Effects of as-built Mirrors - analysis using FFT -

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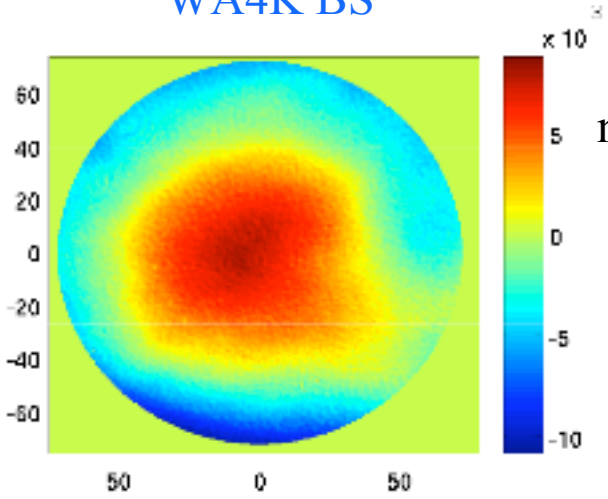
- LIGO I mirror phase map
- FFT tools
- Thermal lensing
- Beam splitter curvature

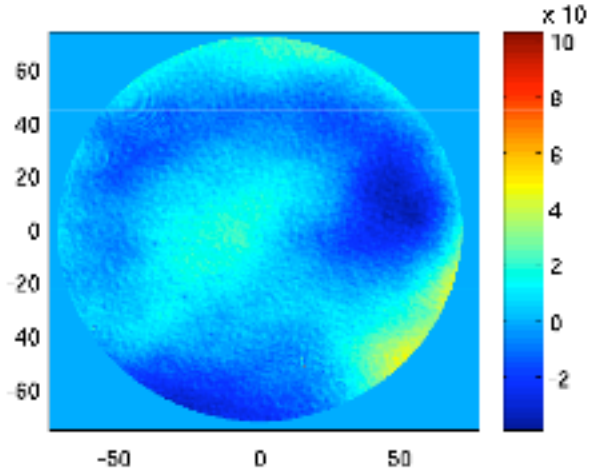
Beam splitter phase map

WA4K BS

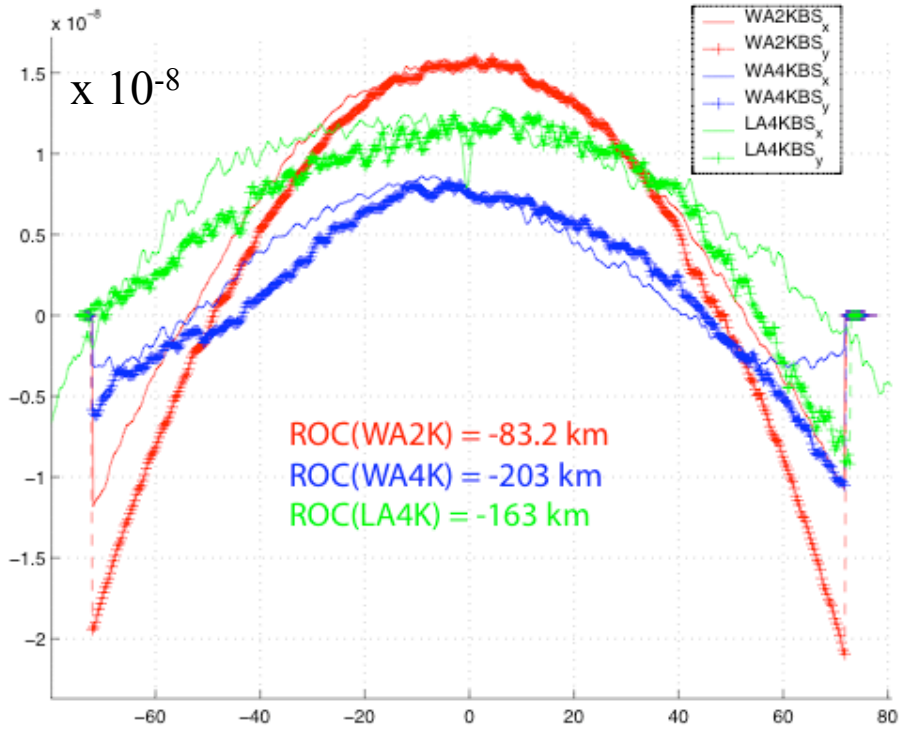


nm

