AdvLIGO
Static Interferometer Simulation

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- AdvLIGO simulation tools
  - » Stationary, frequency domain and time domain
- Stationary Interferometer Simulation, SIS, basic
  - » Motivation
  - » physics
- SIS applications
  - » Stationary Michelson cavity
  - » Beam splitter Wedge angle effect
  - » Surface aberration

Advanced LIGO Interferometer Simulation Tools

model	Description	Applications
Stationary Interferometer Simulation a.ka. FFT	Stationary field simulation with detailed optics	✦Effect of realistic optics »Finite size, surface aberration, thermal deformation ✦Effect of realistic fields »Diffraction, scattering, excitation by complex mirror motion
Opticle	Frequency domain simulation with optical springs and quantum noises	✦Control system design ✦Trade study of optical system design ✦Noise analysis with full control systems
End to End model	Time domain simulation of opto-mechanical system with realistic controls	✦Lock acquisition design and test ✦Study of transient and stability issues ✦Analysis of subsystems with strong correlations

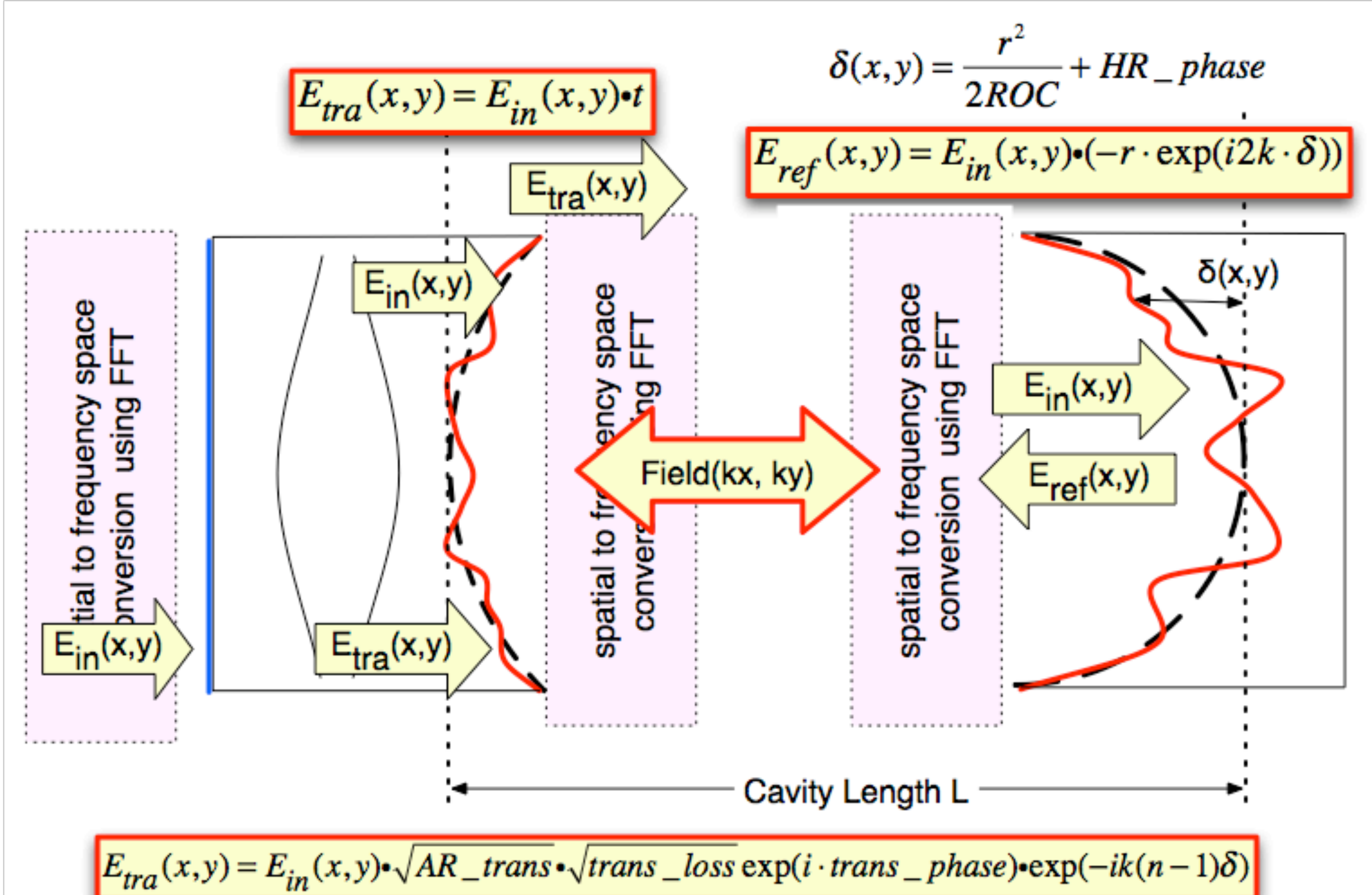
SIS Basic Motivation

- AdvLIGO design tool
- Interferometer configuration trade study
- Effect of finite size optics
  - » BS, flat, wedge angle, baffle, etc
- Tolerance of radius of curvature of COC mirrors
- Surface aberration
  - » Requirements of the surface quality to satisfy the limit of loss in arm, total of 75ppm
- Subsystem performance simulation
  - » TCS, ISC, COC, AOC, ...
