Beam Splitter in aLIGO

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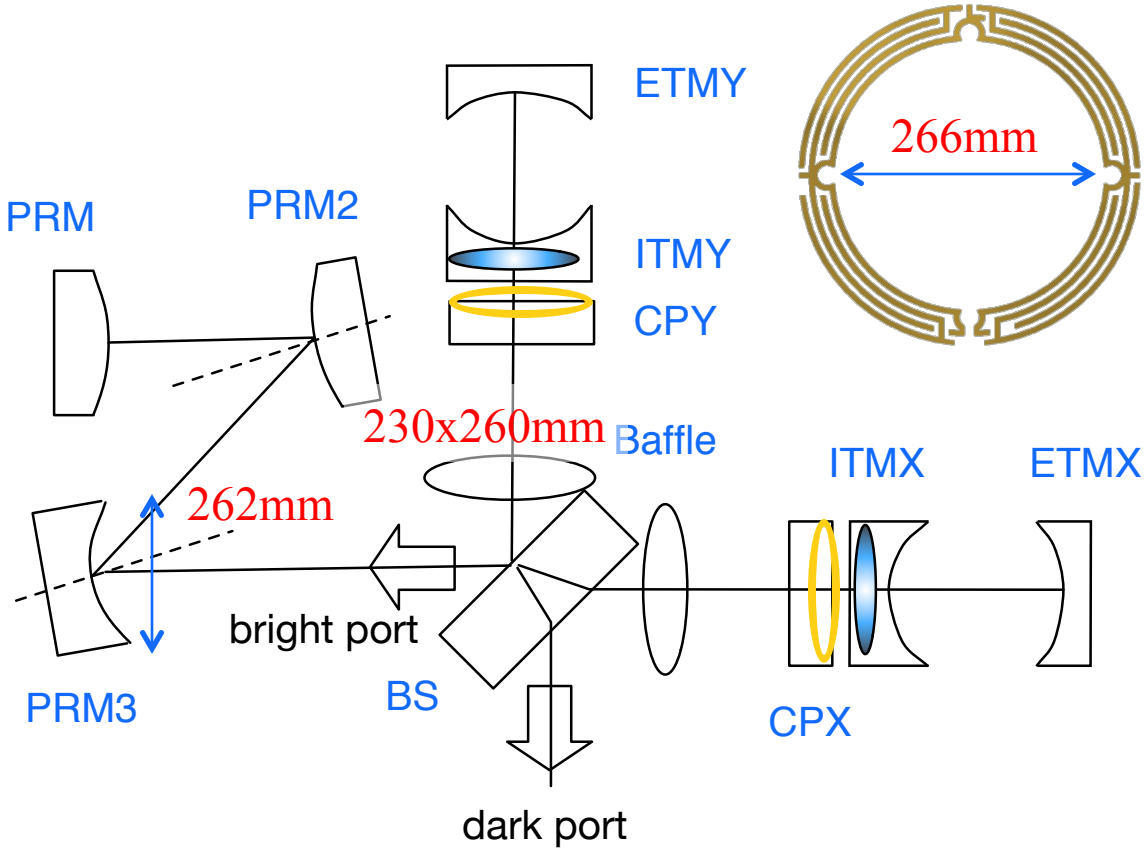
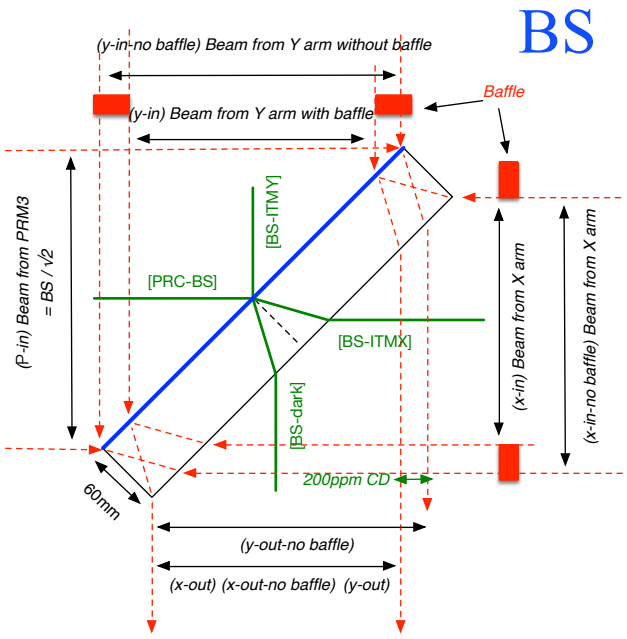
- BS02 to BS05? larger BS?
- BS in aLIGO IFO for near future upgrade
  - » All COC optics of L1 as is except for BS
  - » TCS can correct power terms in ITM substrate
    - – ITM power terms are nullified, to be realized by re-polished CP
- Performance degradation by geometrical hierarchy
- Effect of RM3 aperture on the beam beyond BS
- Effect of ITM inhomogeneity, mixing with BS inhomogeneity
- Effect of ESD, visible for larger BS
- Summary

Geometry related to performance



ESD on CP

(modeled by a simple with hole with 266mm aperture)



