SIS
AdvLIGO Static Interferometer Simulation

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- SIS Basic
  - motivation
  - physics
- Using SIS
  - configurations
  - actions
- Simulation of Stable Michelson Cavity
  - String focusing needs adaptive FFT window structure - N and W
  - Diffraction in a short cavity

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SIS Basic Motivation

- AdvLIGO design tool
- Optics configuration trade study
- Tolerance of radius of curvature of COC mirrors
  - » Yi Pan's estimation of 2076 +3m - 1m too stringent
- Surface aberration
  - » Requirements of the surface quality to satisfy the limit of loss in arm, total of 75ppm
  - » Loss due to dusts
- Subsystem performance simulation
  - » TCS, ISC, COC, AOC, ...
- Parametric instability
  - » highly distorted field, hard to be expressed by simple functions

SIS Basic Requirement

- Details of Optics
  - » surface map, size, flat, wedge angle, etc
- Flexibility
  - » Various optics arrangements
- Physics
  - » Realistic locking by using error signals
  - » Signal sideband generation
  - » Built-in thermal deformation function
- Analysis tool
  - » beam profiler
  - » mode analysis

SIS Basic Phsysics

- Lock

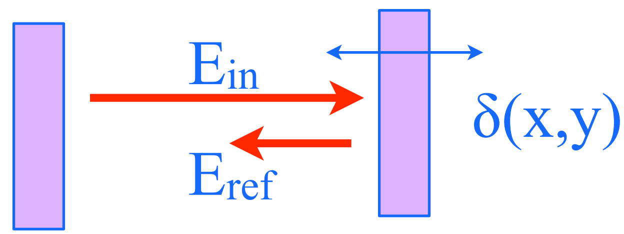
```
Error signal = imag( CR*SB ) ~ imag( CR * promptly reflected CR )
```

- Signal Sideband Generation

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

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

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



- Thermal deformation : Hello, Vinet

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

Parameters : power or rate

- Random surface - 2D surface with f^{-power}

```
NOISESPEC( rand_seed, rms, power, WykoIndex )
```