- Parametric instability
  - » highly distorted field, hard to be expressed by simple functions

SIS Basic
Ingredient Requirements

- Details of Optics
  - surface map, size, flat, wedge angle, etc
- Flexibility
  - Various optics configurations
  - Now, only FP and couple cavity with BS
- Physics
  - Realistic locking by using error signals
  - Signal sideband generation
  - Built-in thermal deformation function
- Analysis tool
  - beam profiler
  - mode analysis

SIS Basic
Optics and fields



SIS Basic Ingredients- 1

- Lock

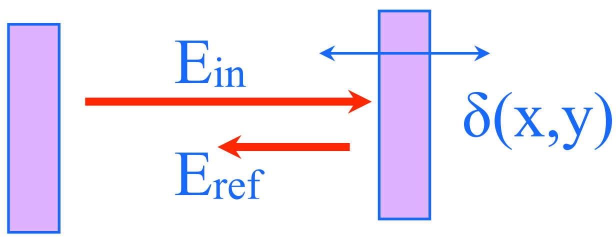
```
Error signal = imag( CR*SB ) ~ imag( CR * promptly reflected CR )
```

- Signal Sideband Generation : any periodic motion of mirror surface

$$E_{ref}(x,y,t) = \exp(2ik\delta(x,y)\cdot\sin(\Omega_{AF}t))\bullet\exp(i\omega_0 t)\bullet E_{in}(x,y)$$

$$\approx \{\exp(i(\omega_0+\Omega_{AF})t)-\exp(i(\omega_0-\Omega_{AF})t)\}\bullet k\delta(x,y)\bullet E_{in}(x,y)$$

$$+\exp(i\omega_0 t)\bullet E_{in}(x,y)$$



- Thermal deformation : Hello, Vinet

Stored beam is used to calculate thermal effects

```
THERMOELASTIC( beamSize, Psubs, Pcoat [, T0] )
THERMALPHASE( beamSize, Psubs, Pcoat [, T0] )
```

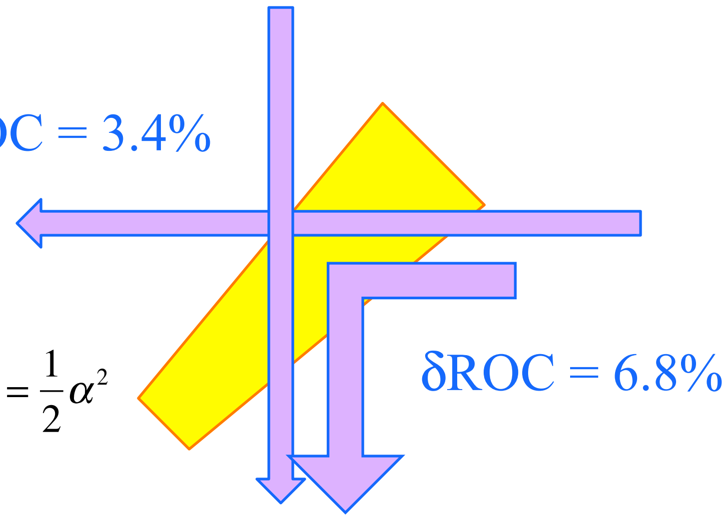
SIS Basic Ingredients - 2

- Random surface - 2D surface with f^{-power}
  - » `NOISESPEC( rand_seed, rms, power, WykoIndex )`
- Wedge angle of beam splitter

$$ROC' = (1+2\varepsilon)ROC$$

$$w' = (1+\varepsilon)w$$

$$\varepsilon = \frac{2(n^2-1)}{\sqrt{2n^2-1}}\vartheta_w = 1.23\vartheta_w = 1.7\%$$