Performance degradation of aLIGO IFO

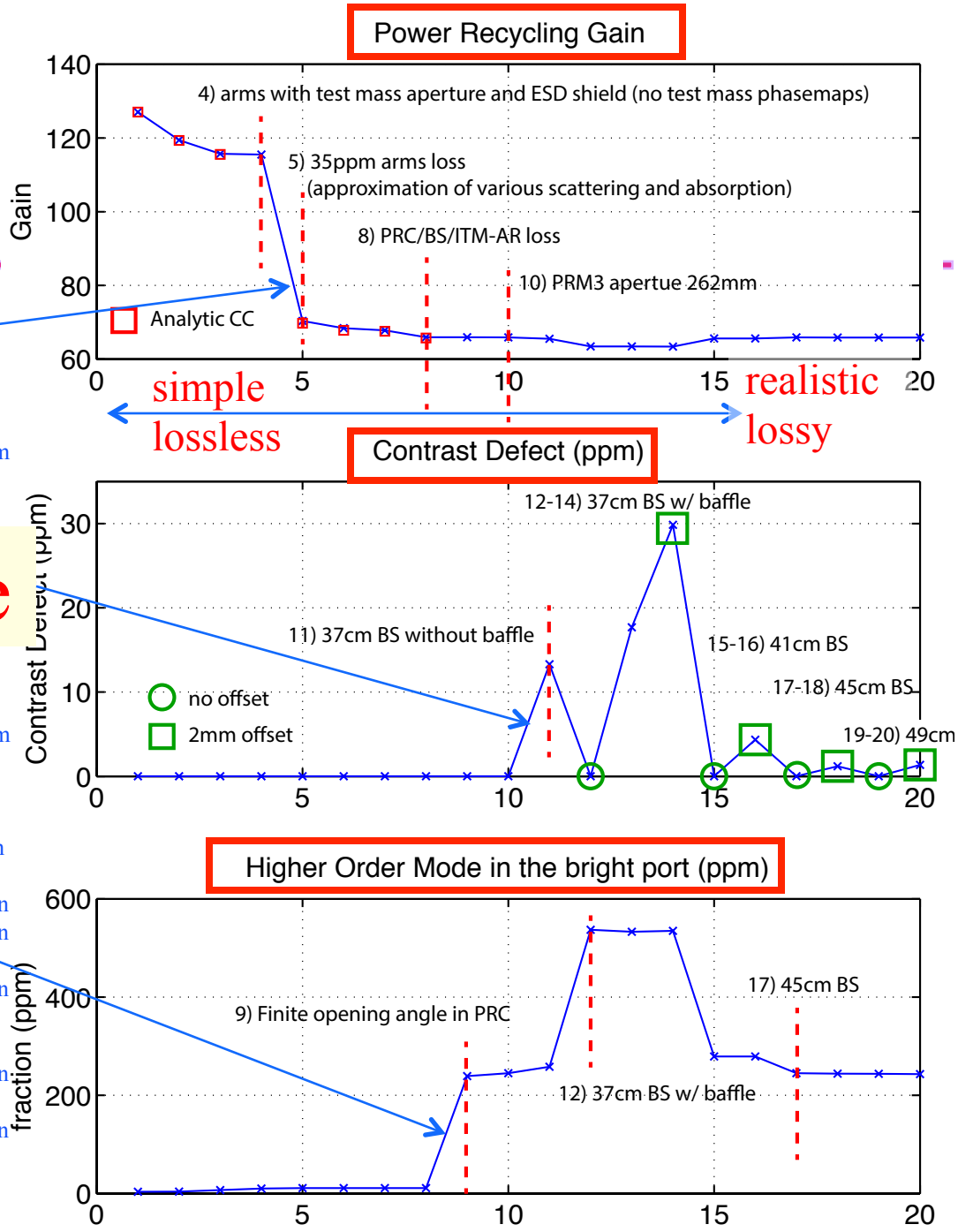
T140

1) no los… OM (3.7ppm) looks a nice gaussian s… is slightly off.
2) 1) + E… M transmittance 3.7ppm
3) 2) + test mass aperture 326mm, round trip loss by the aperture is 1.94ppm (with 340mm, RTL is 0.6ppm)
4) 3) + 266mm ESD aperture, placed using BS baffle (266mmx266mm) in fron…
5) …
6) …
of lo…
7) 5) + ITM AR side loss, (ITMX loss 200ppm, ITMY loss 330ppm)
8) 5) + 6) and 7), i.e., losses and transmission in the PRC, BS and ITM AR
9) 8) + finite opening angles in PRC (0.79° for PRM2 and 0.615° for PRM3). Among the total HOM of 240ppm, major ones are HG(1,0) of 12ppm and HG(0,2) of 210ppm.
10) 9)
11) 10…
12) 11… from 260ppm…
13) 12… ection
14) 12… ection
15) 10… ection
16) 15…
17) 10… perform…
18) 17… ection
19) 10… BS 490mm×360mm with BS baffle (266mm×266mm)
20) 19) with BS baffle facing to X arm offset by *2mm* in horizontal direction

