix} \qquad M1_{ITM} = \begin{bmatrix} 1 & 0 \\ 1.625 \cdot 10^{-7} & 0.686 \end{bmatrix}$$

thickness of ITM

$$T_{ITM} := \begin{bmatrix} 1 & t_{ITM} \\ 0 & 1 \end{bmatrix} \qquad T_{ITM} = \begin{bmatrix} 1 & 200 \\ 0 & 1 \end{bmatrix}$$

second surface ITM

$$M2_{ITM} := \begin{bmatrix} 1 & 0 \\ \dfrac{n-1}{R2_{ITM}} & n \end{bmatrix} \qquad M2_{ITM} = \begin{bmatrix} 1 & 0 \\ 4.585 \cdot 10^{-65} & 1.458 \end{bmatrix}$$

translation ITM to BS Ellip Baf

$$T_{ITM\_BSellipbaf} := \begin{bmatrix} 1 & l_{ITM\_bsellip} \\ 0 & 1 \end{bmatrix} \qquad T_{ITM\_BSellipbaf} = \begin{bmatrix} 1 & 4.89 \cdot 10^{3} \\ 0 & 1 \end{bmatrix}$$

translation ITM to BS $T_{ITM\_BS} := \begin{bmatrix} 1 & l_{ITM\_BS} \\ 0 & 1 \end{bmatrix}$ $T_{ITM\_BS} = \begin{bmatrix} 1 & 4.983 \cdot 10^{3} \\ 0 & 1 \end{bmatrix}$

translation BS to BS Ellip baf $T_{BS\_BSellipbaf} := \begin{bmatrix} 1 & l_{BS\_bsellip} \\ 0 & 1 \end{bmatrix}$ $T_{BS\_BSellipbaf} = \begin{bmatrix} 1 & 93.246 \\ 0 & 1 \end{bmatrix}$

translation BS Ellip Baf to SR3 $T_{BSellip\_SR3} := \begin{bmatrix} 1 & l_{BSellipbaf\_SR3} \\ 0 & 1 \end{bmatrix}$ $T_{BSellip\_SR3} = \begin{bmatrix} 1 & 1.965 \cdot 10^{4} \\ 0 & 1 \end{bmatrix}$

SR3 mirror $M_{SR3} := \begin{bmatrix} 1 & 0 \\ \dfrac{2}{R_{SR3}} & 1 \end{bmatrix}$ $M_{SR3} = \begin{bmatrix} 1 & 0 \\ -5.556 \cdot 10^{-5} & 1 \end{bmatrix}$

translation SR3 to SR2 $T_{SR3\_SR2} := \begin{bmatrix} 1 & l_{SR3\_SR2} \\ 0 & 1 \end{bmatrix}$

SR2 mirror $M_{SR2} := \begin{bmatrix} 1 & 0 \\ \dfrac{2}{R1_{SR2}} & 1 \end{bmatrix}$ $M_{SR2} = \begin{bmatrix} 1 & 0 \\ 3.11 \cdot 10^{-4} & 1 \end{bmatrix}$

translation SR2 to SRM $T_{SR2\_SRM} := \begin{bmatrix} 1 & l_{SR2\_SRM} \\ 0 & 1 \end{bmatrix}$ $T_{SR2\_SRM} = \begin{bmatrix} 1 & 1.574 \cdot 10^{4} \\ 0 & 1 \end{bmatrix}$

first surface SRM $M1_{SRM} := \begin{bmatrix} 1 & 0 \\ \dfrac{1-n}{n \cdot R1_{SRM}} & \dfrac{1}{n} \end{bmatrix}$ $M1_{SRM} = \begin{bmatrix} 1 & 0 \\ -5.525 \cdot 10^{-5} & 0.686 \end{bmatrix}$

thickness of SRM $T1_{SRM} := \begin{bmatrix} 1 & t_{SRM} \\ 0 & 1 \end{bmatrix}$ $T1_{SRM} = \begin{bmatrix} 1 & 75 \\ 0 & 1 \end{bmatrix}$

- -

second surface SRM

$$M2_{SRM} := \begin{bmatrix} 1 & 0 \\ \dfrac{n-1}{R2_{SRM}} & n \end{bmatrix} \qquad M2_{SRM} = \begin{bmatrix} 1 & 0 \\ 4.585 \cdot 10^{-65} & 1.458 \end{bmatrix}$$

first surface SR2

$$M1_{SR2} := \begin{bmatrix} 1 & 0 \\ \dfrac{1-n}{n \cdot R1_{SR2}} & \dfrac{1}{n} \end{bmatrix} \qquad M1_{SR2} = \begin{bmatrix} 1 & 0 \\ -4.889 \cdot 10^{-5} & 0.686 \end{bmatrix}$$

thickness of SR2

$$T_{SR2} := \begin{bmatrix} 1 & t_{SR2} \\ 0 & 1 \end{bmatrix} \qquad T_{SR2} = \begin{bmatrix} 1 & 75 \\ 0 & 1 \end{bmatrix}$$

second surface SR2

$$M2_{SR2} := \begin{bmatrix} 1 & 0 \\ \dfrac{n-1}{R2_{SR2}} & n \end{bmatrix} \qquad M2_{SR2} = \begin{bmatrix} 1 & 0 \\ 4.585 \cdot 10^{-65} & 1.458 \end{bmatrix}$$

translation SR2AR to SR2 AR Baff

$$T_{SR2ar\_SR2arbaf} := \begin{bmatrix} 1 & l_{SR2ar\_SR2arbaff} \\ 0 & 1 \end{bmatrix} \qquad T_{SR2ar\_SR2arbaf} = \begin{bmatrix} 1 & 705 \\ 0 & 1 \end{bmatrix}$$