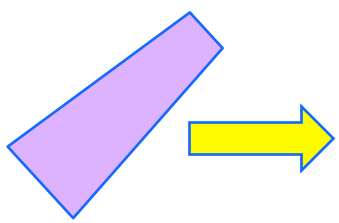


$$ModeMismatch(R, R+\delta R) = \frac{1}{2}\alpha^2$$

$$\begin{aligned}\alpha &= k\frac{w^2}{4}\frac{\delta R/R}{R}\\ &= 0.1 \quad advLIGO\\ &= 0.004 \quad LIGO\ I\end{aligned}$$

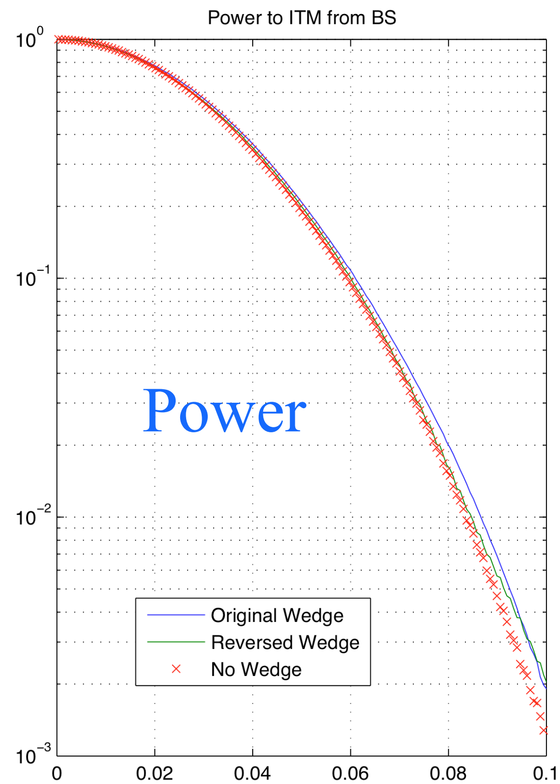
Using SIS to study wedge angle effect - 1