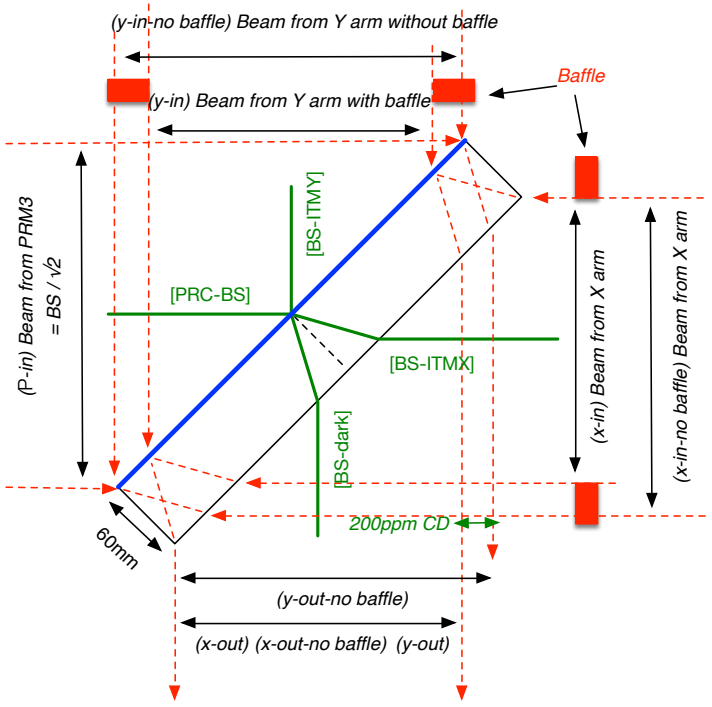
Arm loss

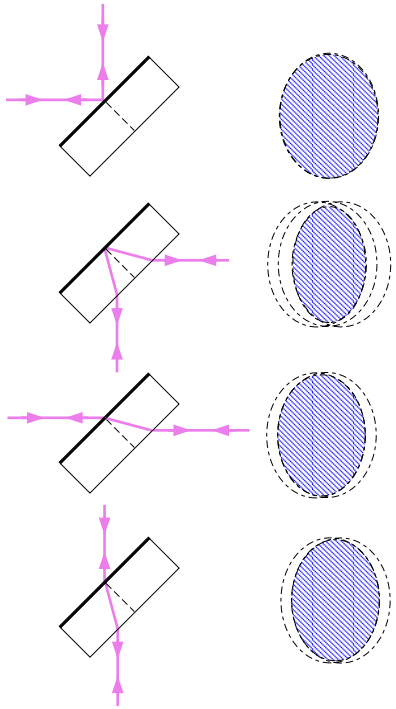
37cm BS w/o baffle

Finite incident angles on PRM2 and PRM3

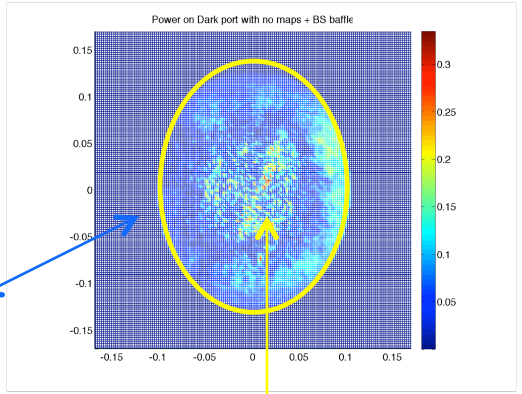


BS baffle designed to suppress CD



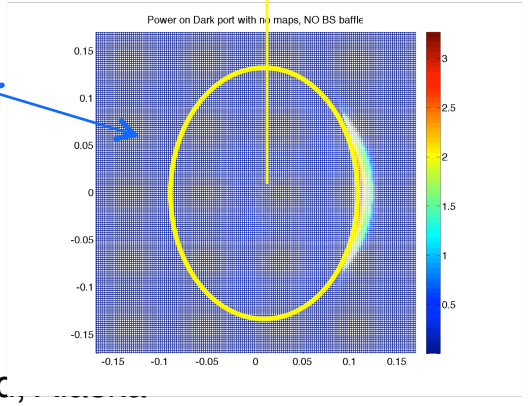


With BS baffle : 7ppm



Without BS baffle : 210ppm

(d) – (b)



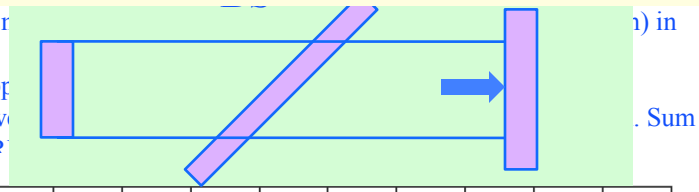
BS size

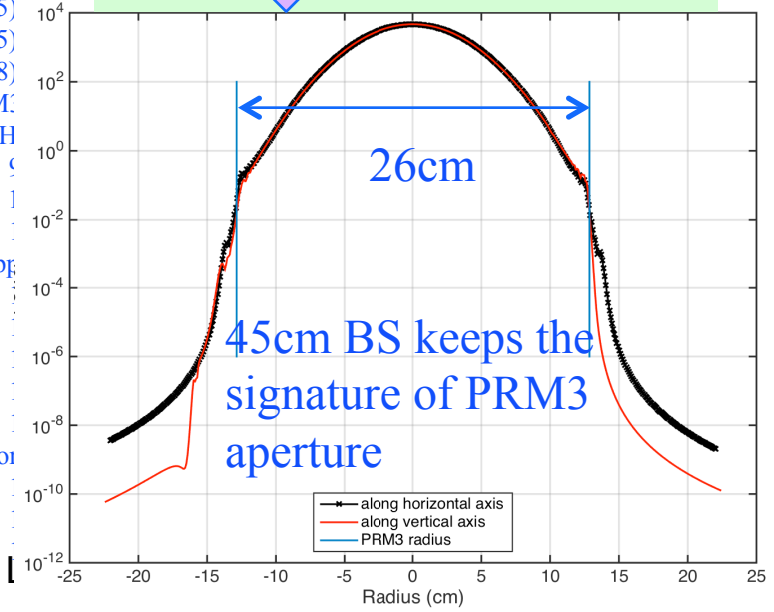
CD nullified by BS baffle

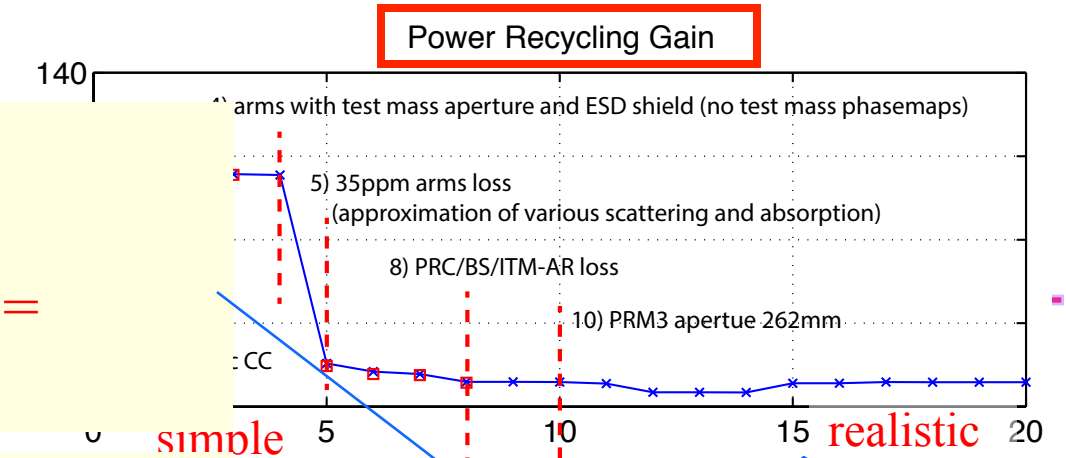
Sensitivity on positioning :