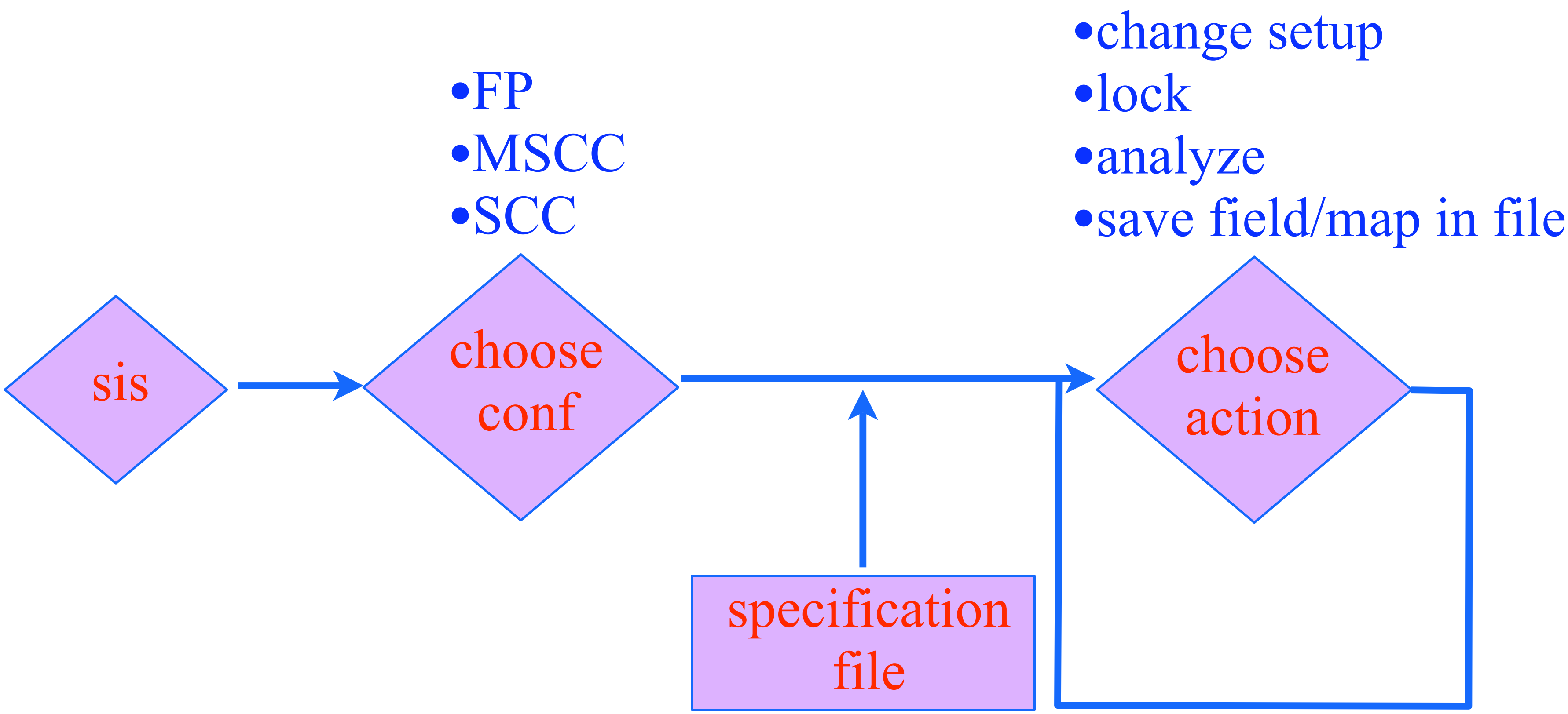
SIS Basic
Program implementation

- Object oriented code using C++
  - ease of modification, adding compensation plate, degenerate to non-degenerate Michelson cavity, etc
  - e2e code reused
- FFT with adaptive grid size
  - fftw for FFT calculation
  - The beam size changes in a concentric configuration
  - Mode matching telescopes can strongly focus beams
  - Use of different number of grids (128, ..., 2048)

SIS Basic Interface

- Specification of distribution
  - » HR / AR, surface / transmission / reflection and any other maps
  - » data file : DATAFILE(filename)
    - – mixture of different formats
    - – no need to make specific grid format
  - » mixture of input data and special functions
    - – 0.1 * DATAFILE(data) + THERMOELASTIC( ) + rr / (2*RH_ROC)
- Loop
  - » scan : angle = angle0 + omega*iLoop; pos = pos0 + vel*iLoop;
  - » Thermal deformation development
  - » Statistical analysis of surface specified by RMS
- e2e style interface
  - » recording and playback

Using SIS workflow



Using SIS specification file

```
ITM.opt.T = 0.005
ITM.opt.R = 1 - ITM.opt.T
ITM.opt.ROC = 1971
ITM.opt.trans_phase = THERMALPHASE( beamWidth, PsubsPwr, PcoatPwr )
ITM.opt.HR_phase = THERMOELASTIC( beamWidth, PsubsPwr, PcoatPwr ) + rr/
(2*ROC_TCS) + DATAFILE( ITMMAP.dat )

ETM.opt.ROC = 2191
ETM.oscillation.amplitude = 1e-15  % 1e-9*x for rotational oscillation
ETM.opt.HR_phase = THERMOELASTIC( beamWidth, PsubsPwr, PcoatPwr ) + rr/
(2*ROC_TCS) + DATAFILE( ETMMAP.dat )

inputBeam.beamType = "LG"
inputBeam.power = 1
inputBeam.waistSize = 0
inputBeam.waistPosition = 0
inputBeam.matchToCavity = 1   % calculate waistSize and waistPosition to match
with the cold cavity
```