translation SR2AR to Hartmann Scraper Baff

$$T_{SR2ar\_hartscrapbaf} := \begin{bmatrix} 1 & l_{SR2ar\_hartscraprbaff} \\ 0 & 1 \end{bmatrix}$$

$$T_{SR2ar\_hartscrapbaf} = \begin{bmatrix} 1 & 1.635 \cdot 10^{3} \\ 0 & 1 \end{bmatrix}$$

translation SR2AR to HWSYM1

$$T_{SR2AR\_HWSYM1} := \begin{bmatrix} 1 & l_{SR2ar\_HWSYM1} \\ 0 & 1 \end{bmatrix}$$

$$T_{SR2AR\_HWSYM1} = \begin{bmatrix} 1 & 894 \\ 0 & 1 \end{bmatrix}$$

translation SR2AR to HWSYM2

$$T_{SR2AR\_HWSYM2} := \begin{bmatrix} 1 & l_{SR2ar\_HWSYM2} \\ 0 & 1 \end{bmatrix}$$

$$T_{SR2AR\_HWSYM2} = \begin{bmatrix} 1 & 2.09 \cdot 10^3 \\ 0 & 1 \end{bmatrix}$$

translation SR2AR to DCBS1

$$T_{SR2AR\_DCBS1} := \begin{bmatrix} 1 & l_{SR2ar\_DCBS1} \\ 0 & 1 \end{bmatrix}$$

$$T_{SR2AR\_DCBS1} = \begin{bmatrix} 1 & 2.158 \cdot 10^3 \\ 0 & 1 \end{bmatrix}$$

translation SR2AR to VAC LENS

$$T_{SR2AR\_vaclens} := \begin{bmatrix} 1 & l_{SR2ar\_vaclens} \\ 0 & 1 \end{bmatrix}$$

$$T_{SR2AR\_vaclens} = \begin{bmatrix} 1 & 2.31 \cdot 10^3 \\ 0 & 1 \end{bmatrix}$$

thin LENSY matrix

$$ML_{vaclensy}\left(f_{vaclensy}\right) := \begin{bmatrix} 1 & 0 \\ \frac{-1}{f_{vaclensy}} & 1 \end{bmatrix}$$

translation VAC LENS to HWSYM3

$$T_{vaclens\_HWSYM3} := \begin{bmatrix} 1 & l_{vaclens\_hwsym3} \\ 0 & 1 \end{bmatrix}$$

$$T_{vaclens\_HWSYM3} = \begin{bmatrix} 1 & 529 \\ 0 & 1 \end{bmatrix}$$

translation VAC LENSY to VP

$$T_{vaclensy\_VP} := \begin{bmatrix} 1 & l_{vaclensy\_VP} \\ 0 & 1 \end{bmatrix}$$

$$T_{vaclensy\_VP} = \begin{bmatrix} 1 & 1.292 \cdot 10^3 \\ 0 & 1 \end{bmatrix}$$

translation SR3 to SR2scraper baf

$$T_{SR3\_SR2scrap} := \begin{bmatrix} 1 & l_{SR3\_SR2scrapbaf} \\ 0 & 1 \end{bmatrix}$$

$$T_{SR3\_SR2scrap} = \begin{bmatrix} 1 & 1.489 \cdot 10^{4} \\ 0 & 1 \end{bmatrix}$$

translation SR3 to HWSXM1

$$T_{SR3\_HWSXM1} := \begin{bmatrix} 1 & l_{SR3\_HWSXM1} \\ 0 & 1 \end{bmatrix}$$

$$T_{SR3\_HWSXM1} = \begin{bmatrix} 1 & 1.526 \cdot 10^{4} \\ 0 & 1 \end{bmatrix}$$

translation SR3 to HARTMANN SCRAPER BAF

$$T_{SR3\_hartscrapbaf} := \begin{bmatrix} 1 & l_{SR3\_hartscrapbaf} \\ 0 & 1 \end{bmatrix}$$

$$T_{SR3\_hartscrapbaf} = \begin{bmatrix} 1 & 1.605 \cdot 10^{4} \\ 0 & 1 \end{bmatrix}$$

translation SR3 to HWSXM2

$$T_{SR3\_HWSXM2} := \begin{bmatrix} 1 & l_{SR3\_HWSXM2} \\ 0 & 1 \end{bmatrix}$$

$$T_{SR3\_HWSXM2} = \begin{bmatrix} 1 & 1.65 \cdot 10^{4} \\ 0 & 1 \end{bmatrix}$$

translation SR3 to HWSXM3

$$T_{SR3\_HWSXM3} := \begin{bmatrix} 1 & l_{SR3\_HWSYM3} \\ 0 & 1 \end{bmatrix}$$

$$T_{SR3\_HWSXM3} = \begin{bmatrix} 1 & 1.691 \cdot 10^{4} \\ 0 & 1 \end{bmatrix}$$

translation SR3 to DCBS1

$$T_{SR3\_DCBS1} := \begin{bmatrix} 1 & l_{SR3\_dcbs1} \\ 0 & 1 \end{bmatrix}$$

$$T_{SR3\_DCBS1} = \begin{bmatrix} 1 & 1.707 \cdot 10^{4} \\ 0 & 1 \end{bmatrix}$$

translation SR3 to VAC LENS

$$T_{SR3\_vaclens} := \begin{bmatrix} 1 & l_{SR3\_vaclens} \\ 0 & 1 \end{bmatrix}$$

$$T_{SR3\_vaclens} = \begin{bmatrix} 1 & 1.739 \cdot 10^{4} \\ 0 & 1 \end{bmatrix}$$

thin LENSX matrix

$$ML_{vaclensx}\left(f_{vaclensx}\right) := \begin{bmatrix} 1 & 0 \\ \dfrac{-1}{f_{vaclensx}} & 1 \end{bmatrix}$$