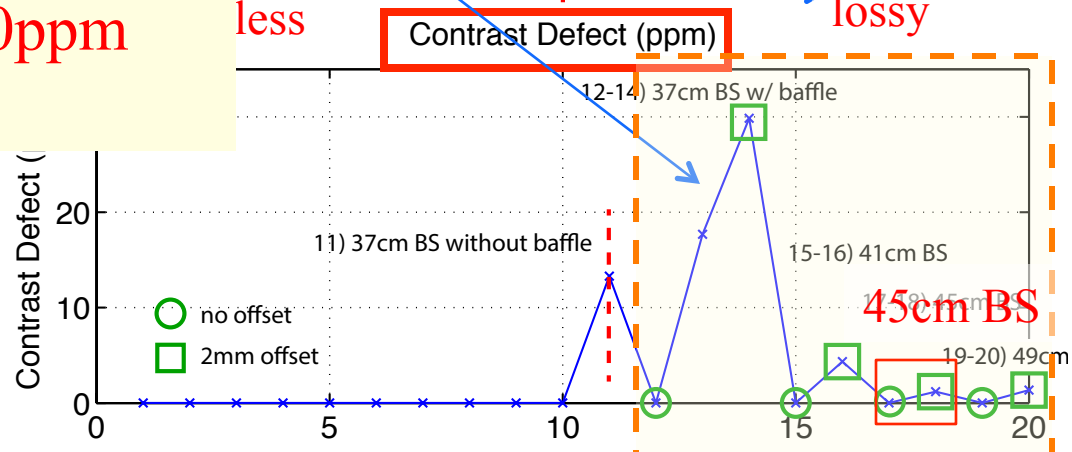
Baffle aperture(11.5cm) =
2.1 x beam size(5.3cm)

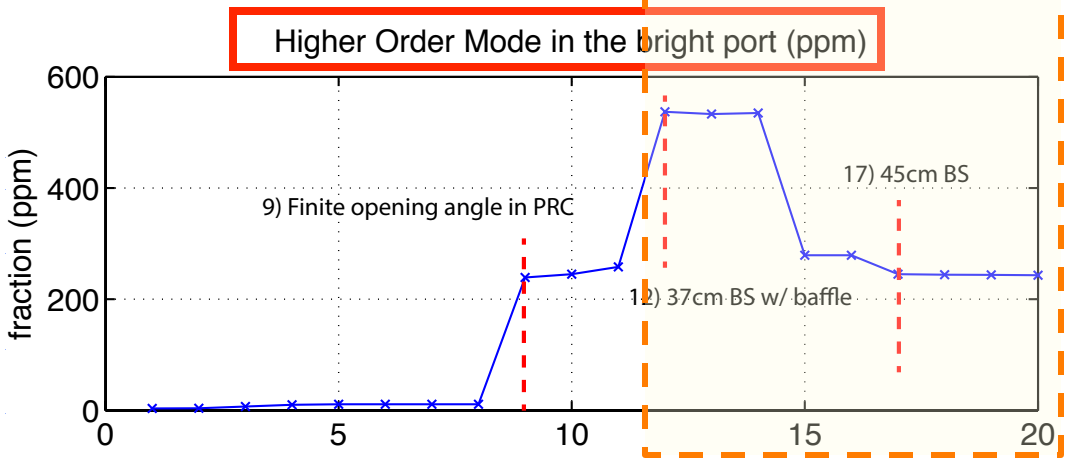
Loss: 37cm BS w/ baffle = 600ppm
45cm BS = 100ppm











ITM / BS aberrations : some sees, some not

Sign flip on resonance

$$E_{ref} \approx \exp(i2\phi)E_{00}$$

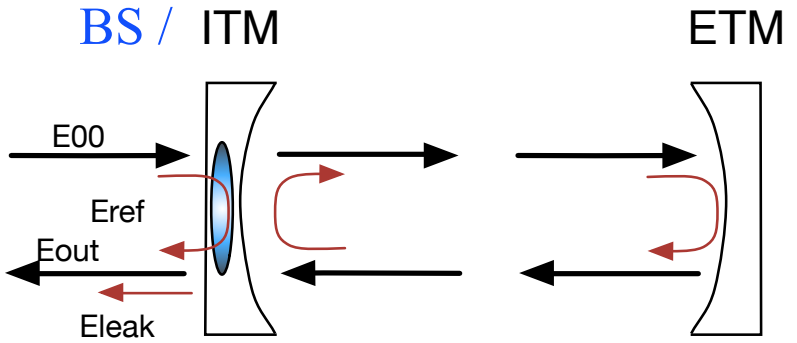
$$E_{leak} = \exp(i\phi)\begin{Bmatrix} -2 \\ 0 \end{Bmatrix} Ein$$

$$E_{tot} = \begin{Bmatrix} \exp(2i\phi) \\ \exp(i2\phi) \end{Bmatrix} E_{00} + \begin{Bmatrix} -2\exp(i\phi) \\ 0 \end{Bmatrix} E_{00} \approx \begin{Bmatrix} -1+O(\phi^2) \\ 1+i2\phi \end{Bmatrix} E_{00}$$