Using SIS
main menu of actions

```
SIS> next action
SIS>
SIS>      lock            calcField       signalGen       timeTrace       delL
SIS>      modeAmp         saveField       mirrorInfo      storeMap        simSpec
SIS>      runSpec         summary         help            exit
SIS>
SIS> Select 1 item(s)
SIS> Type "name" to choose item(s)  >> ?
SIS>
SIS>    lock        : Lock the cavity
SIS>    calcField   : Calculate stationary field
SIS>    signalGen   : Generate audio signal by sinusoidal motion of mirrors
SIS>    timeTrace   : Move mirror and save field evolution
SIS>    delL        : Print and set the cavity length
SIS>    modeAmp     : Decompose a field by LG or HG
SIS>    saveField   : Save field in a file
SIS>    mirrorInfo  : View mirror information
SIS>    storeMap    : Store mirror maps
SIS>    simSpec     : Set simulation parameters
SIS>    runSpec     : Set run conditions, like convergence criteria
SIS>    summary     : Print summary status
SIS>    help        : main help
SIS>    exit        : Exit this process
SIS> Select 1 item(s)
```

Field calculation

analysis

setting

Using SIS support functionality

```
SIS> Type "name" to choose item(s)  >> help
--------------------------------------------
  1) @(filename
     ...
     @)
     saves key strokes in filename

  2) @REPEATBEGIN Nbegin Nend
     ...
     @REPEATEND
     to define repeat process
     Commands between these two @ are
     repeated Nend-Nbegin times,
     or variable iLoop goes from Nbegin to
     Nend-1.
     iLoop can be changed in simSpec,
     together with iLoopEnd, the end of the loop

  3) @PRINT val1 val2 ...
     print values and
     @PRINT filename << val1 val2 ...
     stores values in filename. Values are
     appended to
     existing file, not replace.

  4) If a filename contains @s, it is replaced
     by the numerical value of iLoop.
     Power@@.dat is replaced by Power00.dat
     etc.
     Number of @s is the number of digits.

  5) @@line1; line2; lineN
     is the same as entering to simSpec
     followed by
     typing line1, line2, etc, and exit
     @@ITM.opt.ROC = 2000; ETM.opt.ROC = 2000
```