WA4K BS - curvature subtracted



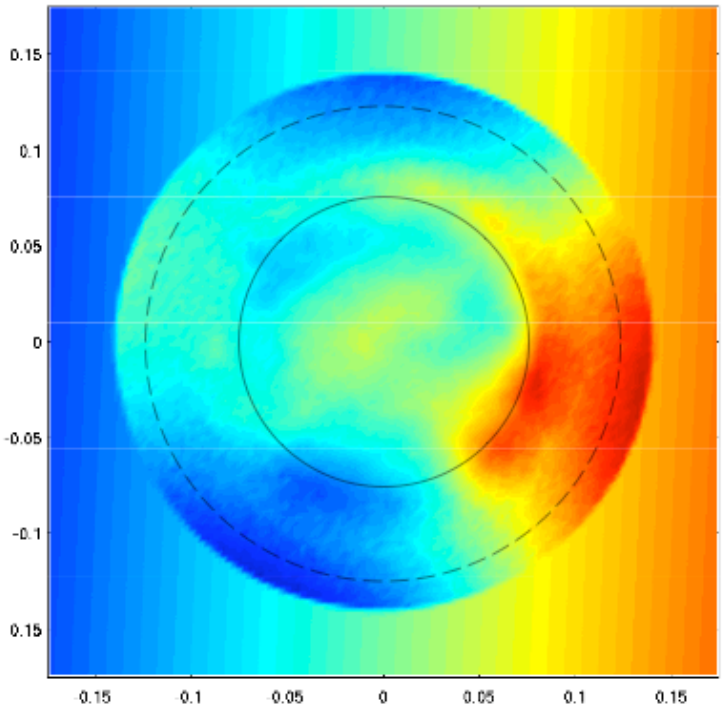
nm



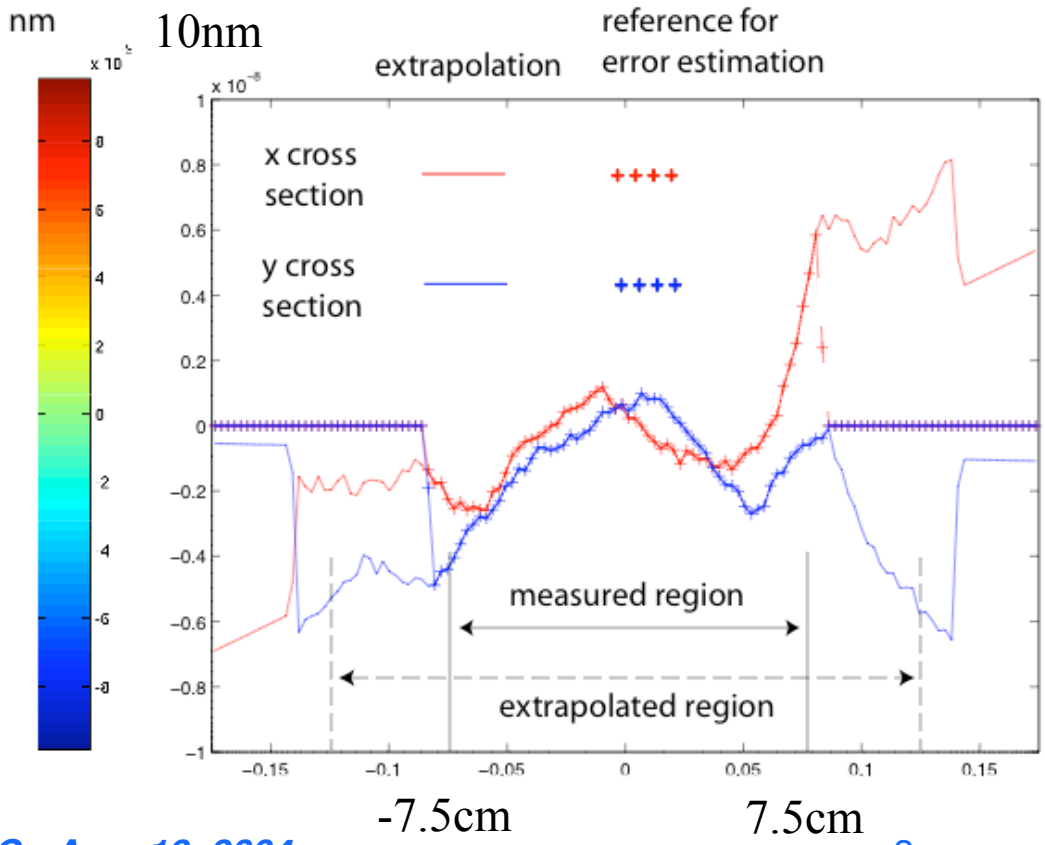
concave ROC > 200km, convex ROC > 720km

Smooth extrapolation from 15cm to 24cm

WA4k BS after curvature subtracted

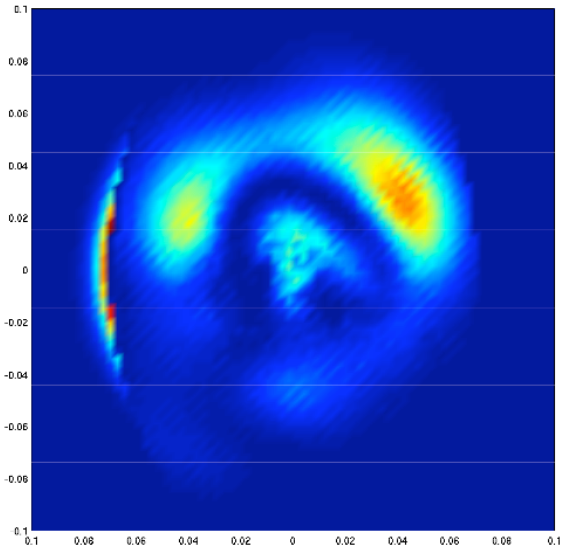


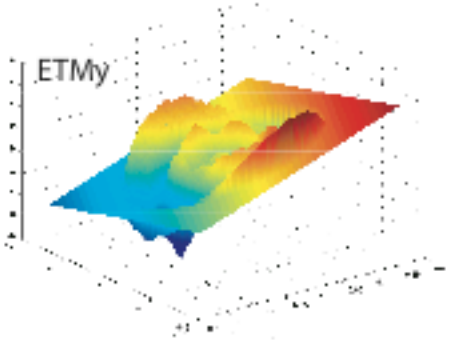
Limited case study shows almost no difference