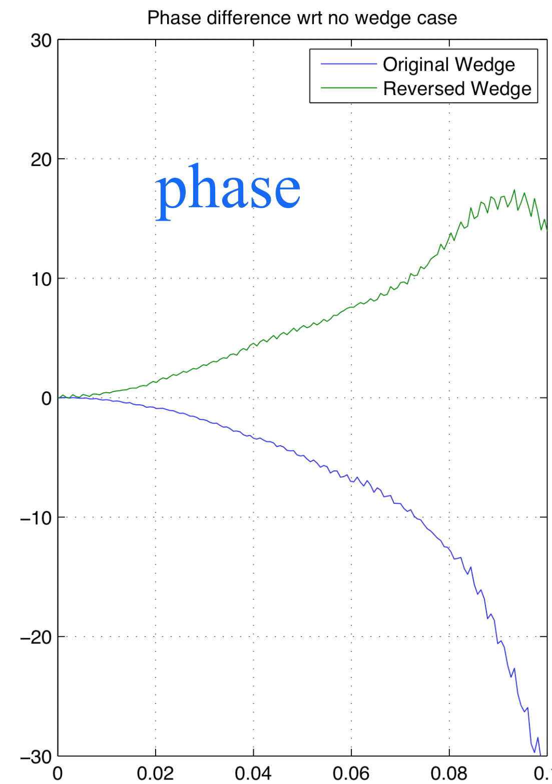
Beam profile going to ITM from BS



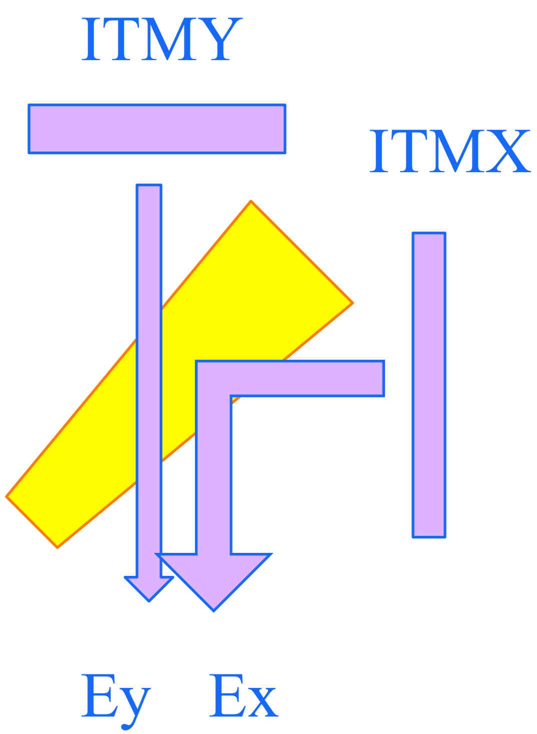
BS with original wedge

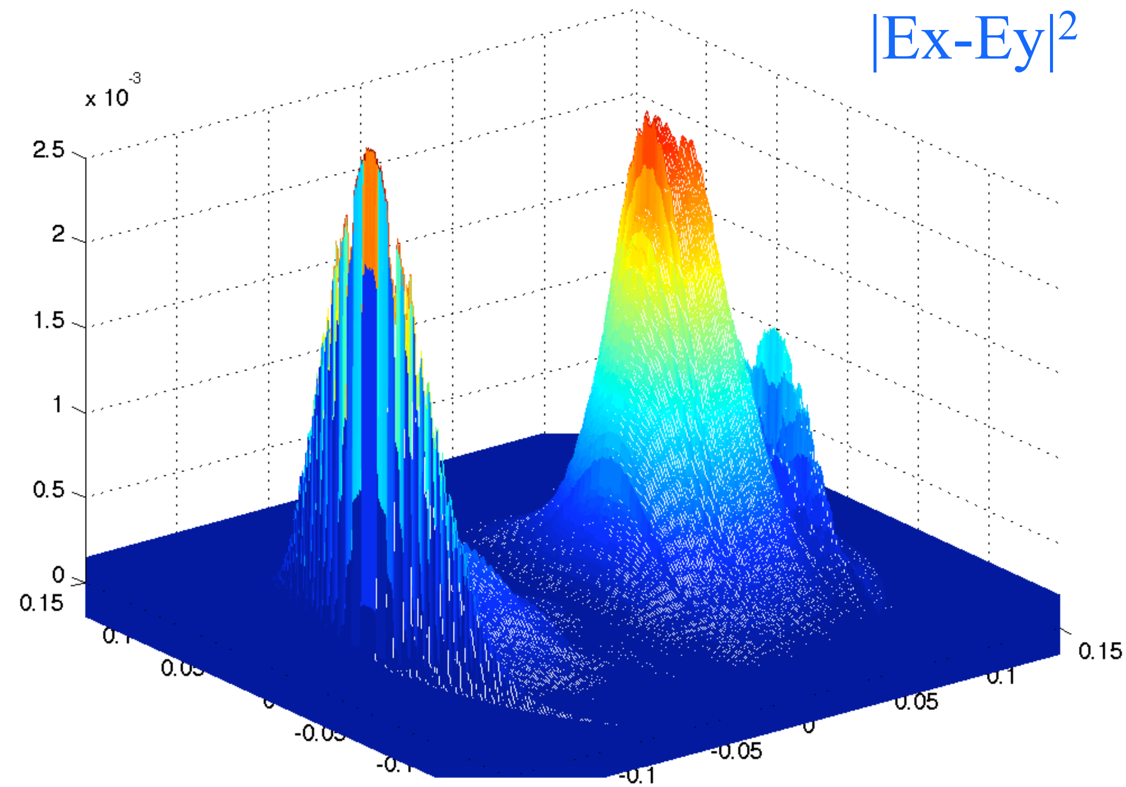
ITM





Using SIS to study wedge angle effect - 2