← CR
← SB

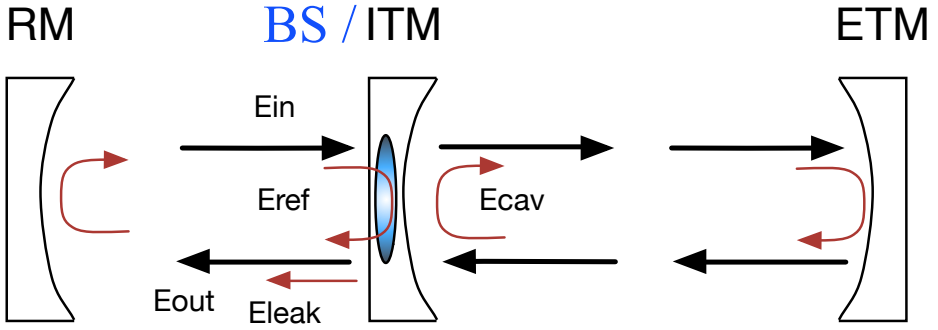
Reflected field by arm

- CR (Eout) : don't see
- SB (Eref) : see
- Signal SB (Eleak) : see



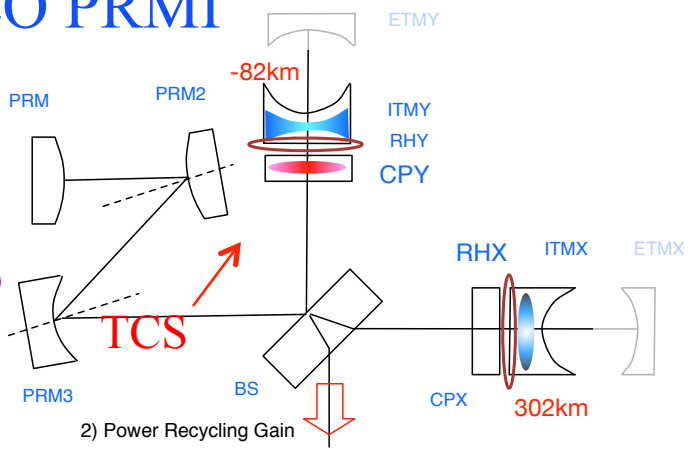
Mode in recycling cavity

- CR : insensitive
- SB, Signal : sensitive

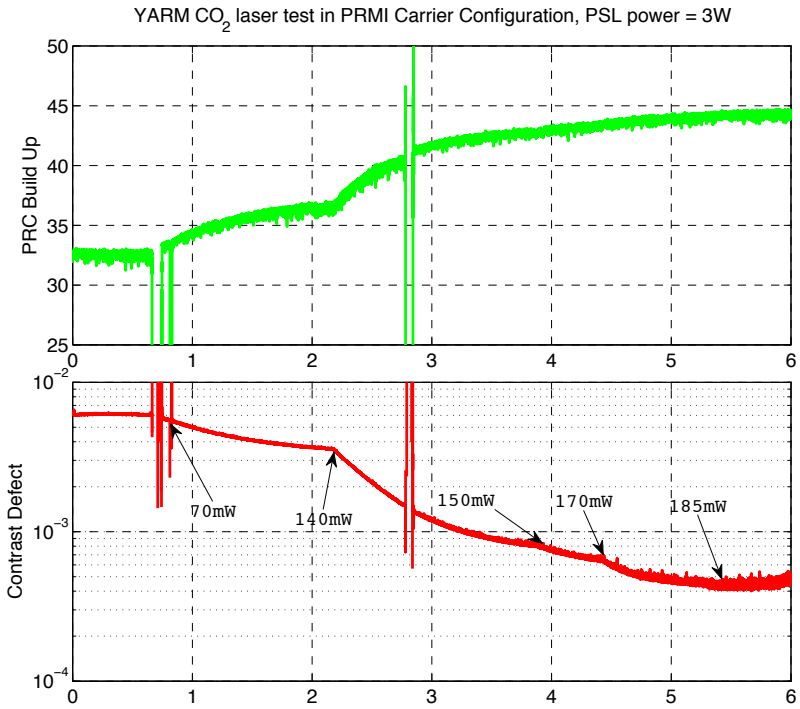


PRG and CD with TCS corrections

LLO PRMI

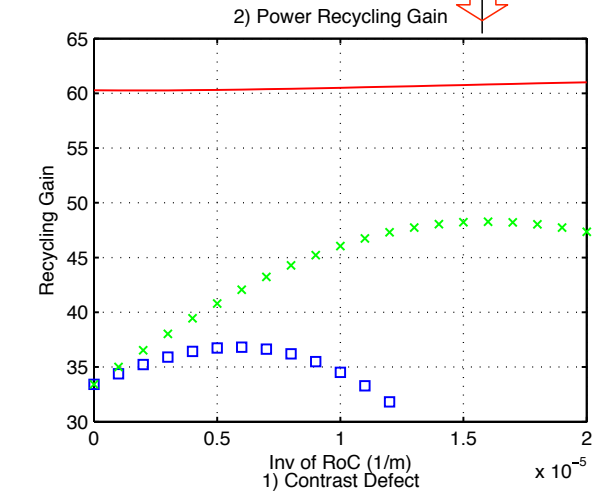


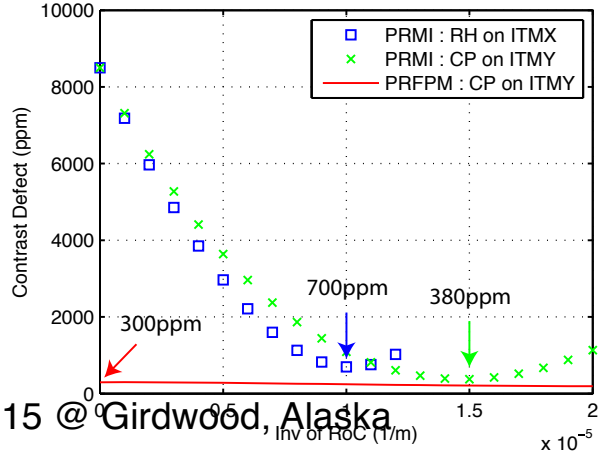
L1 data



log11140 CD~400ppm, PRG~45

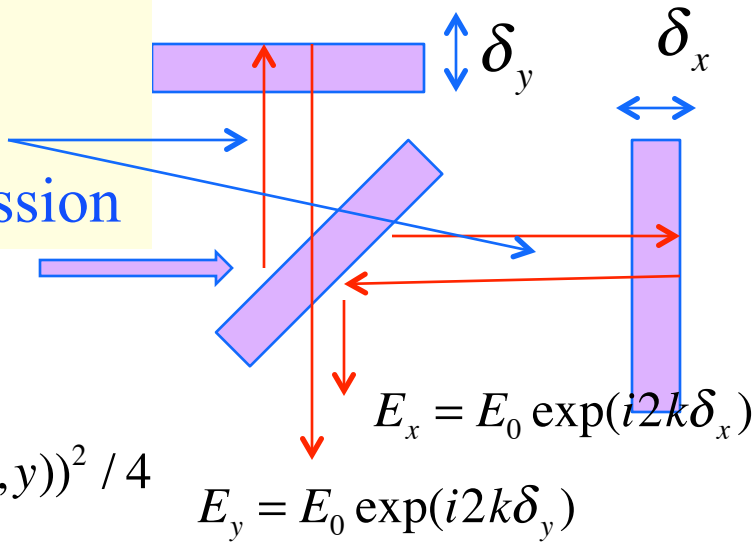