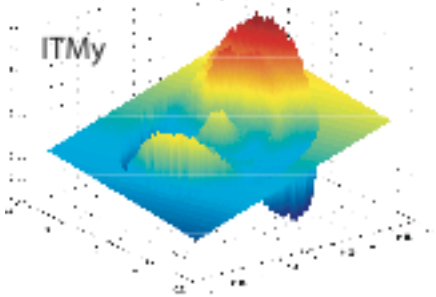


Contrast Defect

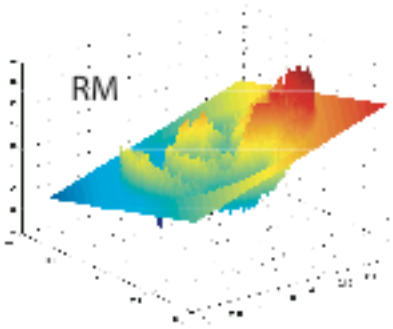
- Ugly but harmless CR from dark port -

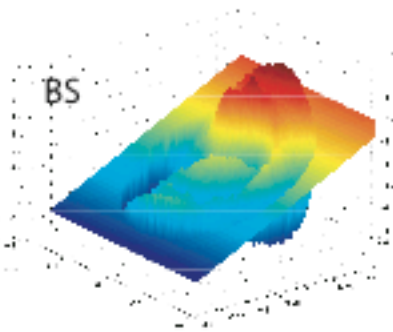


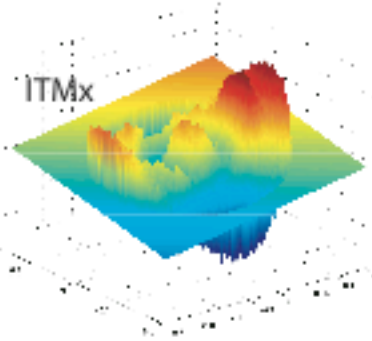


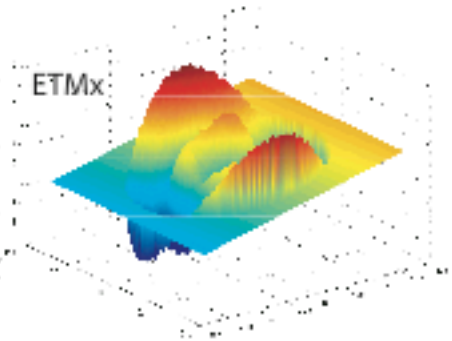


Mode matched, identical arms	5.5e-7
+ as-built arms	6.8e-5
+ BS curvature	1.2e-4
+ Mirror phase maps	2.3e-4
+ Differential heating	2.5e-4









LIGO I Mirror phase maps available

- All phase maps available from e2e home page
  - LHO4k, LHO2k, LLO4k
  - Smooth extrapolation set and reference set
  - 128 x 128 and 256 x 256
- Tilt removed
  - Poor mans ASC
- R.Dodda (2003 SURF from SLU), X.Xu (2004 SURF from Caltech)

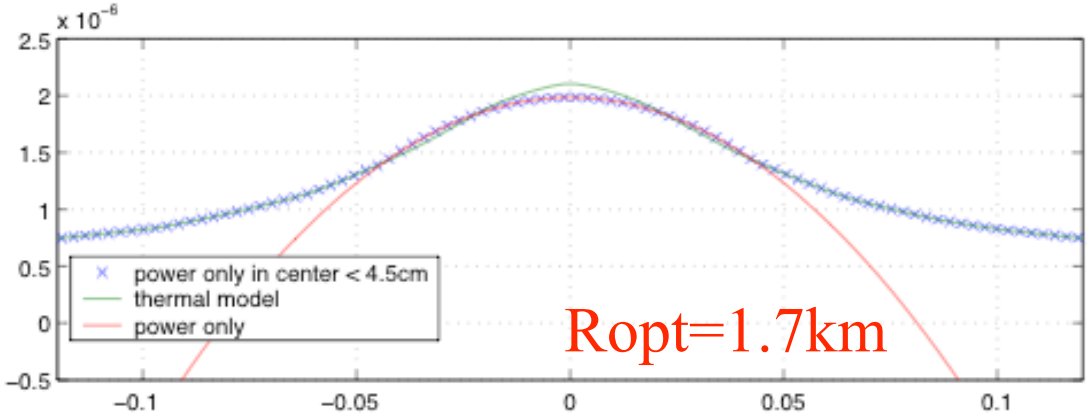
FFT tools

- Beam splitter curvature
  - Explicit support by adding pixel by pixel extra length by √2 x sag
  - Planned to confirm using e2e (modal model)
- FFT lock vs LSC lock
  - FFT lock uses only CR, LSC lock uses CR and SBs
  - Lock FFT by itself -> Lock using ASQ,REFL,POB
  - DARM,CARM change by 10^-12m, PRC,MICH by 10^-9m
  - Quantitative results affected, most of qualitative results OK
  - Discussed later
- Propagation with magnification (not in this talk)
  - Virgo Physics Book, Volume 2 “OPTICS and related TOPICS”, 3.1.7
  - FFT pixel size can be scaled - 25 cm mirrors to mm detector
  - Fields can be propagated through telescopes to actual detectors

Thermal lensing in FFT

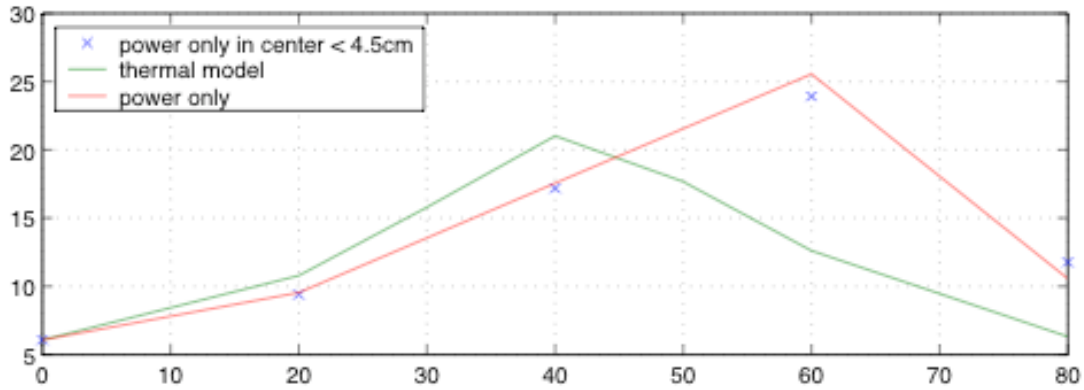
- Phil W. calculated based on MIT model -

