Scatter Loss in Quantum-Noise Filter Cavities

Jan Harms for

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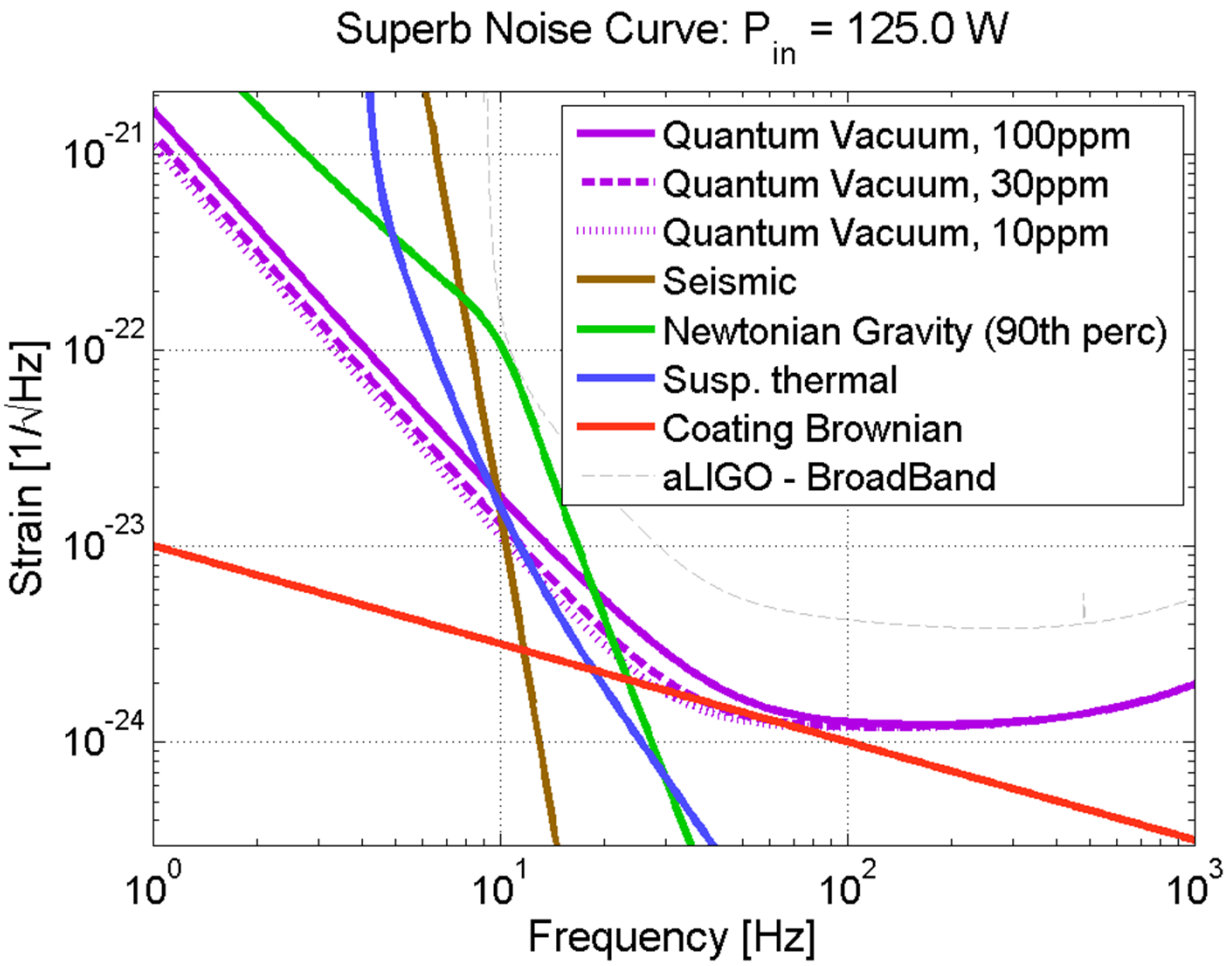