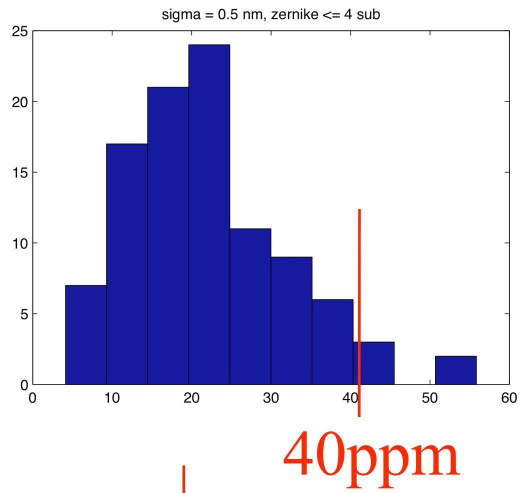


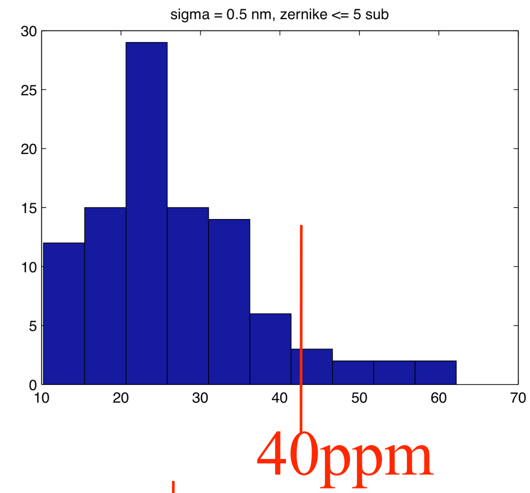


Using SIS to study mirror rms requirement

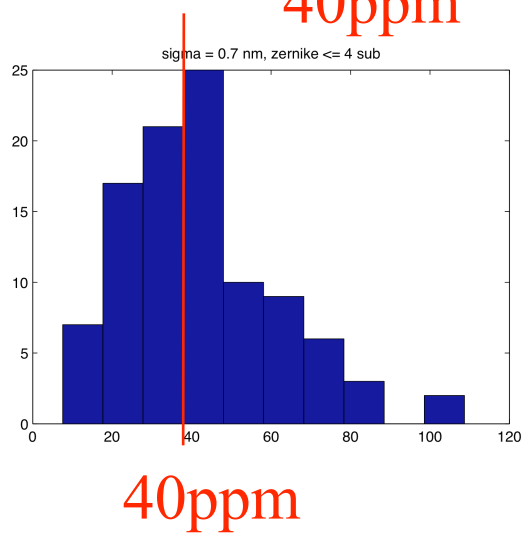
Zernike <=4 subtracted | Zernike <=5 subtracted