Optical thickness @ 1w



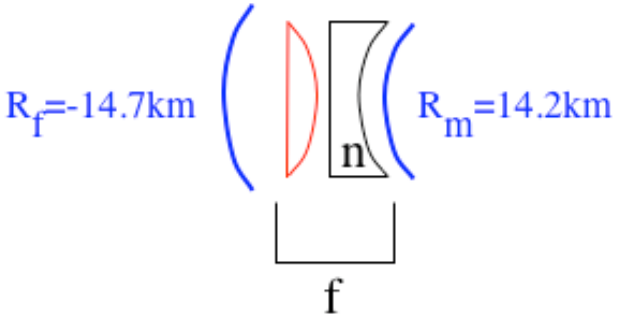
radius (m)

Sideband recycling gain



total heating (mW)

Ropt / Power

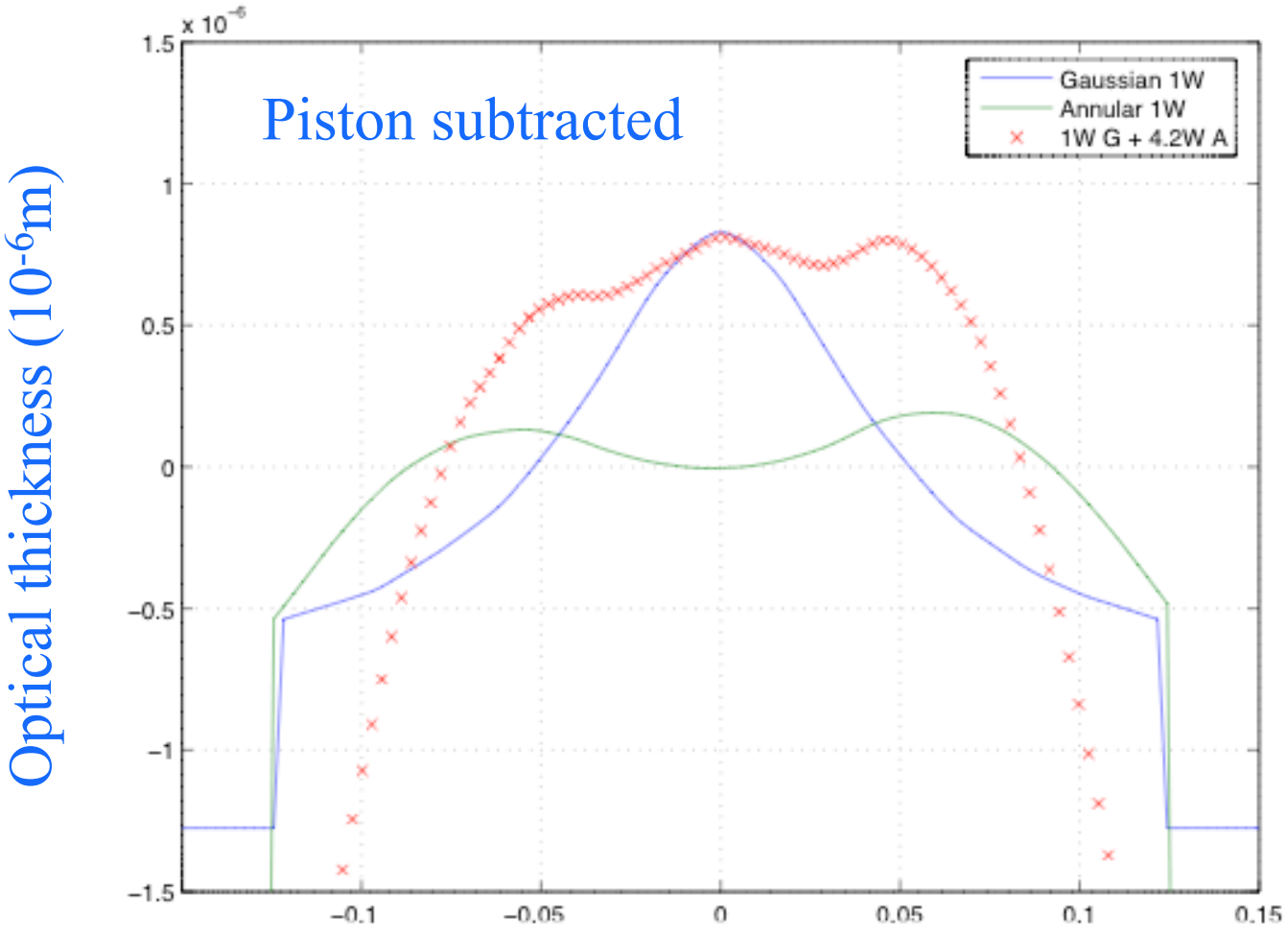


$$\frac{1}{f} = -\frac{n-1}{Rm} + \frac{1}{Ropt} Power$$

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

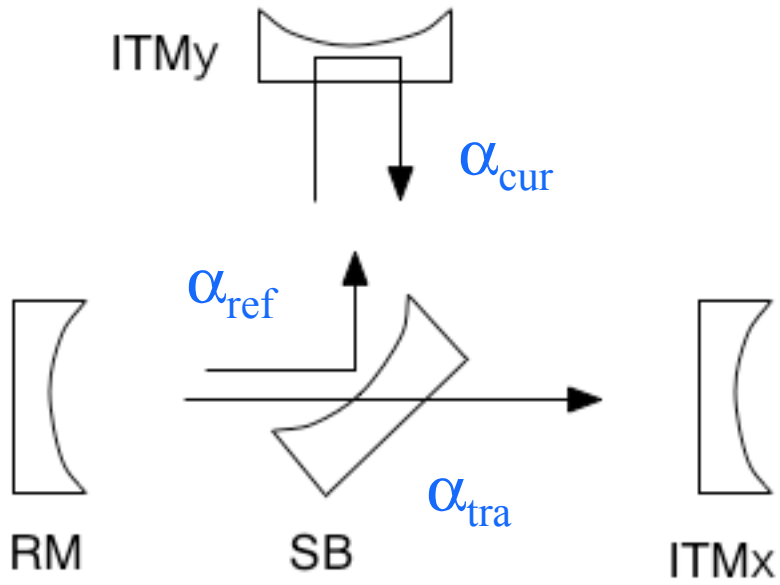
Power = 58mW

Gaussian and Annular



Beam splitter curvature

$$TEM00(out) = \frac{1}{\sqrt{(1+i\alpha_x)(1+i\alpha_y)}} TEM00(in)$$



$$\alpha_{cur} = \frac{z}{z_0}\left(1 - \frac{R_f(z)}{R_{ITM}}\right)$$ 0.23 (cold) ~ 0 (hot)