Simulation





Effect of BS/ITM aberration on CD

Through near field propagation:
Power distribution does not change
Phase can change on reflection/transmission

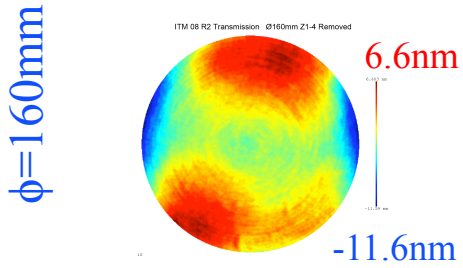


$$CD = Power(E_x - E_y) / Power(E_x + E_y)$$

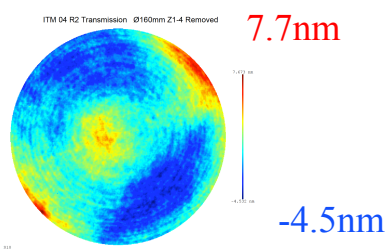
$$= \int dx\,dy (2k)^2 \frac{2}{\pi w^2} \exp(-2\frac{r^2}{w^2})(\delta_x(x,y) - \delta_y(x,y))^2 / 4$$

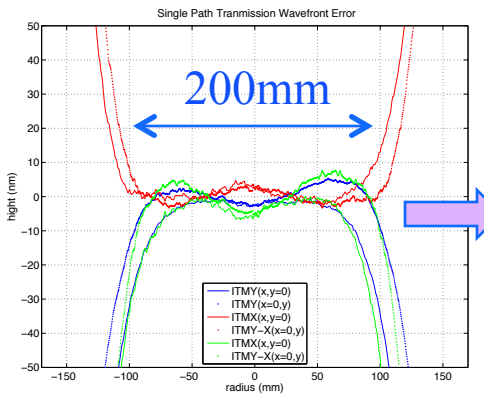
ITM transmission map after power term removed