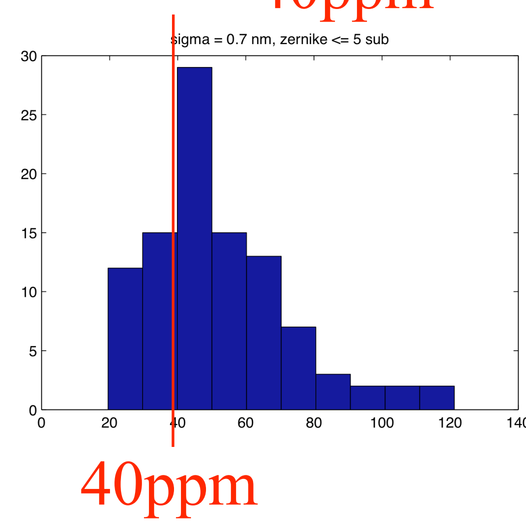
rms = 0.5nm



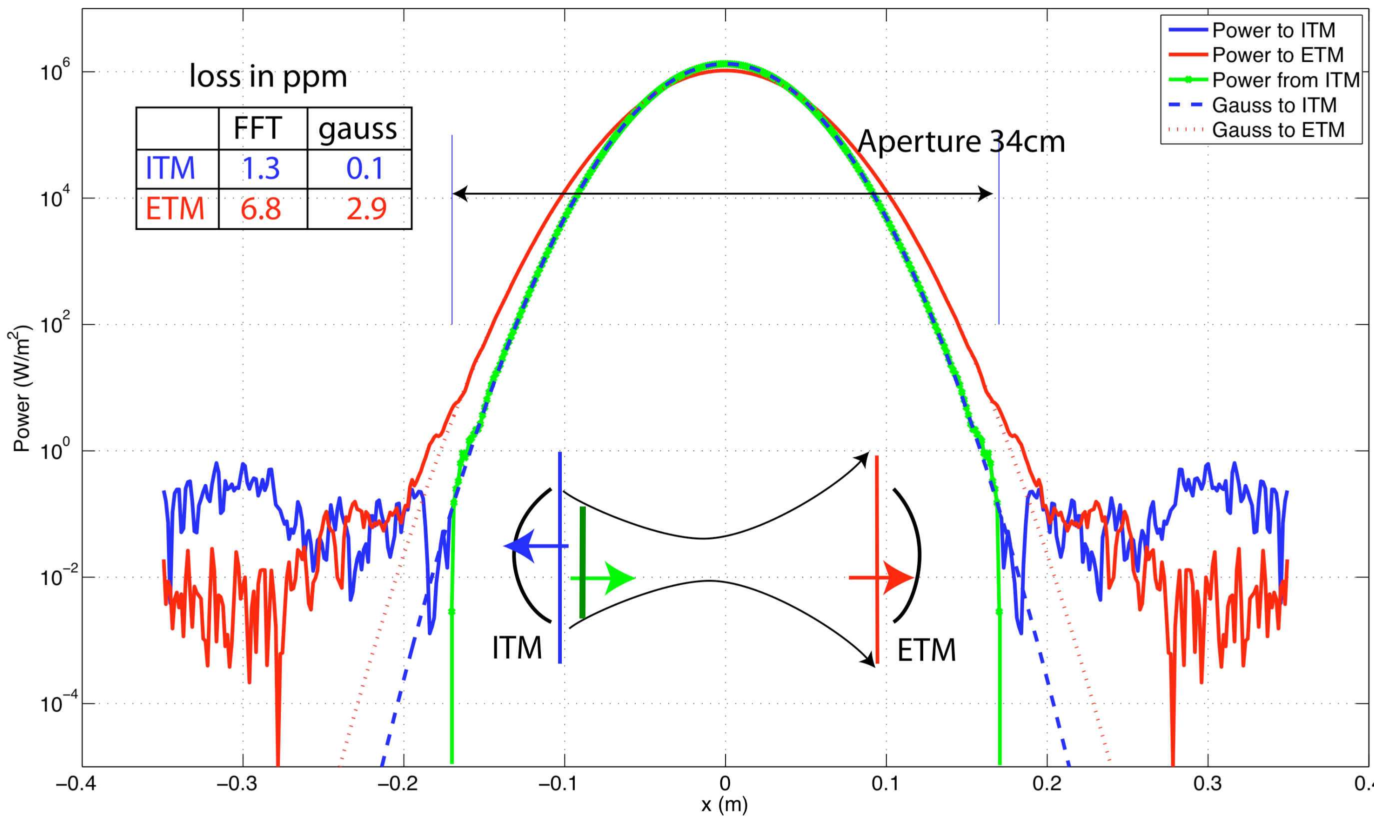


rms = 0.7nm



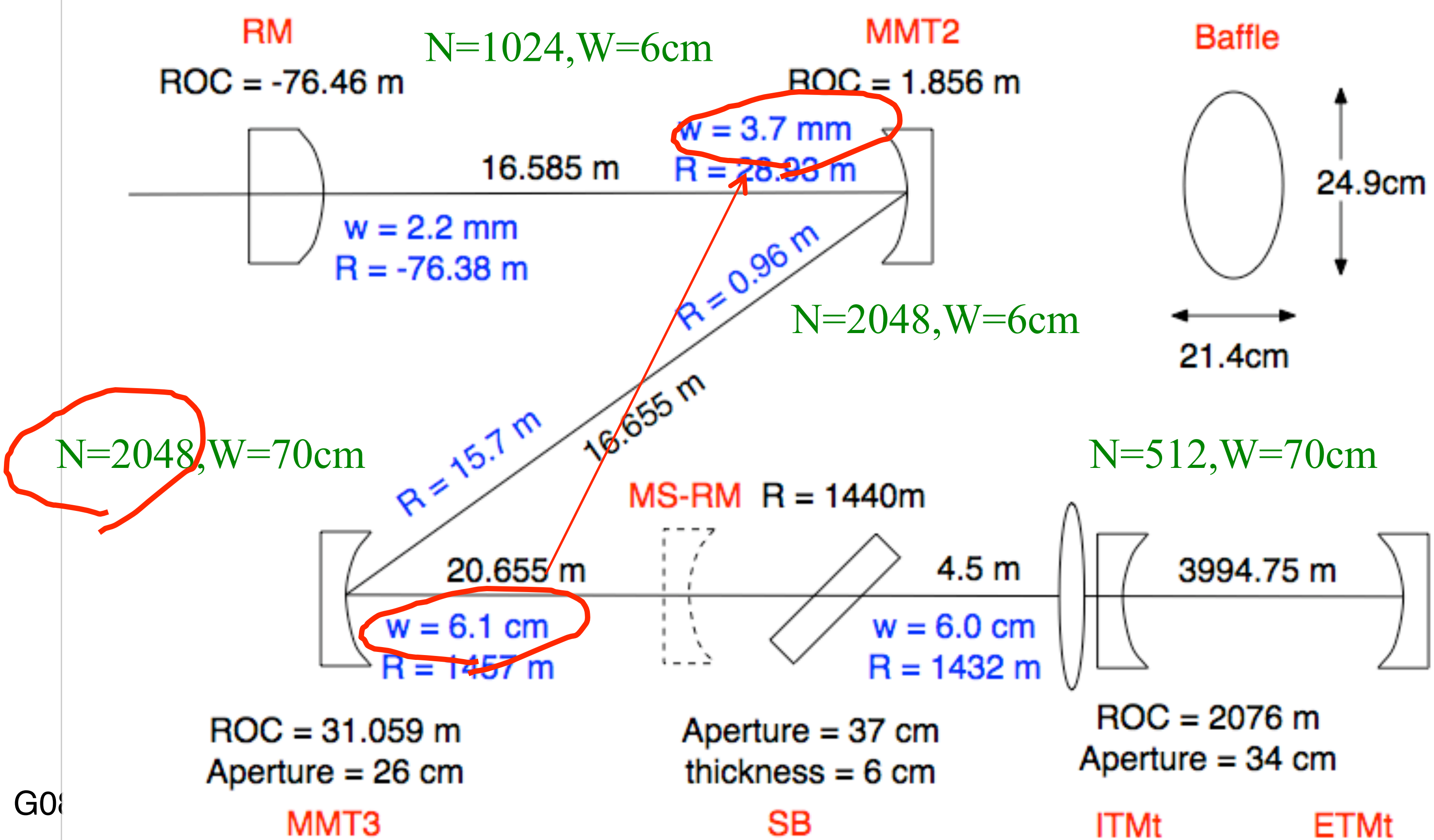


Diffraction effect in FP cavity

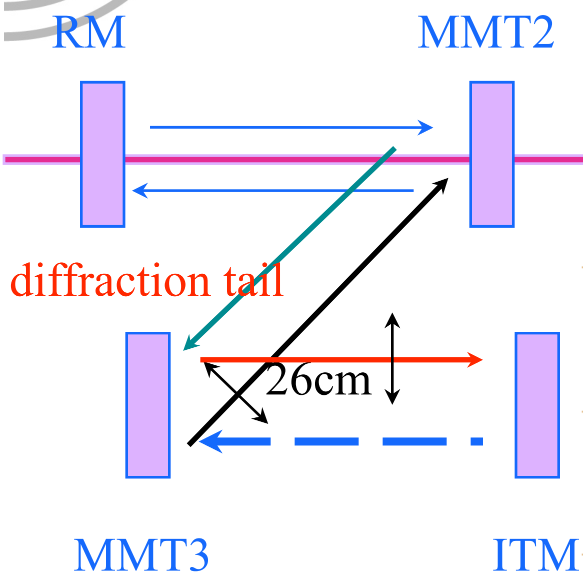


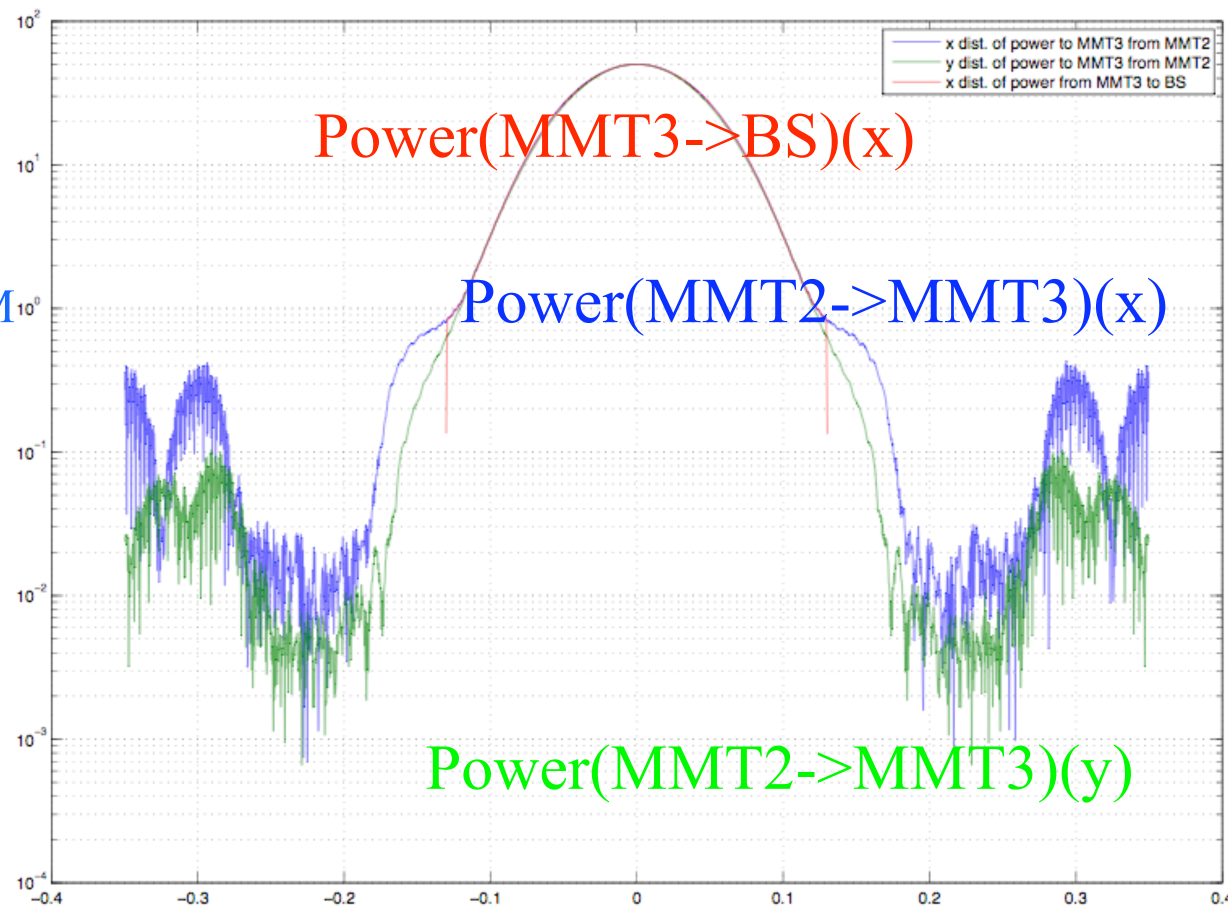
Diffraction effect in Stable Michelson cavity

```
ITM.opt.AR_trans =
if( pow(2*x/0.214,2)+pow(2*y/0.249,2) < 1, 1, 0 )
```



Power loss on MMT3 (ITMY<->SRM case)





loss = 330ppm
(energy outside of
MMT3 surface)

Loss under different conditions

MMT aperture (cm)	beam size on ITM (cm)	Coupled cavity	loss on MMT3 (ppm)
26cm	6cm	Y-arm + SRM(*)	330