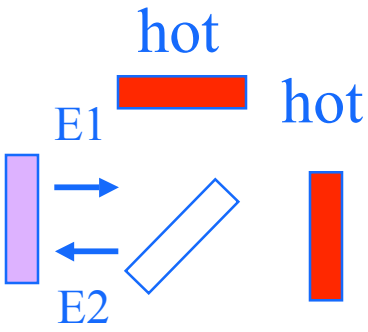
$$\alpha_{ref}(x,y) = -\frac{z}{z_0}\frac{R_f(z)}{R_{BS}\cos(\theta_{inc})^{\pm 1}}$$ 0.027

$$\alpha_{tra} = -\frac{n-1}{2}\alpha_{ref}$$ -0.005

rayleigh length z_0 = 3.6km, distance to waist z = -1km, R_{ITM}=-14km, R_{BS}=-200km,
Beam curvature R_f(BS) = -14km, R_f(ITMy)= 1/(1/R_f(BS) -(n(ITMy)-1)/R_m)=-27km

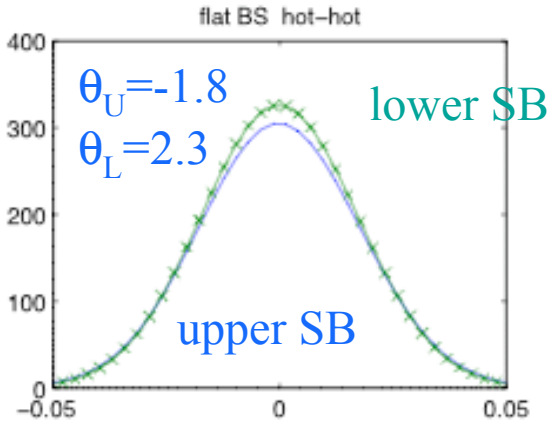
ITM differential heating vs beam splitter curvature