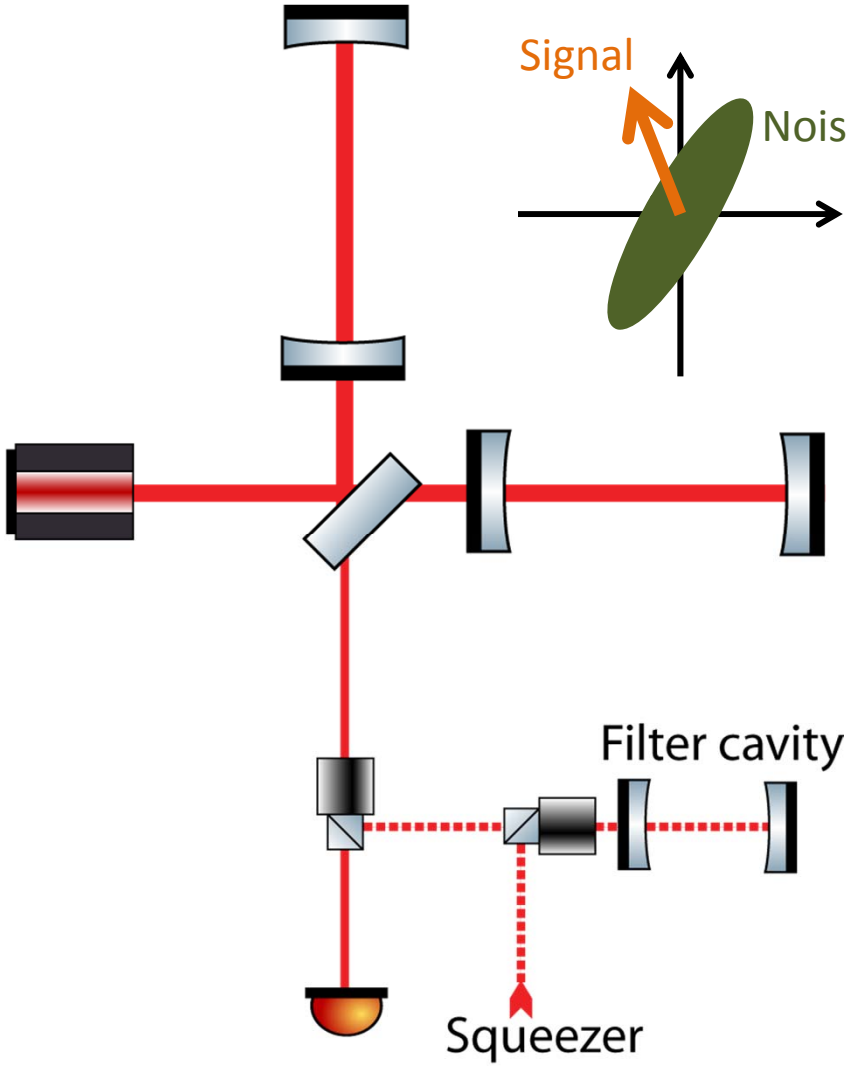
Eric Gustafson, Bill Kells, Fabian Magana-Sandoval,
Josh Smith, Hiro Yamamoto, Liyuan Zhang