translation VAC LENSX to VP

$$T_{vaclensx\_VP} := \begin{bmatrix} 1 & l_{vaclensx\_vp} \\ 0 & 1 \end{bmatrix}$$

$$T_{vaclensx\_VP} = \begin{bmatrix} 1 & 688.1 \\ 0 & 1 \end{bmatrix}$$

beam paramaters at ITM mirror

system matrix from IFO beam waist to ITM mirror

$$M := T_{ifo\_ITM}$$

$$M = \begin{bmatrix} 1 & 1.835 \cdot 10^{6} \\ 0 & 1 \end{bmatrix}$$

$M_{0,0} = 1$ $M_{0,1} = 1.835 \cdot 10^6$

$M_{1,0} = 0$ $M_{1,1} = 1$

$$w_{itm} := \left(\frac{\lambda}{\pi} \cdot \frac{-\left(M_{0,1}\right)^2 - \left(M_{0,0}\right)^2 \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda}\right)^2}{\pi \cdot \frac{w_{01}{}^2}{\lambda} \cdot \left(M_{0,1} \cdot M_{1,0} - M_{0,0} \cdot M_{1,1}\right)} \right)^{0.5}$$

$w_{itm} = 53.162$

10 ppm beam radius multiple $m_{10ppm} := \sqrt{\frac{5}{2} \cdot ln(10)}$ $m_{10ppm} = 2.399$

$$R_{itm} := \frac{\left(M_{0,0}\right)^2 \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda}\right)^2 + \left(M_{0,1}\right)^2}{\left(M_{1,0} \cdot M_{0,0}\right) \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda}\right)^2 + M_{0,1} \cdot M_{1,1}}$$

$R_{itm} = 1.934 \cdot 10^6$

system matrix up to the ITM **AR**

$Mx := M2_{ITM} \cdot T_{ITM} \cdot M1_{ITM} \cdot T_{ifo\_ITM}$

distance from ITMAR to beam waist, mm

$$l_{itmar0} := \frac{-\left(\left(\pi \cdot \frac{w_{01}^{2}}{\lambda}\right)^{2}\right) \cdot Mx_{1,0} \cdot Mx_{0,0} - Mx_{0,1} \cdot Mx_{1,1}}{\left(\left(\pi \cdot \frac{w_{01}^{2}}{\lambda}\right)^{2}\right) \cdot \left(Mx_{1,0}\right)^{2} + \left(Mx_{1,1}\right)^{2}}$$

$$l_{itmar0} := 1.293 \cdot 10^{6}$$

$$l_{itmar0} = 1.293 \cdot 10^{6}$$

translation to beam waist

$$T_{itmar0} := \begin{bmatrix} 1 & l_{itmar0} \\ 0 & 1 \end{bmatrix}$$

total system matrix to ITMAR beam waist

$$M := T_{itmar0} \cdot Mx$$

$$A := M_{0,0} \qquad B := M_{0,1}$$

$$C := M_{1,0} \qquad D := M_{1,1}$$

beam waist after ITMAR, mm

$$w_{itmar0} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^{2} - A^{2} \cdot \left(\pi \cdot \frac{w_{01}^{2}}{\lambda}\right)^{2}}{\pi \cdot \frac{w_{01}^{2}}{\lambda} \cdot (B \cdot C - A \cdot D)}\right)^{0.5}$$

$$w_{itmar0} = 105.336$$

beam paramaters at BS Ellip Baf

system matrix from IFO beam waist
to BS elli baf

$$M := T_{ITM\_BSellipbaf} \cdot T_{ifo\_ITM}$$

$$M = \begin{bmatrix} 1 & 1.84 \cdot 10^{6} \\ 0 & 1 \end{bmatrix}$$

$M_{0,0} = 1$ $\quad M_{0,1} = 1.84 \cdot 10^{6}$

$M_{1,0} = 0$ $\quad M_{1,1} = 1$

$$w_{bsellipbaf} := \left(\frac{\lambda}{\pi} \cdot \frac{-\left(M_{0,1}\right)^2 - \left(M_{0,0}\right)^2 \cdot \left(\pi \cdot \frac{w_{01}^{\ 2}}{\lambda}\right)^2}{\pi \cdot \frac{w_{01}^{\ 2}}{\lambda} \cdot \left(M_{0,1} \cdot M_{1,0} - M_{0,0} \cdot M_{1,1}\right)} \right)^{0.5}$$

$w_{bsellipbaf} = 53.297$

beam parameters at SR3 mirror

system matrix from beam waist
to SR3 mirror

$$M := T_{BSellip\_SR3} \cdot T_{BS\_BSellipbaf} \cdot T_{ITM\_BSellipbaf} \cdot M2_{ITM} \cdot T_{ITM} \cdot M1_{ITM} \cdot T_{ifo\_ITM}$$

$$M = \begin{bmatrix} 1.006 & 1.871 \cdot 10^{6} \\ 2.371 \cdot 10^{-7} & 1.435 \end{bmatrix}$$

$M_{0,0} = 1.006$ $\quad M_{0,1} = 1.871 \cdot 10^{6}$

$M_{1,0} = 2.371 \cdot 10^{-7}$ $M_{1,1} = 1.435$

beam radius at SR3

$$w_{SR3} := \left(\frac{\lambda}{\pi} \cdot \frac{-\left(M_{0,1}\right)^2 - \left(M_{0,0}\right)^2 \cdot \left(\pi \cdot \frac{w_{01}^{\;2}}{\lambda}\right)^2}{\pi \cdot \frac{w_{01}^{\;2}}{\lambda} \cdot \left(M_{0,1} \cdot M_{1,0} - M_{0,0} \cdot M_{1,1}\right)} \right)^{0.5}$$