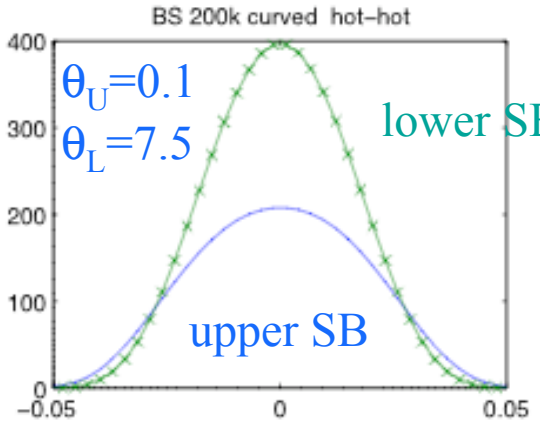
Power on ITMy

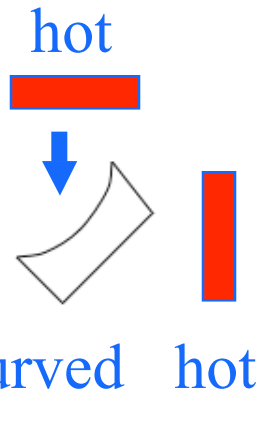


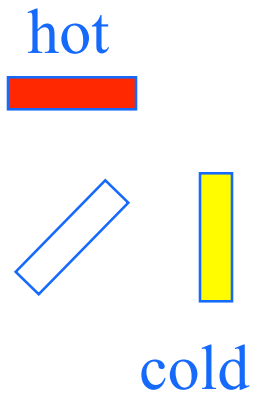
$E2 = E1 * \exp(i\theta)$

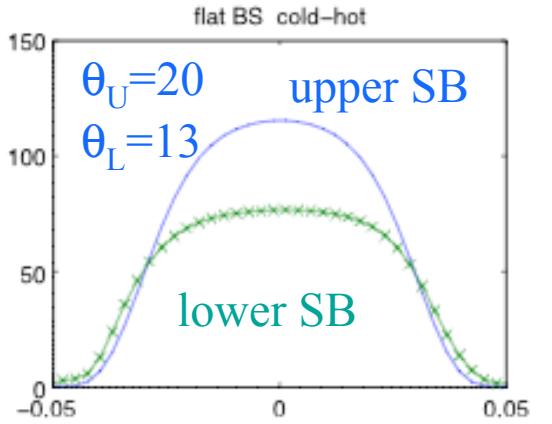
θ in mrad

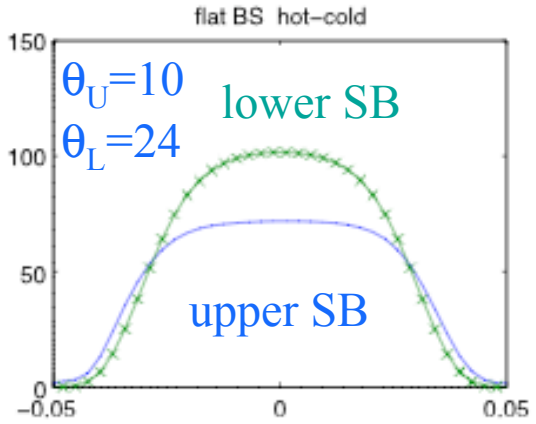


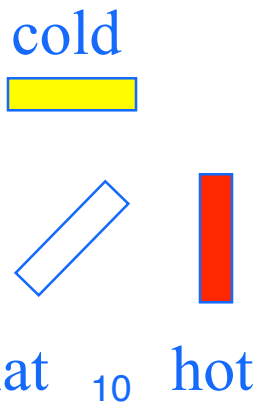








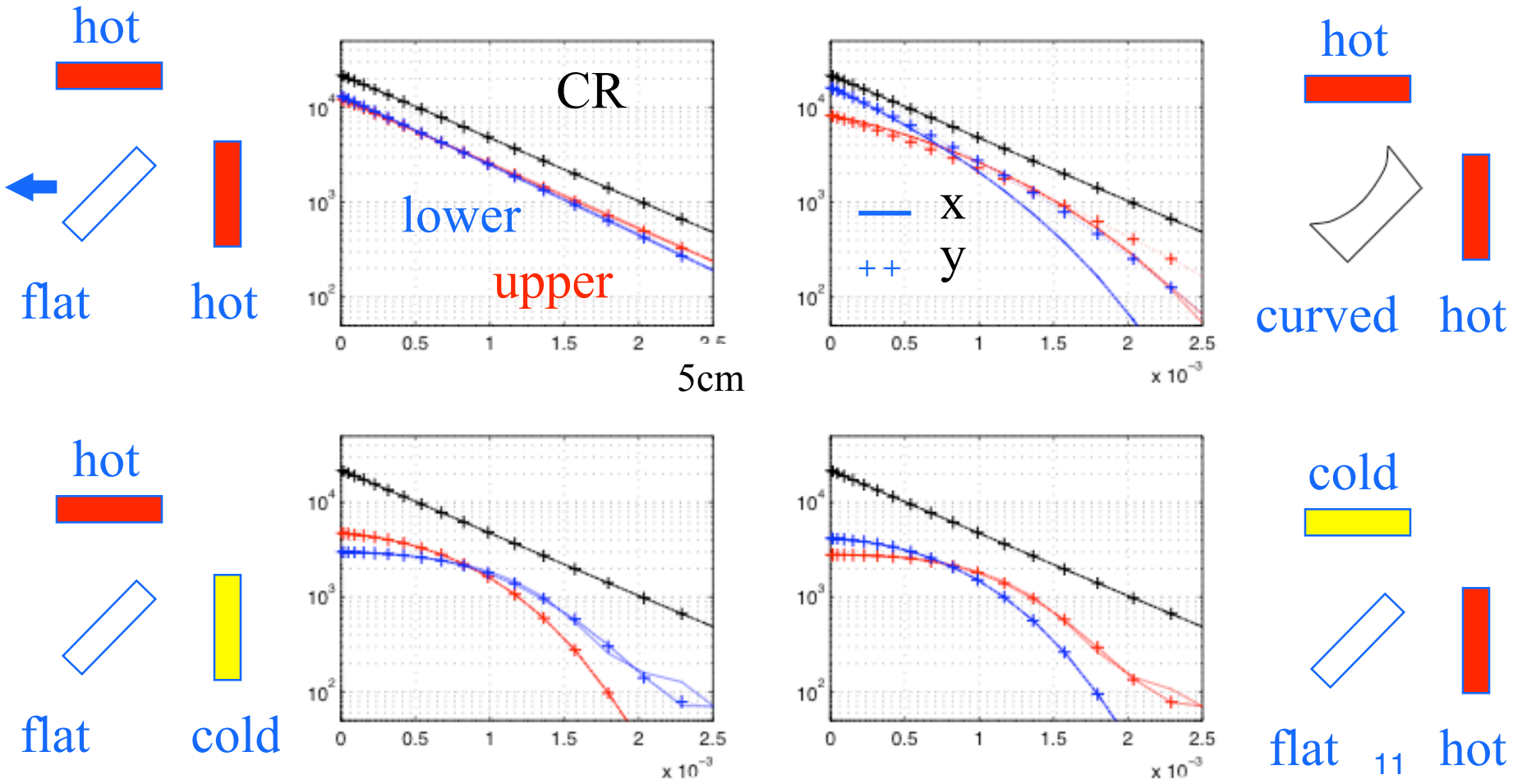




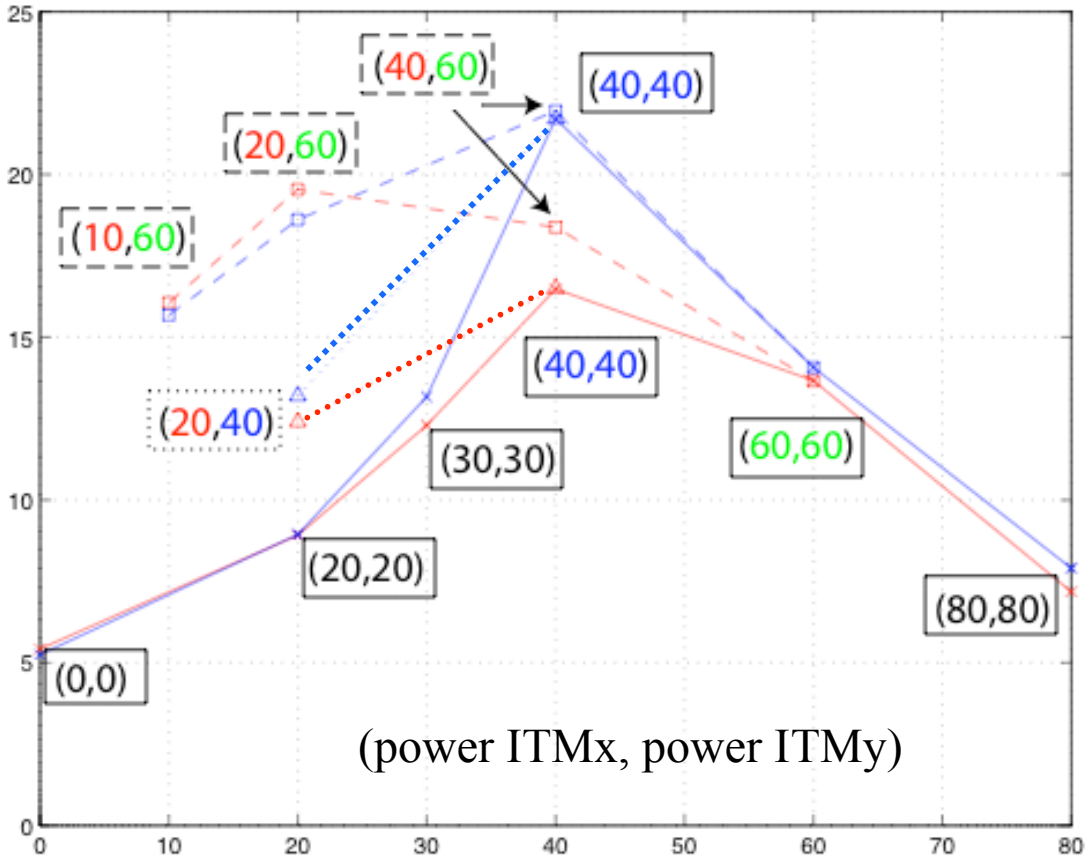
Power only
thermal

Gaussianity of CR & SBs

Power on Symmetric port : log(power) vs x^2