Better than Advanced



Quantum-Noise Filters



Squeezed light without filter cavity alters quantum noise as if laser power is changed.

Only one filter cavity required for aLIGO broadband configuration.

Filter cavity needs very small bandwidth.

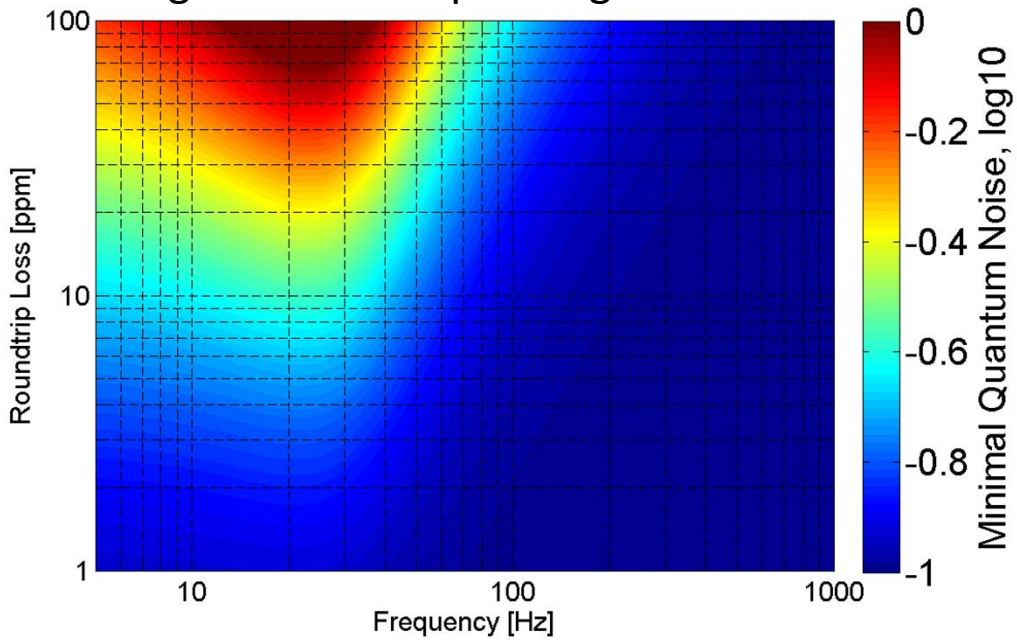
Filter cavity needs to be realized with bandwidth and resonance very close to some target values.

Effects of Cavity Loss

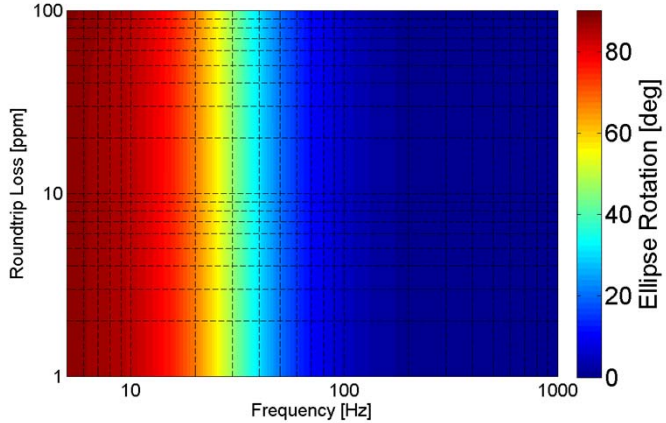
Parameters:

- Factor 10 (noise amplitude) squeezing
- 300m cavity
- Filter: -22Hz detuning, 550ppm input transmission

Degradation of squeezing:



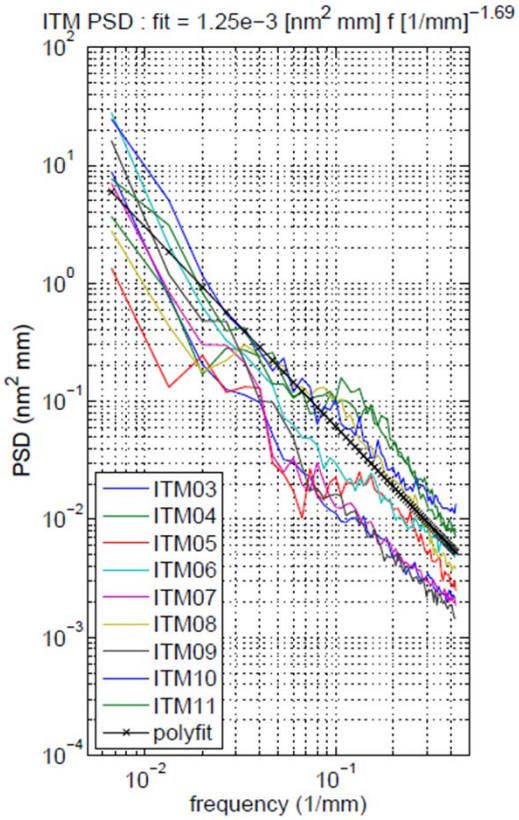
Deviation in rotation:



- Weak effect from wrong rotation
- Strong effect from mixing in loss vacuum
- These two results are not valid for all configurations