$w_{SR3} = 54.156$

$w_{10ppmSR3} := 2.399 \cdot w_{SR3}$ $w_{10ppmSR3} = 129.92$

beam curvature radius after SR3

system matrix after the SR3 mirror

$$Mx_{SR3} := M_{SR3} \cdot T_{BSellip\_SR3} \cdot T_{BS\_BSellipbaf} \cdot T_{ITM\_BSellipbaf} \cdot M2_{ITM} \cdot T_{ITM} \cdot M1_{ITM} \cdot T_{ifo\_ITM}$$

$M := Mx_{SR3}$

$$R_{sr3} := \frac{\left(M_{0,0}\right)^2 \cdot \left(\pi \cdot \frac{w_{01}^{\;2}}{\lambda}\right)^2 + \left(M_{0,1}\right)^2}{\left(M_{1,0} \cdot M_{0,0}\right) \cdot \left(\pi \cdot \frac{w_{01}^{\;2}}{\lambda}\right)^2 + M_{0,1} \cdot M_{1,1}}$$

$R_{sr3} = -1.824 \cdot 10^{4}$

Beam Waist after SR3

system matrix up to the **SR3 mirror**

$Mx := Mx_{SR3}$

distance from **SR3** to beam waist, mm

$$l_{SR30} := \frac{-\left(\left(\pi \cdot \frac{w_{01}^{2}}{\lambda}\right)^{2}\right) \cdot Mx_{1,0} \cdot Mx_{0,0} - Mx_{0,1} \cdot Mx_{1,1}}{\left(\left(\pi \cdot \frac{w_{01}^{2}}{\lambda}\right)^{2}\right) \cdot \left(Mx_{1,0}\right)^{2} + \left(Mx_{1,1}\right)^{2}}$$

$l_{SR30} = 1.824 \cdot 10^{4}$

translation to beam waist $T_{SR30} := \begin{bmatrix} 1 & l_{SR30} \\ 0 & 1 \end{bmatrix}$

total system matrix to **SR3** beam waist

$M := T_{SR30} \cdot Mx$

$A := M_{0,0}$ $B := M_{0,1}$

$C := M_{1,0}$ $D := M_{1,1}$

beam waist after **SR3,** mm

$$w_{SR30} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^{2} - A^{2} \cdot \left(\pi \cdot \frac{w_{01}^{2}}{\lambda}\right)^{2}}{\pi \cdot \frac{w_{01}^{2}}{\lambda} \cdot (B \cdot C - A \cdot D)}\right)^{0.5}$$

$w_{SR30} = 0.114$

beam parameters at SR2 Scraper baf

total system matrix to SR2 Scraper baf

$$M_{sr2scrap} := T_{SR3\_SR2scrap} \cdot Mx_{SR3}$$

$$M := M_{sr2scrap}$$

$$A := M_{0,0} \qquad B := M_{0,1}$$

$$C := M_{1,0} \qquad D := M_{1,1}$$

output beam radius, mm

$$w_{sr2scrap} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}^{\ 2}}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}^{\ 2}}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5} \qquad w_{sr2scrap} = 9.961$$

$$w_{10ppmSR2scrap} := 2.399 \cdot w_{sr2scrap} \qquad w_{10ppmSR2scrap} = 23.895$$

beam parameters at SR2 HR mirror

total system matrix to SR2 HR

$$M_{sr2hr} := T_{SR3\_SR2} \cdot Mx_{SR3}$$

$$M := M_{sr2hr}$$

$$A := M_{0,0} \qquad B := M_{0,1}$$

$C := M_{1,0}$ $D := M_{1,1}$

output beam radius, mm

$$w_{sr2hr} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}^2}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}^2}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5}$$

$w_{sr2hr} = 8.259$

$w_{10ppmsrhr} := 2.399 \cdot w_{sr2hr}$ $w_{10ppmsrhr} = 19.814$

Beam Waist after SR2 AR

system matrix up to the **SR2 AR**

$M_{sr2ar} := M2_{SR2} \cdot T_{SR2} \cdot M1_{SR2} \cdot M_{sr2hr}$

$Mx := M_{sr2ar}$

distance from **SR2 AR** to beam waist, mm

$$l_{SR2AR0} := \frac{-\left(\left(\pi \cdot \frac{w_{01}^2}{\lambda} \right)^2 \right) \cdot Mx_{1,0} \cdot Mx_{0,0} - Mx_{0,1} \cdot Mx_{1,1}}{\left(\left(\pi \cdot \frac{w_{01}^2}{\lambda} \right)^2 \right) \cdot \left(Mx_{1,0} \right)^2 + \left(Mx_{1,1} \right)^2}$$

$l_{SR2AR0} = 2.270 \cdot 10^3$

translation to beam waist

$$T_{SR2AR0} := \begin{bmatrix} 1 & l_{SR2AR0} \\ 0 & 1 \end{bmatrix}$$

total system matrix to **SR2 AR** beam waist

$$M := T_{SR2AR0} \cdot Mx$$

$$A := M_{0,0} \qquad B := M_{0,1}$$

$$C := M_{1,0} \qquad D := M_{1,1}$$

beam waist after **SR2 AR,**
mm

$$w_{SR2AR0} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}{}^2}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5}$$

$$w_{SR2AR0} = 0.095$$

beam parameters at SR2 AR Baf

system matrix from IFO waist to SR2 AR Baf

$$M_{sr2arbaf} := T_{SR2ar\_SR2arbaf} \cdot M_{sr2ar}$$

$$M := M_{sr2arbaf}$$

$$A := M_{0,0} \qquad B := M_{0,1}$$

$$C := M \qquad D := M$$

$C := M_{1,0}$ $D := M_{1,1}$

output beam radius, mm

$$w_{sr2arbaf} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}{}^2}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5}$$