Using SIS
modeAmp : mode analysis

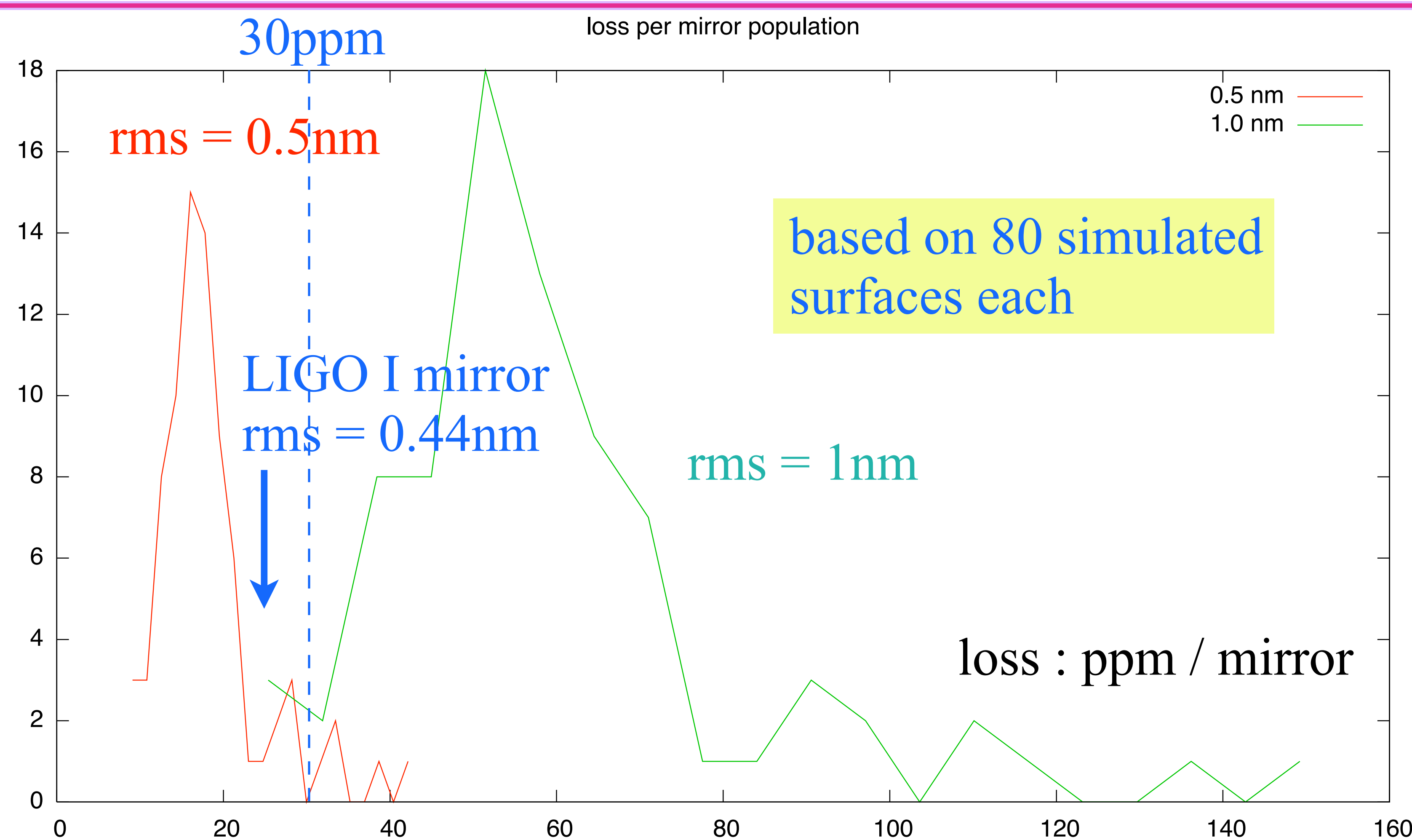
```
SIS>        0.fromRM                1.toBSfromRMorMMT        2.fromBStoITM
SIS>        3.toITMfromBS           4.fromITMtoBS            5.toBSfromITM
SIS>        6.fromBStoRMorMMT       7.toRM                   8.inputBeam
SIS>        9.totalREFLfromRM       10.promptREFLfromRM      11.promptREFLfromITM
SIS>        12.fromITMtoETM         13.toETMfromITM          14.fromETMtoITM
SIS>        15.toITMfromETM         16.transmitted           all
SIS>        exit
SIS> Type "name" to choose item(s)  >> 7
+++ Field "toRM" +++
Mode base  : z = 1338.508       z0 = 198.8382
           : w = 0.05584789     R = 1368.046
Fit result : w = 0.05583107     R = 1368.758      x0 = 0          y0 = 0
SIS>        LaguerreGauss       HermiteGauss      nextField       exit
SIS> Type "name" to choose item(s)  >> L
SIS> Max mode for expansion (def=7,[1:INF])  >> 2
+++ Field "toRM" +++

 Amplitude = ( Re, Im ) [ subPower, fraction ]

LG( 0 , 0 ) = (-3.9554857703695,0.0056639344345407)        [ 15.645899759749, 0.99997662411402 ]
LG( 0 , -1 ) = (3.9973060583398e-16,3.6876260134332e-15)   [ 1.375837017219e-29, 8.7933891750295e-31 ]
LG( 0 , 1 ) = (1.9210585886333e-14,6.9048530167936e-15)    [ 4.1672360527971e-28, 2.6634061983976e-29 ]
LG( 1 , 0 ) = (0.0003809451007902,-2.9926126324013e-05)    [ 1.4601474285281e-07, 9.3322424322612e-09 ]
LG( 0 , -2 ) = (-1.0234160699019e-16,1.6450778998802e-17)  [ 1.0744432651003e-32, 6.8670908387198e-34 ]
LG( 0 , 2 ) = (0.00034485063881116,-1.4825579381902e-05)   [ 1.1914176089247e-07, 7.6147091364319e-09 ]

Total power = 15.646265505067 and power fraction of higher modes is 2.3358939031382e-05
```