26cm	6cm	X-arm + SRM(*)	600
28cm	6cm	Y-arm + SRM	140
26cm	5.5cm (**)	Y-arm + SRM	47
26cm	5.5cm (**)	X-arm + SRM	60

ETM ROC
ITM ROC
2076m + 2076m

ETM ROC
ITM ROC
1971m + 2191m

(*) When a baffle is plac nt of ITMY, Y-arm+SRM configuration comes very close to X-arm+SRM case.
(**) http://ilog.ligo-wa.c du:7285/advligo/Test_Mass_Beam_Sizes, asymmetric case with 5.5cm on ITM and 6.2cm on ETM.

With the baffle size of Mike's choice - 214mm x 249mm - the beam going through a baffle is cut off by 250ppm. If the baffle size of 1cm larger in both direction (224mm x 259mm), the cutoff is 55ppm. The numbers in the above table were calculated without baffles.

Using SIS to study PI
Signal generation by surface map

- Investigating a Parametric Instability
- SUFR project by Hans Bantilan, mentored by Bill Kells
  - » G060385-00-Z
- Simulate a stationary field for a given acoustic mode, instead of using modal expansion, to calculate the overlapping integral
- Combined with Dennis' FEM package to calculate acoustic modes
- 9061 modes for f < 90KHz

What you need to run SIS

- gcc compiler + fftw library
- or use program on Caltech machine
- SIS manual T070039
- Patience to simulate stable cavity – 2048 grids