$w_{sr2arbaf} = 5.569$

$w_{10ppmsr2arbaf} := 2.399 \cdot w_{sr2arbaf}$ $w_{10ppmsr2arbaf} = 13.359$

beam parameters at SRM HR

total system matrix to SRM HR

$M_{srmhr} := T_{SR2\_SRM} \cdot M_{SR2} \cdot T_{SR3\_SR2} \cdot Mx_{SR3}$

$M := M_{srmhr}$

$A := M_{0,0}$ $B := M_{0,1}$

$C := M_{1,0}$ $D := M_{1,1}$

output beam radius, mm

$$w_{srmhr} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}{}^2}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5}$$

$w_{srmhr} = 2.077$

$w_{10ppmsrmhr} := 2.399 \cdot w_{srmhr}$ $\quad w_{10ppmsrmhr} = 4.982$

$$R_{srmhr} := \frac{\left(M_{0,0}\right)^2 \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda}\right)^2 + \left(M_{0,1}\right)^2}{\left(M_{1,0} \cdot M_{0,0}\right) \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda}\right)^2 + M_{0,1} \cdot M_{1,1}} \qquad R_{srmhr} = -5.661 \cdot 10^3$$

total system matrix to SRM AR

$M_{srmar} := M2_{SRM} \cdot T1_{SRM} \cdot M1_{SRM} \cdot T_{SR2\_SRM} \cdot M_{SR2} \cdot T_{SR3\_SR2} \cdot Mx_{SR3}$

$M := M_{srmar}$

$A := M_{0,0}$ $\quad B := M_{0,1}$

$C := M_{1,0}$ $\quad D := M_{1,1}$

output beam radius, mm

$$w_{srmar} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda}\right)^2}{\pi \cdot \frac{w_{01}{}^2}{\lambda} \cdot (B \cdot C - A \cdot D)}\right)^{0.5} \qquad w_{srmar} = 2.049$$

$w_{10ppmsrmhr} := 2.399 \cdot w_{srmhr}$ $\quad w_{10ppmsrmhr} = 4.982$

$$R_{srmar} := \frac{\left(M_{0,0}\right)^2 \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda}\right)^2 + \left(M_{0,1}\right)^2}{\left(M_{1,0} \cdot M_{0,0}\right) \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda}\right)^2 + M_{0,1} \cdot M_{1,1}}$$

$R_{srmar} = -3.841 \cdot 10^3$

$R_{srmar} = -3.841 \cdot 10^{\smile}$

Beam Waist after SRM output

system matrix up to the SRM mirror

$$Mx := M2_{SRM} \cdot T1_{SRM} \cdot M1_{SRM}$$

distance from SRM mirror to beam waist, mm

$$l_{srm0} := \frac{-\left(\left(\pi \cdot \frac{w_{01}^{\;2}}{\lambda}\right)^2\right) \cdot Mx_{1,0} \cdot Mx_{0,0} - Mx_{0,1} \cdot Mx_{1,1}}{\left(\left(\pi \cdot \frac{w_{01}^{\;2}}{\lambda}\right)^2\right) \cdot \left(Mx_{1,0}\right)^2 + \left(Mx_{1,1}\right)^2}$$

$$l_{srm0} = 1.235 \cdot 10^4$$

translation to beam waist $M_{srm0} := \begin{bmatrix} 1 & l_{srm0} \\ 0 & 1 \end{bmatrix}$

total system matrix to SRM beam waist

$$M := M_{srm0} \cdot Mx$$

$A := M_{0,0}$ $B := M_{0,1}$

$C := M_{1,0}$ $D := M_{1,1}$

output beam radius, mm

$$w_{srm0} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}^{\ 2}}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}^{\ 2}}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5}$$

$w_{srm0} = 0.35$

HARTMAN
N Y

beam parameters at HWSYM1

system matrix from IFO waist to HWSYM1

$$M_{HWSYM1} := T_{SR2AR\_HWSYM1} \cdot M_{sr2ar}$$

$$M := M_{HWSYM1}$$

$A := M_{0,0}$ $B := M_{0,1}$

$C := M_{1,0}$ $D := M_{1,1}$

output beam radius, mm

$$w_{HWSYM1} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}^{\ 2}}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}^{\ 2}}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5}$$

$w_{HWSYM1} = 4.896$

$w_{10PPMHWSYM1} := 2.399 \cdot w_{HWSYM1}$ $w_{10PPMHWSYM1} = 11.746$

beam parameters at HARTMANN Y SCRAPER BAF

system matrix from IFO waist to HARTMANN Y SCRAPER Baf

$M_{sr2hartscrapbaf} := T_{SR2ar\_hartscrapbaf} \cdot M_{sr2ar}$

$M := M_{sr2hartscrapbaf}$

$A := M_{0,0}$ $B := M_{0,1}$

$C := M_{1,0}$ $D := M_{1,1}$

output beam radius, mm

$$w_{hartyscrapbaf} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}^{\ 2}}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}^{\ 2}}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5}$$

$w_{hartyscrapbaf} = 2.261$

$w_{10ppmhartyscrapbaf} := 2.399 \cdot w_{hartyscrapbaf}$ $w_{10ppmhartyscrapbaf} = 5.425$

beam parameters at HWSYM2

system matrix from IFO waist to HWSYM2

system matrix from IFO waist to HWSYM2

$M_{HWSYM2} := T_{SR2AR\_HWSYM2} \cdot M_{sr2ar}$

$M := M_{HWSYM2}$

$A := M_{0,0}$ $B := M_{0,1}$

$C := M_{1,0}$ $D := M_{1,1}$

output beam radius, mm

$$w_{HWSYM2} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}^{\;2}}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}^{\;2}}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5}$$