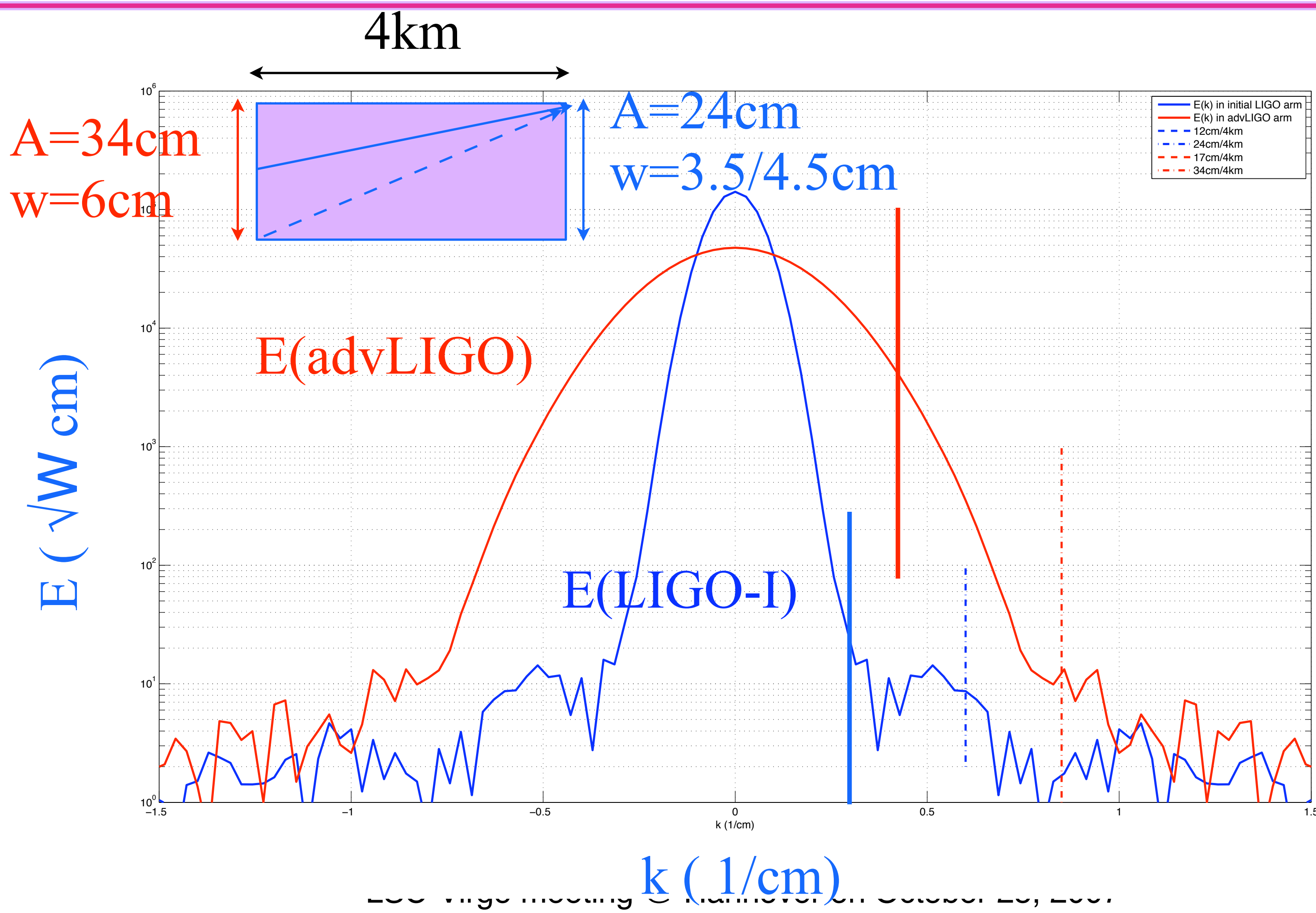
Using SIS
Random phasemap and loop



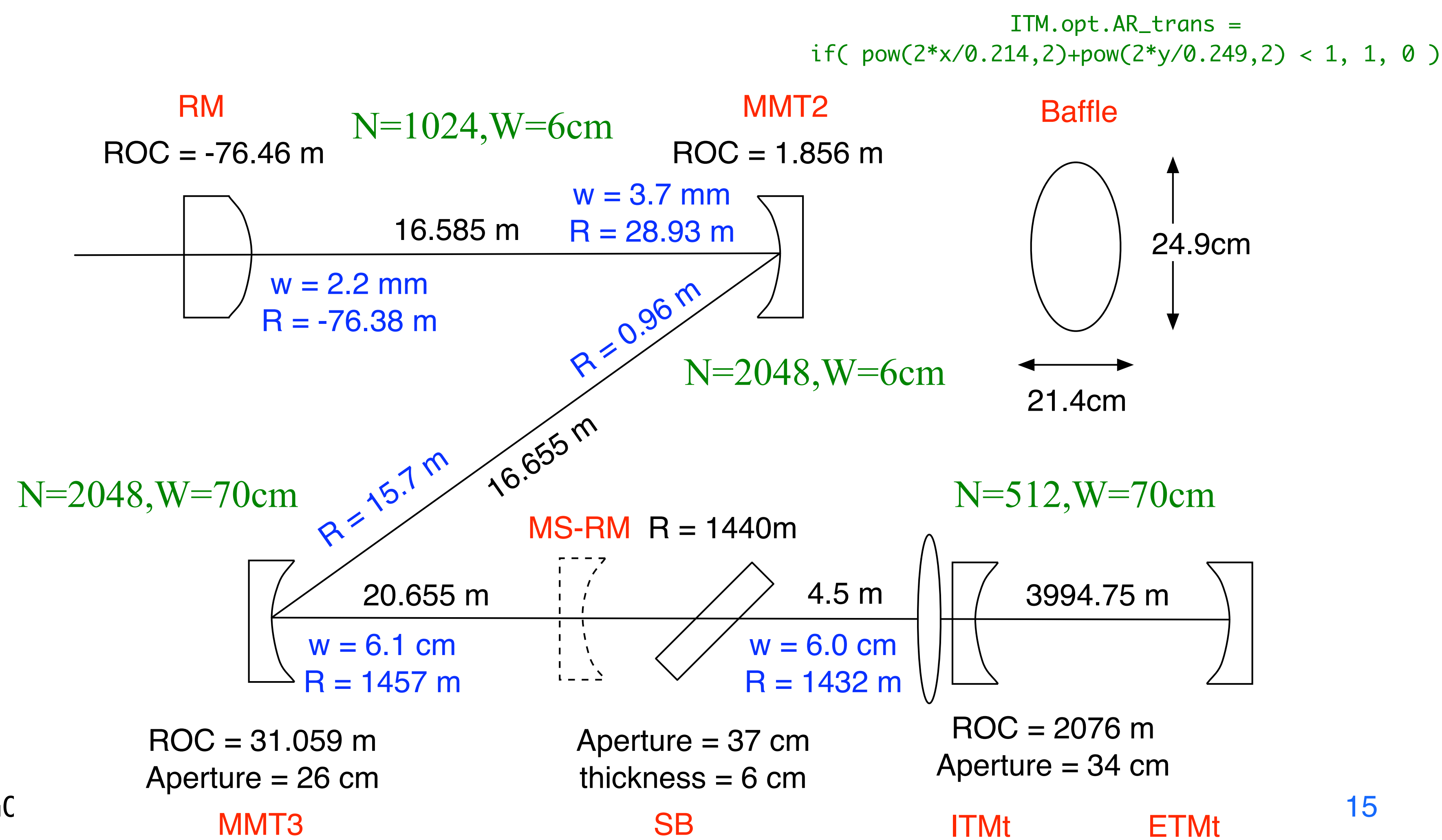
Using SIS
Signal generation by map

- Investigating a Parametric Instability in the LIGO Test Masses
- 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