ITM08 / ITMY



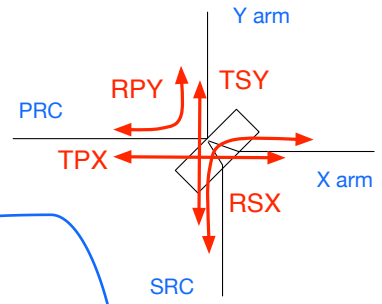
ITM04 / ITMX

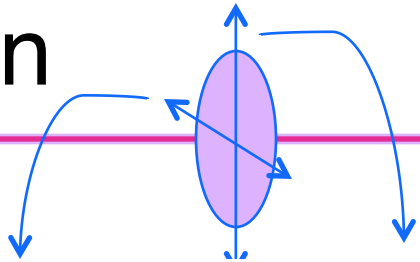




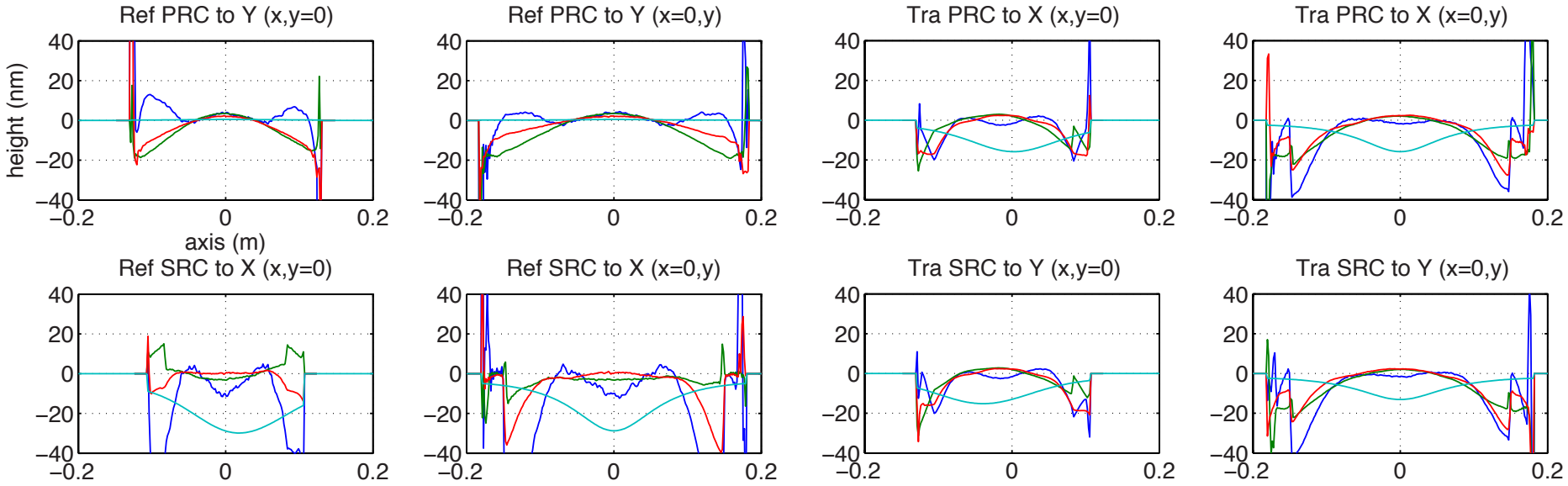
BS uniformity needs to be good only in 280mm x 200mm

BS : Three maps and Thermal distortion

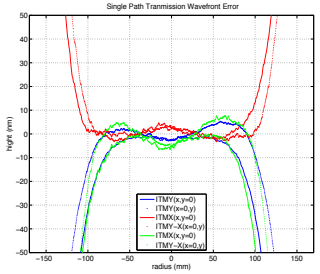




BS02 LLO now
BS05 LLO
BS06 LHO
BS Thermal



BS Reflections

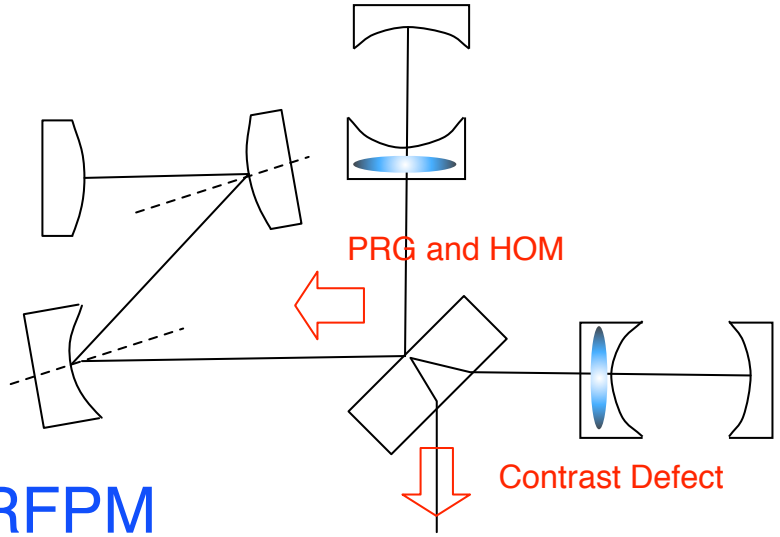


BS Transmissions

ITM Transmissions

Effects of BS on CR and SB simulation

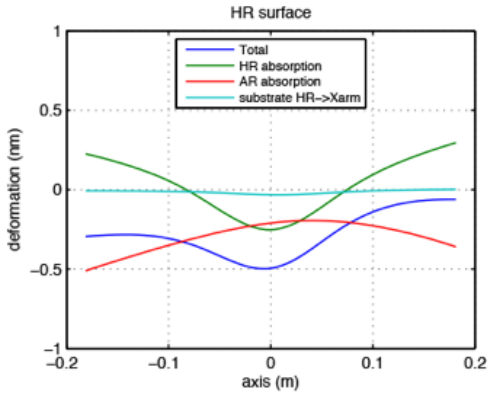
- L1 with all known COC data including reflection and transmission maps of ITM
- Lock by CR
- MICH to make dark port darkest
- 9MHz RF SB within this locked PRFPM
- Two ITM thermal states
  - » Cold : ITMs have no power in the transmission maps
  - » Optimal : ITMs have 50km lens in the transmission maps
- Mode is defined by arm, with 50km static lens in ITMs

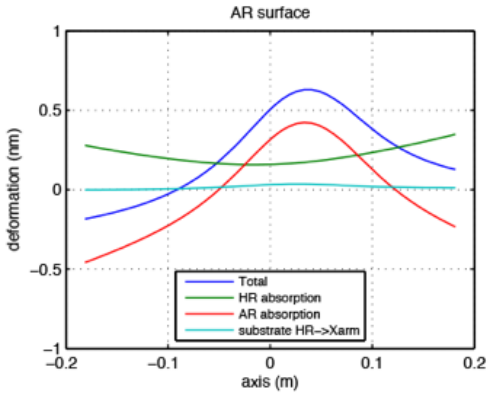


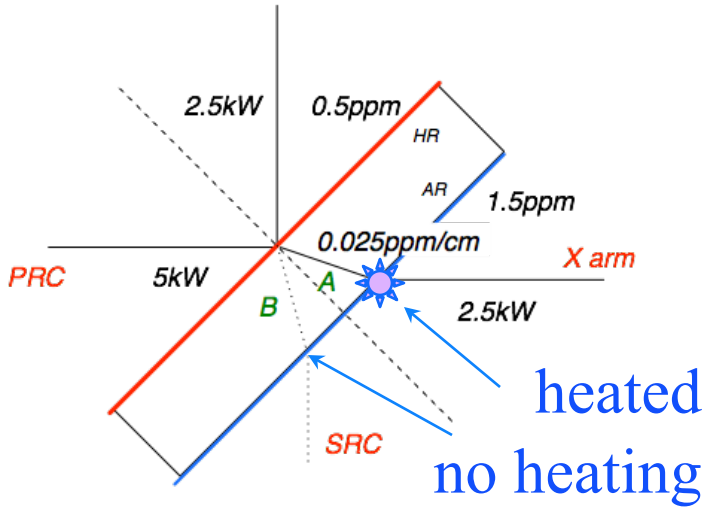
Effects of BS on CR and SB quantitative view