$w_{HWSYM2} = 0.648$

$w_{10PPMHWSYM2} := 2.399 \cdot w_{HWSYM2}$ $w_{10PPMHWSYM2} = 1.554$

beam parameters at DCBS1Y

system matrix from IFO waist to DCBS1

$M_{DCBS1} := T_{SR2AR\_DCBS1} \cdot M_{sr2ar}$

$M := M_{DCBS1}$

$A := M_{0,0}$ $B := M_{0,1}$

$C := M_{1,0}$ $D := M_{1,1}$

output beam radius, mm

$$w_{DCBS1Y} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}{}^2}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5}$$

$$w_{DCBS1Y} = 0.41$$

$$w_{10PPMDCBS1Y} := 2.399 \cdot w_{DCBS1Y}$$

$$w_{10PPMDCBS1Y} = 0.984$$

beam parameters at VAC LENSY

system matrix from IFO waist to VAC LENSY

$$M_{vaclensy} := T_{SR2AR\_vaclens} \cdot M_{sr2ar}$$

$$M := M_{vaclensy}$$

$$A := M_{0,0}$$

$$B := M_{0,1}$$

$$C := M_{1,0}$$

$$D := M_{1,1}$$

output beam radius, mm

$$w_{vaclensy} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}{}^2}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5}$$

$$w_{vaclensy} = 0.171$$

$$w_{10ppmvaclensy} = 0.41$$

$$w_{10ppmvaclensy} := 2.399 \cdot w_{vaclensy}$$

Beam Waist after VAC LENSY

system matrix up to the **VAC LENSY**

$$Mx\left(f_{vaclensy}\right) := ML_{vaclensy}\left(f_{vaclensy}\right) \cdot M_{vaclensy}$$

distance from **VAC LENSX** to beam waist, mm

$$l_{vaclensy0}\left(f_{vaclensy}\right) := \frac{-\left(\left(\pi \cdot \frac{w_{01}{}^{2}}{\lambda}\right)^{2}\right) \cdot Mx\left(f_{vaclensy}\right)_{1,0} \cdot Mx\left(f_{vaclensy}\right)_{0,0} - Mx\left(f_{vaclensy}\right)_{0,1} \cdot Mx\left(f_{vaclensy}\right)_{1,1}}{\left(\left(\pi \cdot \frac{w_{01}{}^{2}}{\lambda}\right)^{2}\right) \cdot \left(Mx\left(f_{vaclensy}\right)_{1,0}\right)^{2} + \left(Mx\left(f_{vaclensy}\right)_{1,1}\right)^{2}}$$

$$l_{vaclensy0}\left(f_{vaclensy}\right) = -4.611$$

translation to beam waist

$$T_{vaclensy0}\left(f_{vaclensy}\right) := \begin{bmatrix} 1 & l_{vaclensy0}\left(f_{vaclensy}\right) \\ 0 & 1 \end{bmatrix}$$

total system matrix to **VAC LENSY** beam waist

$$M\left(f_{vaclensy}\right) := T_{vaclensy0}\left(f_{vaclensy}\right) \cdot Mx\left(f_{vaclensy}\right)$$

$$A := M\left(f_{vaclensy}\right)_{0,0} \qquad B := M\left(f_{vaclensy}\right)_{0,1}$$

$$C := M\left(f_{vaclensy}\right)_{1,0} \qquad D := M\left(f_{vaclensy}\right)_{1,1}$$

beam waist after **VAC**

beam waist after **VAC LENSY,** mm

$$w_{vaclensy0}\left(f_{vaclensy}\right) := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - \left(M\left(f_{vaclensy}\right)_{0,0}\right)^2 \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda}\right)^2}{\pi \cdot \frac{w_{01}{}^2}{\lambda} \cdot \left(M\left(f_{vaclensy}\right)_{0,1} \cdot M\left(f_{vaclensy}\right)_{1,0} - M\left(f_{vaclensy}\right)_{0,0} \cdot M\left(f_{vaclensy}\right)_{1,1}\right)}\right)^{0.5}$$

$$w_{vaclensy0}\left(f_{vaclensy}\right) = 0.171$$

beam parameters at HWSYM3

system matrix from IFO waist to HWSYM3

$$M_{HWSYM3}\left(f_{vaclensy}\right) := T_{vaclens\_HWSYM3} \cdot ML_{vaclensy}\left(f_{vaclensy}\right) \cdot M_{vaclensy}$$

$$M\left(f_{vaclensy}\right) := M_{HWSYM3}\left(f_{vaclensy}\right)$$

$$A := M\left(f_{vaclensy}\right)_{0,0} \qquad B := M\left(f_{vaclensy}\right)_{0,1}$$

$$C := M\left(f_{vaclensy}\right)_{1,0} \qquad D := M\left(f_{vaclensy}\right)_{1,1}$$

output beam radius, mm

$$w_{HWSYM3}\left(f_{vaclensy}\right) := \left(\frac{\lambda}{\pi} \cdot \frac{-\left(M\left(f_{vaclensy}\right)_{0,1}\right)^2 - \left(M\left(f_{vaclensy}\right)_{0,0}\right)^2 \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda}\right)^2}{\pi \cdot \frac{w_{01}{}^2}{\lambda} \cdot \left(M\left(f_{vaclensy}\right)_{0,1} \cdot M\left(f_{vaclensy}\right)_{1,0} - M\left(f_{vaclensy}\right)_{0,0} \cdot M\left(f_{vaclensy}\right)_{1,1}\right)}\right)^{0.5}$$

$w_{HWSYM3}\left(f_{vaclensy}\right)$ $w_{HWSYM3}\left(f_{vaclensy}\right)=1.073$

$w_{10PPMHWSYM3}\left(f_{vaclensy}\right):=2.399\cdot w_{HWSYM3}\left(f_{vaclensy}\right)$ $w_{10PPMHWSYM3}\left(f_{vaclensy}\right)=2.574$

beam parameters at HARTMANN Y VP

system matrix from IFO waist to HARTMANN Y VP

$M_{hartyvp}\left(f_{vaclensy}\right):=T_{vaclensy\_VP}\cdot ML_{vaclensy}\left(f_{vaclensy}\right)\cdot M_{vaclensy}$