Using SIS
saveField : k space distribution

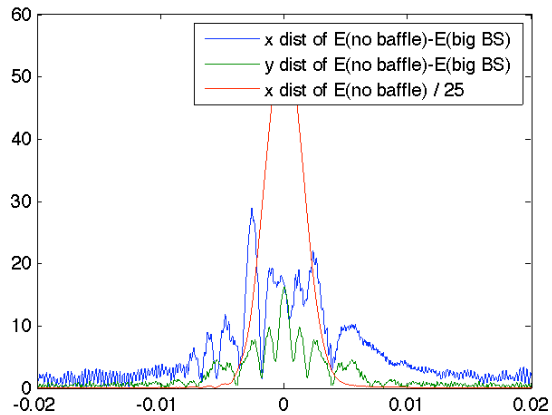


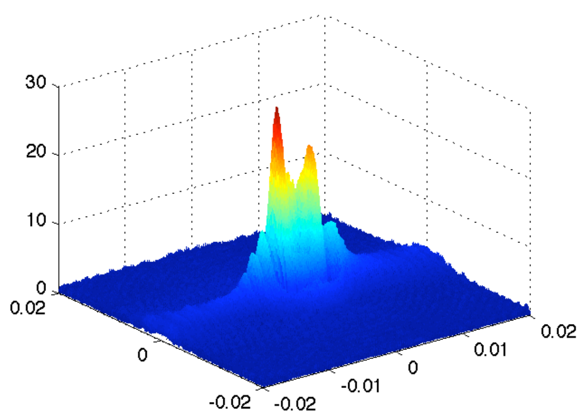
Diffraction effect in Stable Michelson cavity



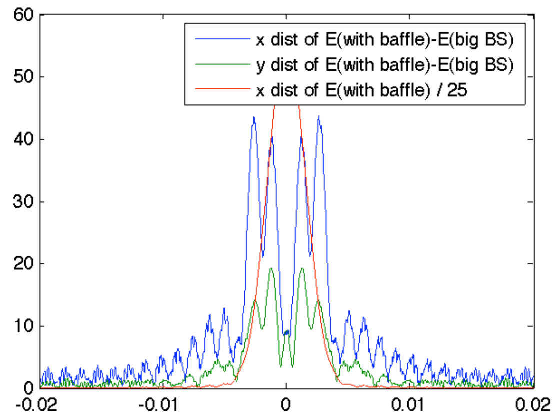
Field on RM(37cmBS) - Field on RM(big BS)