SB gain vs Gaussian heating with curved BS



powerX,Y for common heating
powerX for differential heating

lower SB

upper SB

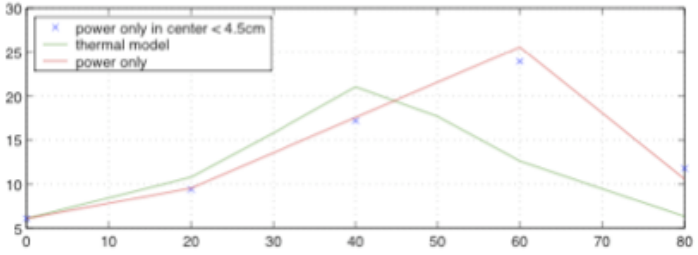
common heating

differential heating

ITMy 40mW

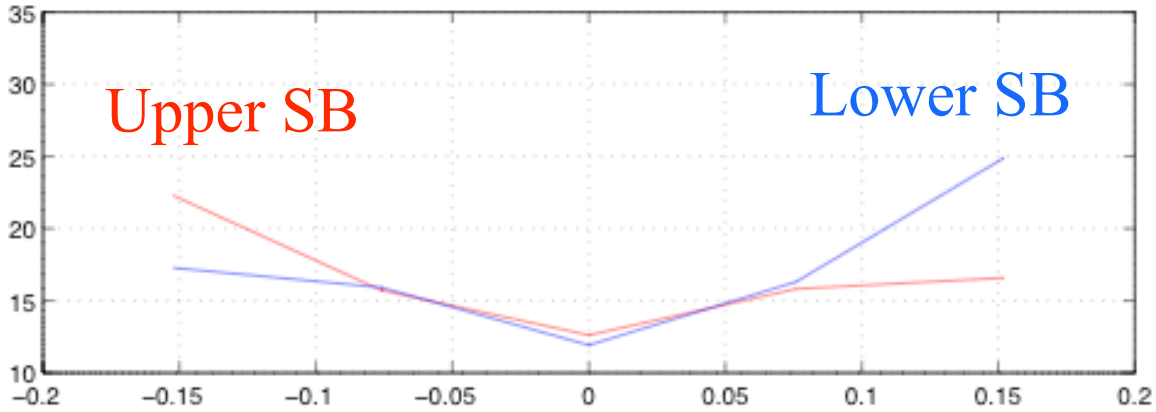
ITMy 60mW

Flat BS

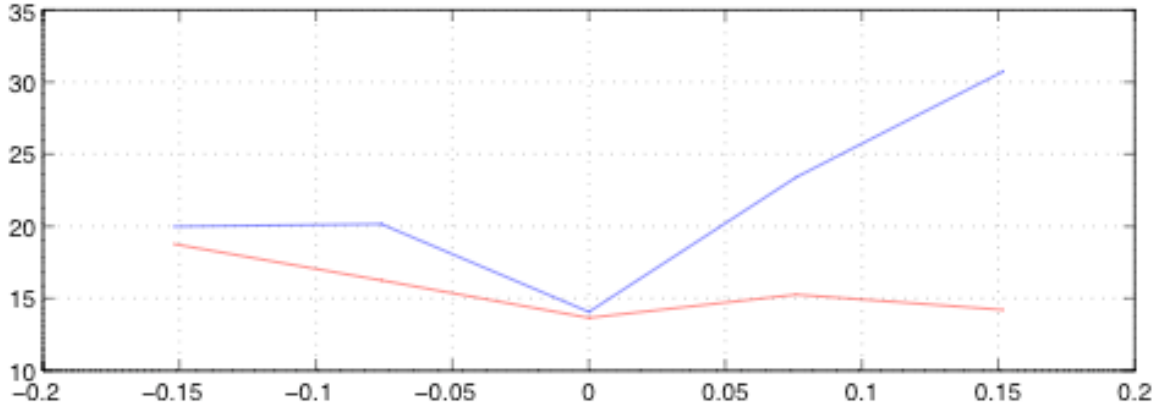


SB gain vs annular heating

Recycling gain



ITMx annular heating ITMy annular heating



-200 mW 200 mW

Flat BS

60mW
Gaussian
On both

200km BS

FFT vs LSC lock

n(ITMx)-n(ITMy)