$M:=M_{hartyvp}$

$A:=M_{hartyvp}\left(f_{vaclensy}\right)_{0,0}$ $B:=M_{hartyvp}\left(f_{vaclensy}\right)_{0,1}$

$C:=M_{hartyvp}\left(f_{vaclensy}\right)_{1,0}$ $D:=M_{hartyvp}\left(f_{vaclensy}\right)_{1,1}$

output beam radius, mm

$$w_{hartyvp}\left(f_{vaclensy}\right):=\left(\frac{\lambda}{\pi}\cdot\frac{-\left(M_{hartyvp}\left(f_{vaclensy}\right)_{0,1}\right)^2-\left(M_{hartyvp}\left(f_{vaclensy}\right)_{0,0}\right)^2\cdot\left(\pi\cdot\frac{w_{01}^{\ 2}}{\lambda}\right)^2}{\pi\cdot\frac{w_{01}^{\ 2}}{\lambda}\cdot\left(M_{hartyvp}\left(f_{vaclensy}\right)_{0,1}\cdot M_{hartyvp}\left(f_{vaclensy}\right)_{1,0}-M_{hartyvp}\left(f_{vaclensy}\right)_{0,0}\cdot M_{hartyvp}\left(f_{vaclensy}\right)_{1,1}\right)}\right)^{0.5}$$

$f_{vaclensy}=60$ $f_{vaclensy}:=60$ $w_{hartyvp}\left(f_{vaclensy}\right)=2.58$ 0.153

$w_{10ppmhartyvp}\left(f_{vaclensy}\right):=2.146\cdot w_{hartyvp}\left(f_{vaclensy}\right)$ $w_{10ppmhartyvp}\left(f_{vaclensy}\right)=5.536$

HARTMANN X

system matrix up to the **SR3 mirror** Mx_{SR3}

beam parameters at HWSXM1

system matrix from IFO waist to HWSXM1

$$M_{HWSXM1} := T_{SR3\_HWSXM1} \cdot Mx_{SR3}$$

$$M := M_{HWSXM1}$$

$$A := M_{0,0} \qquad B := M_{0,1}$$

$$C := M_{1,0} \qquad D := M_{1,1}$$

output beam radius, mm

$$w_{HWSXM1} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}^{\,2}}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}^{\,2}}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5} \qquad w_{HWSXM1} = 8.871$$

$$w_{10PPMHWSXM1} := 2.399 \cdot w_{HWSXM1} \qquad w_{10PPMHWSXM1} = 21.282$$

beam parameters at Hartmann-X Scraper Baf

system matrix from IFO waist to Hart-X Scraper Baf

$$M_{hartxscrapbaf} := T_{SR3\_hartscrapbaf} \cdot Mx_{SR3}$$

$$M := M_{hartxscrapbaf}$$

$A := M_{0,0}$ $B := M_{0,1}$

$C := M_{1,0}$ $D := M_{1,1}$

output beam radius, mm

$$w_{hartxscrapbaf} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}^{\ 2}}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}^{\ 2}}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5}$$

$w_{hartxscrapbaf} = 6.52$

$w_{10ppmhartxscrapbaf} := 2.399 \cdot w_{hartxscrapbaf}$ $w_{10ppmhartxscrapbaf} = 15.64$

beam parameters at HWSXM2

system matrix from IFO waist to HWSXM2

$M_{HWSXM2} := T_{SR3\_HWSXM2} \cdot Mx_{SR3}$

$M := M_{HWSXM2}$

$A := M_{0,0}$ $B := M_{0,1}$

$C := M_{1,0}$ $D := M_{1,1}$

output beam radius, mm

$$w_{HWSXM2} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}^{\ 2}}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}^{\ 2}}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5}$$

$w_{HWSXM2} = 5.164$

$w_{10PPMHWSXM2} := 2.399 \cdot w_{HWSXM2}$ $w_{10PPMHWSXM2} = 12.388$

beam parameters at HWSYM3

system matrix from IFO waist to HWSYM3

$M_{HWSXM3} := T_{SR3\_HWSXM3} \cdot Mx_{SR3}$

$M := M_{HWSXM3}$

$A := M_{0,0}$ $B := M_{0,1}$

$C := M_{1,0}$ $D := M_{1,1}$

output beam radius, mm

$$w_{HWSXM3} := \left(\frac{\lambda}{\pi} \cdot \frac{-\left(M_{0,1}\right)^2 - \left(M_{0,0}\right)^2 \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda}\right)^2}{\pi \cdot \frac{w_{01}{}^2}{\lambda} \cdot \left(M_{0,1} \cdot M_{1,0} - M_{0,0} \cdot M_{1,1}\right)} \right)^{0.5}$$

$w_{HWSXM3} = 3.972$

$w_{10PPMHWSXM3} := 2.399 \cdot w_{HWSXM3}$ $w_{10PPMHWSXM3} = 9.529$

beam parameters at DCBS1X

system matrix from IFO waist to DCBS1X

$$M_{DCBS1X} := T_{SR3\_DCBS1} \cdot Mx_{SR3}$$

$$M := M_{DCBS1X}$$

$$A := M_{0,0} \qquad B := M_{0,1}$$

$$C := M_{1,0} \qquad D := M_{1,1}$$

output beam radius, mm

$$w_{DCBS1X} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}{}^2}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5} \qquad w_{DCBS1X} = 3.487$$