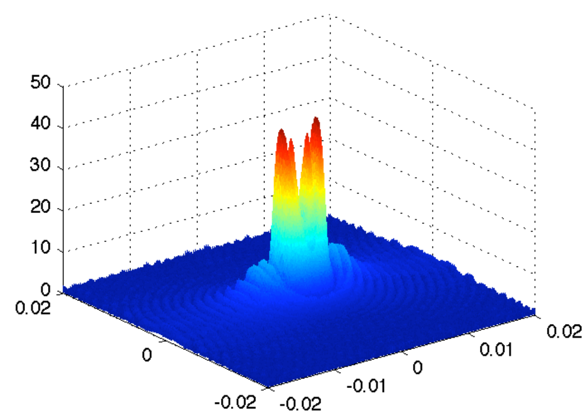
without baffle



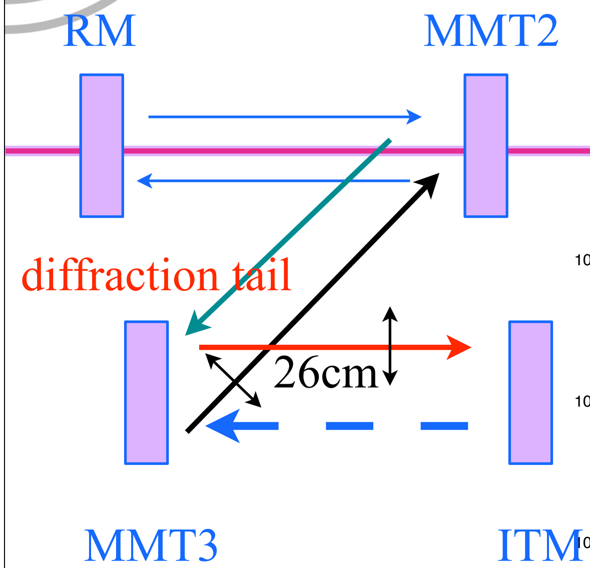


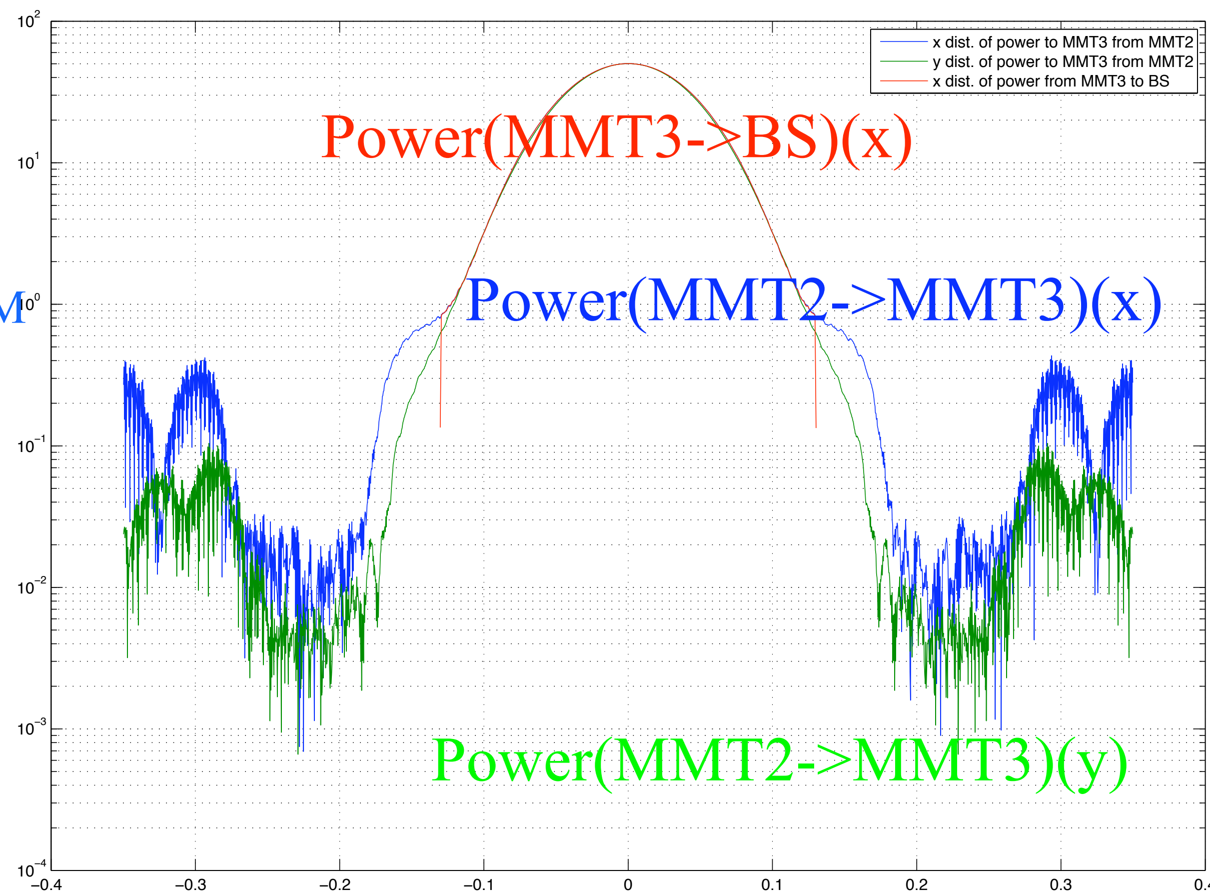
With baffle





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





loss = 330ppm
(energy outside of MMT3 surface)

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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

(*) When a baffle is placed in front of ITMY, Y-arm+SRM configuration comes very close to X-arm+SRM case.
(**) http://ilog.ligo-wa.caltech.edu: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.

SIS
Quantifying the truth of imperfect world

Signal loss vs curvature error