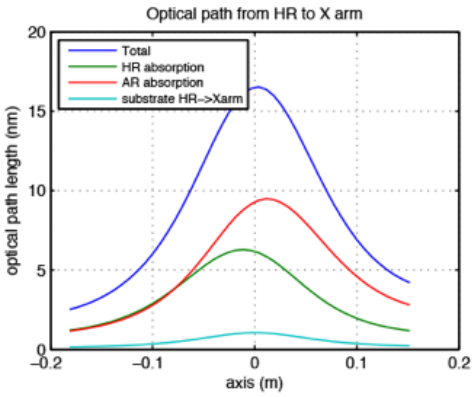
			No BS (37cm)	BS02 (37cm)	BS05 (37cm)	No BS (45cm)	Beam on ITM
Cold	CR	PRG	39	39	40	41	5.33cm
		CD (ppm)	66	225	114	76	
		HOM (ppm)	790	780	690	470	
	SB	PRG	55	50	40	48	5.95cm
		HOM (%)	2.3%	2.5%	3.0%	2.2%	
optimal	CR	PRG	39	39	40	40	5.30cm
		CD (ppm)	82	210	136	108	
		HOM (ppm)	2100	2300	2400	1450	
	SB	PRG	108	108	108	114	5.35cm
		HOM (ppm)	580	780	1200	340	

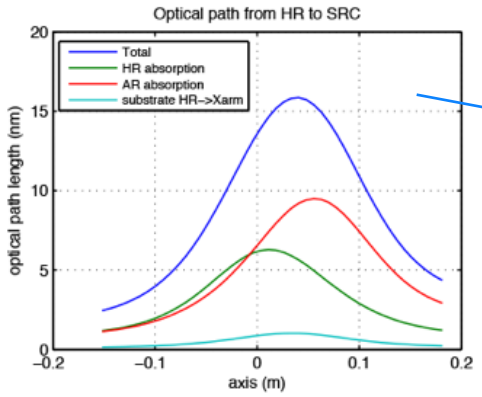
BS Thermal distortion

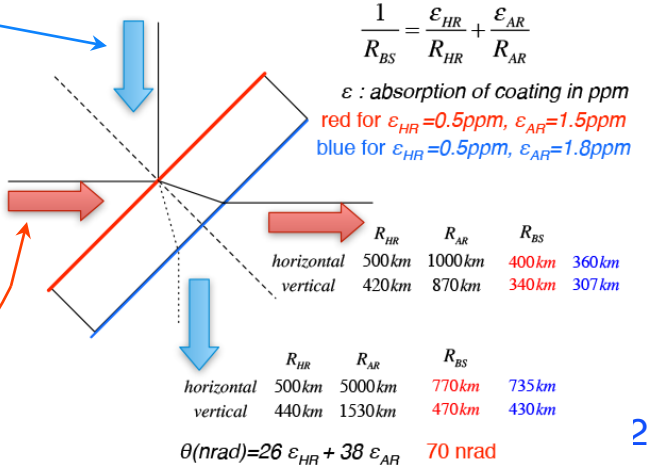






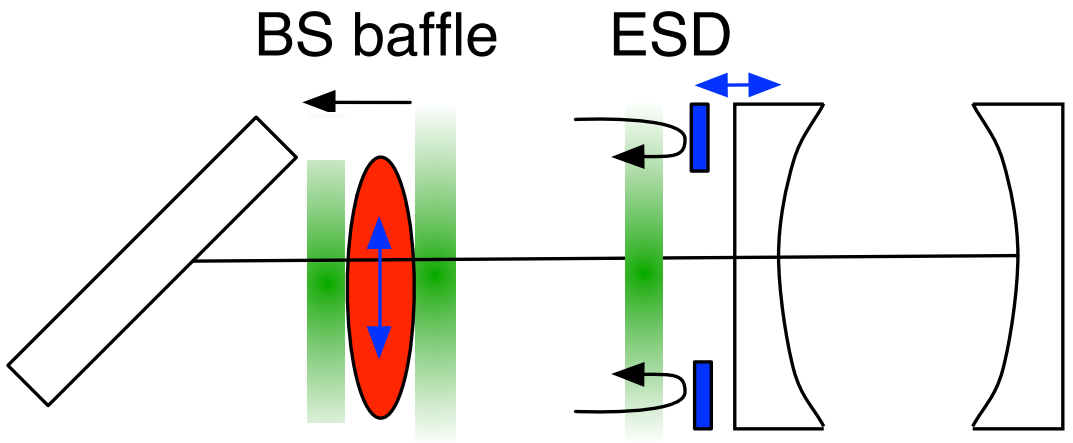






Noises by BS baffle and ESD motions

- BS baffle motion for 37cm BS
  - » $h(f) = 4 \times 10^{-11}\ \delta_{ISI}(f)$
- ESD motion for 45cm BS
  - » $h(f) = 2 \times 10^{-9}\ \delta_{CP\text{-}ITM}(f)$
- Both are smaller by 100 than the requirements



Summary

- BS02 vs BS05
  - » If it ain't broken, don't fit it.
  - » Some may improve, but will see some new issue
- Aperture change from 37cm to 45cm
  - » Improve total loss around BS
  - » Less critical to positioning of beams and mechanical structure
- Noises due to BS baffle or ESD motions are negligible