0.96-0.96

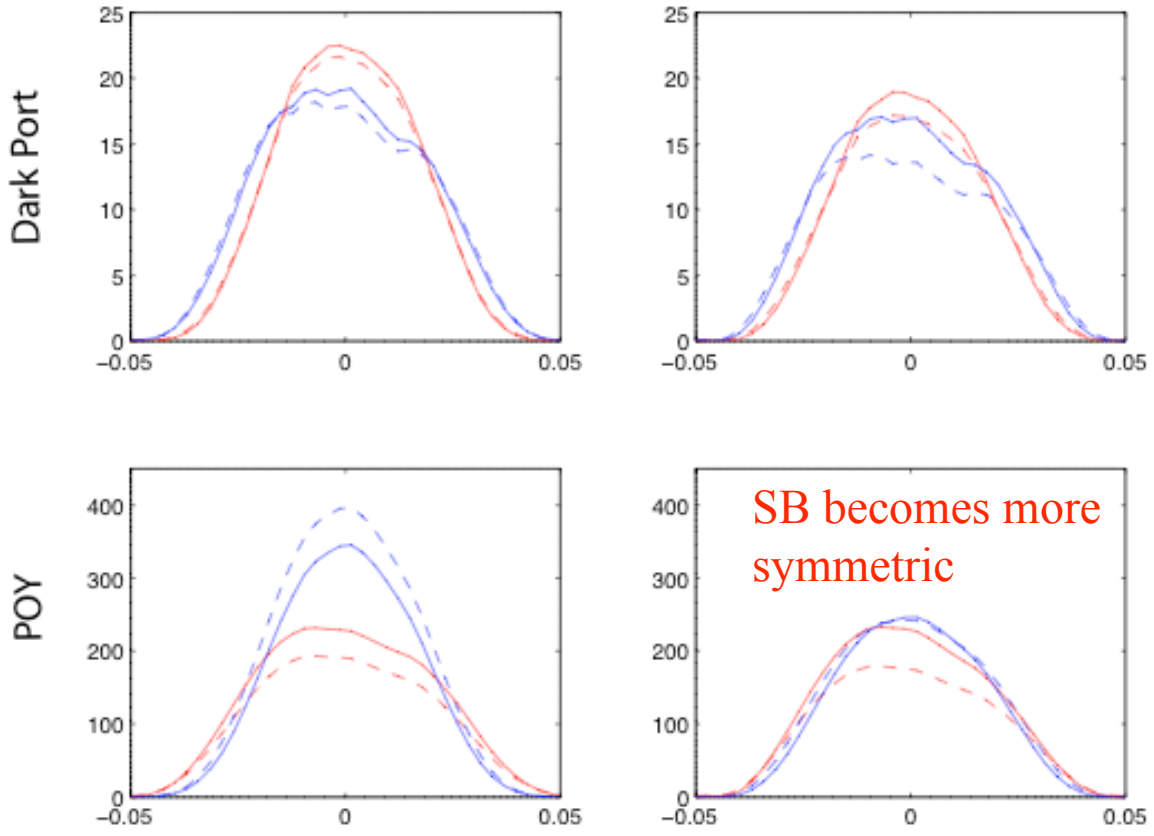
Symmetric Heating

1.10-0.96

Differential Heating
ITMx cooler than ITMy

lower SB upper SB

FFT lock LSC lock



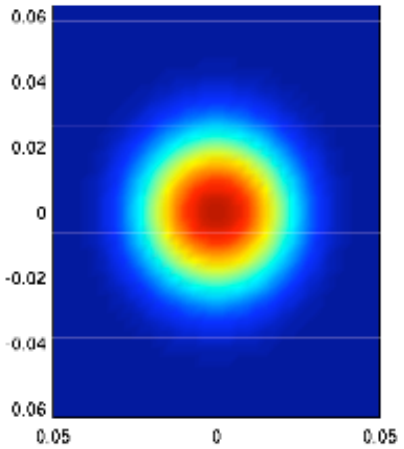
		FFT	LSC
symmetric	θCR	0.3	-1.9
	θSB+	-0.6	-2.3
	θSB-	7.2	5.1
	Spob	-0.57i	-0.57i
differential	θCR	0.2	-8
	θSB+	4.9	-1.2
	θSB-	11.8	5.1
	Spob	-0.48i	-0.50i

Dark Port sideband profile
- after LSC lock -

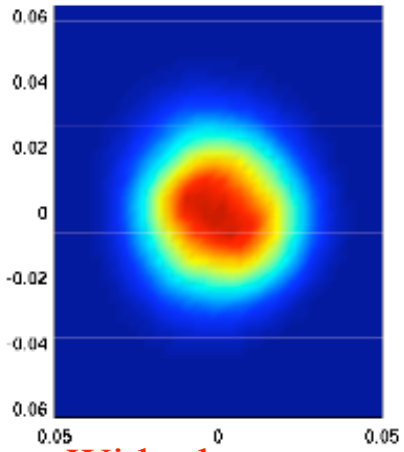
upper SB

200k BS curvature

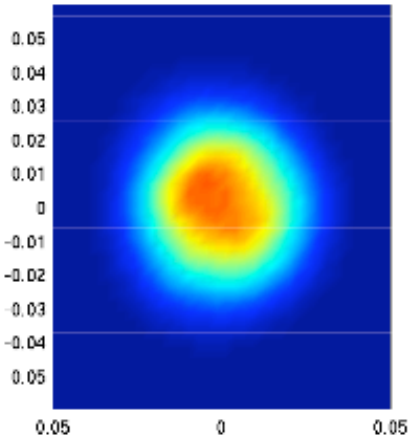
lower SB



No phase map
Symmetric heating



With phase map
Symmetric heating



With phase map
Differential heating