$$w_{10PPMDCBS1X} := 2.399 \cdot w_{DCBS1X} \qquad w_{10PPMDCBS1X} = 8.366$$

beam parameters at VAC LENSX

system matrix from IFO waist to VAC LENSX

$$M_{vaclensx} := T_{SR3\_vaclens} \cdot Mx_{SR3}$$

$$M := M_{vaclensx}$$

$$A := M_{0,0} \qquad B := M_{0,1}$$

$$C := M_{1,0} \qquad D := M_{1,1}$$

output beam radius, mm

$$w_{vaclensx} := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - A^2 \cdot \left(\pi \cdot \frac{w_{01}^{\ 2}}{\lambda} \right)^2}{\pi \cdot \frac{w_{01}^{\ 2}}{\lambda} \cdot (B \cdot C - A \cdot D)} \right)^{0.5}$$

$$w_{vaclensx} = 2.523$$

$$w_{10ppmvaclensx} := 2.399 \cdot w_{vaclensx}$$

$$w_{10ppmvaclensx} = 6.054$$

Beam Waist after VAC LENSX

system matrix up to the **VAC LENSX**

$$Mx\left(f_{vaclensx}\right) := ML_{vaclensx}\left(f_{vaclensx}\right) \cdot M_{vaclensx}$$

distance from **VAC LENSX** to beam waist, mm

$$l_{vaclensx0}\left(f_{vaclensx}\right) := \frac{-\left(\left(\pi \cdot \frac{w_{01}^{\ 2}}{\lambda}\right)^2\right) \cdot Mx\left(f_{vaclensx}\right)_{1,0} \cdot Mx\left(f_{vaclensx}\right)_{0,0} - Mx\left(f_{vaclensx}\right)_{0,1} \cdot Mx\left(f_{vaclensx}\right)_{1,1}}{\left(\left(\pi \cdot \frac{w_{01}^{\ 2}}{\lambda}\right)^2\right) \cdot \left(Mx\left(f_{vaclensx}\right)_{1,0}\right)^2 + \left(Mx\left(f_{vaclensx}\right)_{1,1}\right)^2}$$

$$l_{vaclensx0}\left(f_{vaclensx}\right) = -3.78 \cdot 10^3$$

translation to beam waist

$$T_{vaclensx0}\left(f_{vaclensx}\right) := \begin{bmatrix} 1 & l_{vaclensx0}\left(f_{vaclensx}\right) \\ 0 & 1 \end{bmatrix}$$

total system matrix to **VAC LENSX** beam waist

$M\left(f_{vaclensx}\right) := T_{vaclensx0}\left(f_{vaclensx}\right) \cdot Mx\left(f_{vaclensx}\right)$

$A := M\left(f_{vaclensx}\right)_{0,0}$ $B := M\left(f_{vaclensx}\right)_{0,1}$

$C := M\left(f_{vaclensx}\right)_{1,0}$ $D := M\left(f_{vaclensx}\right)_{1,1}$

beam waist after **VAC LENSX,** mm

$$w_{vaclensx0}\left(f_{vaclensx}\right) := \left(\frac{\lambda}{\pi} \cdot \frac{-B^2 - \left(M\left(f_{vaclensx}\right)_{0,0}\right)^2 \cdot \left(\pi \cdot \frac{w_{01}{}^2}{\lambda}\right)^2}{\pi \cdot \frac{w_{01}{}^2}{\lambda} \cdot \left(M\left(f_{vaclensx}\right)_{0,1} \cdot M\left(f_{vaclensx}\right)_{1,0} - M\left(f_{vaclensx}\right)_{0,0} \cdot M\left(f_{vaclensx}\right)_{1,1}\right)}\right)^{0.5}$$

$w_{vaclensx0}\left(f_{vaclensx}\right) = 0.518$

beam parameters at HARTMANN X VP

system matrix from IFO waist to HARTMANN X VP

$M_{hartmanxvp}\left(f_{vaclensx}\right) := T_{vaclensx\_VP} \cdot ML_{vaclensx}\left(f_{vaclensx}\right) \cdot T_{SR3\_vaclens} \cdot Mx_{SR3}$

$M := M_{hartmanxvp}\left(f_{vaclensx}\right)$

$A := M_{hartmanxvp}\left(f_{vaclensx}\right)_{0,0}$ $B := M_{hartmanxvp}\left(f_{vaclensx}\right)_{0,1}$

$C := M_{hartmanxvp}\left(f_{vaclensx}\right)_{1,0}$

$D := M_{hartmanxvp}\left(f_{vaclensx}\right)_{1,1}$

output beam radius, mm

$$w_{hartmanxvp}\left(f_{vaclensx}\right) := \left(\frac{\lambda}{\pi} \cdot \frac{-\left(M_{hartmanxvp}\left(f_{vaclensx}\right)_{0,1}\right)^2 - \left(M_{hartmanxvp}\left(f_{vaclensx}\right)_{0,0}\right)^2 \cdot \left(\pi \cdot \frac{w_{01}^{\,2}}{\lambda}\right)^2}{\pi \cdot \frac{w_{01}^{\,2}}{\lambda} \cdot \left(M_{hartmanxvp}\left(f_{vaclensx}\right)_{0,1} \cdot M_{hartmanxvp}\left(f_{vaclensx}\right)_{1,0} - M_{hartmanxvp}\left(f_{vaclensx}\right)_{0,0} \cdot M_{hartmanxvp}\left(f_{vaclensx}\right)_{1,1}\right)}\right)^{0.5}$$

$w_{vaclensx} = 2.523$

$f_{vaclensx} = -700$ $\quad f_{vaclensx} := -850$ $\quad w_{hartmanxvp}\left(f_{vaclensx}\right) = 2.527$ $\quad 2.519$

$w_{10ppmhartmanxvp}\left(f_{vaclensx}\right) := 2.399 \cdot w_{hartmanxvp}\left(f_{vaclensx}\right)$ $\quad w_{10ppmhartmanxvp}\left(f_{vaclensx}\right) = 6.063$