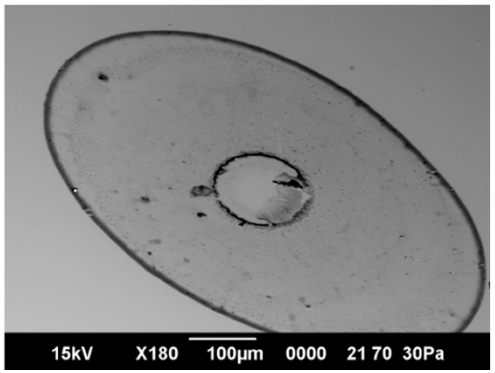
Scatter Loss

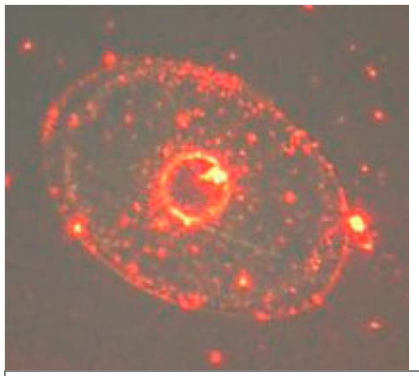
Surface-roughness scattering



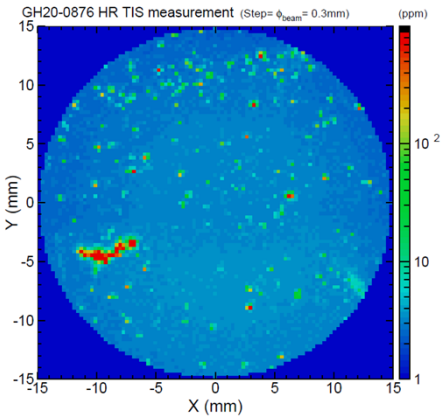
Spectrum (RMS and slope)

Point-defect scattering





Moriwaki (SEM, EDS)

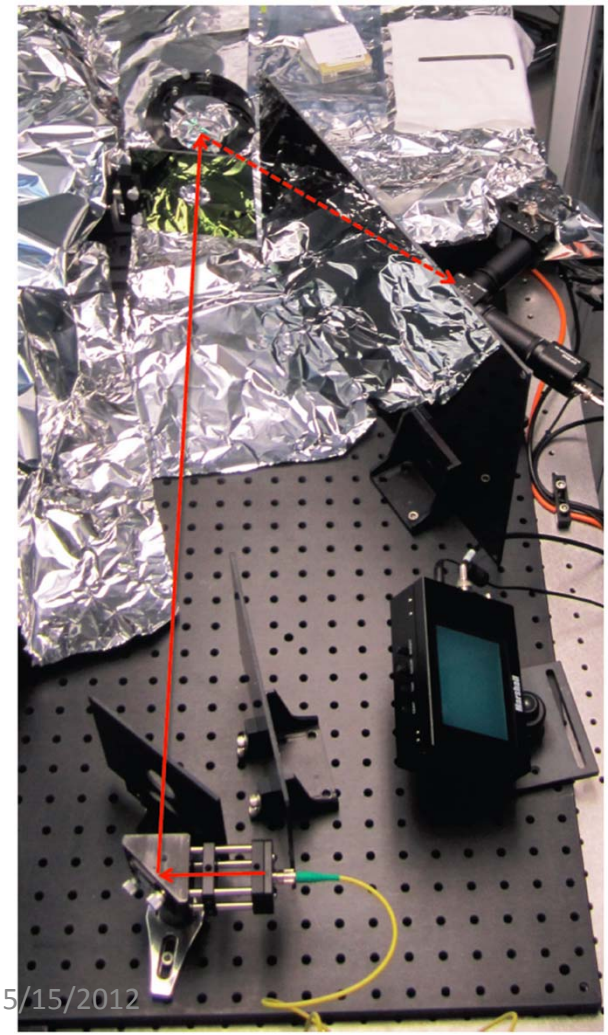


Defect morphology

Defect distribution

BSDF Experiment I

Valera Frolov (LLO)



Optic	*BRDF=dP/P/dΩ/cos(ϑ) (10^{-6}/sr)	Comment
2" ATF #1004	0.5-1	ISC optic from Lisa. Drag wiped - no other cleaning was done.
2" ATF #897	1-1.5	ISC optic from Lisa. Went through cleaning.
2" REO	3-5	iLIGO HAM4 AS top periscope mirror
2" REO	1-2	Same optic as above after drag wipe

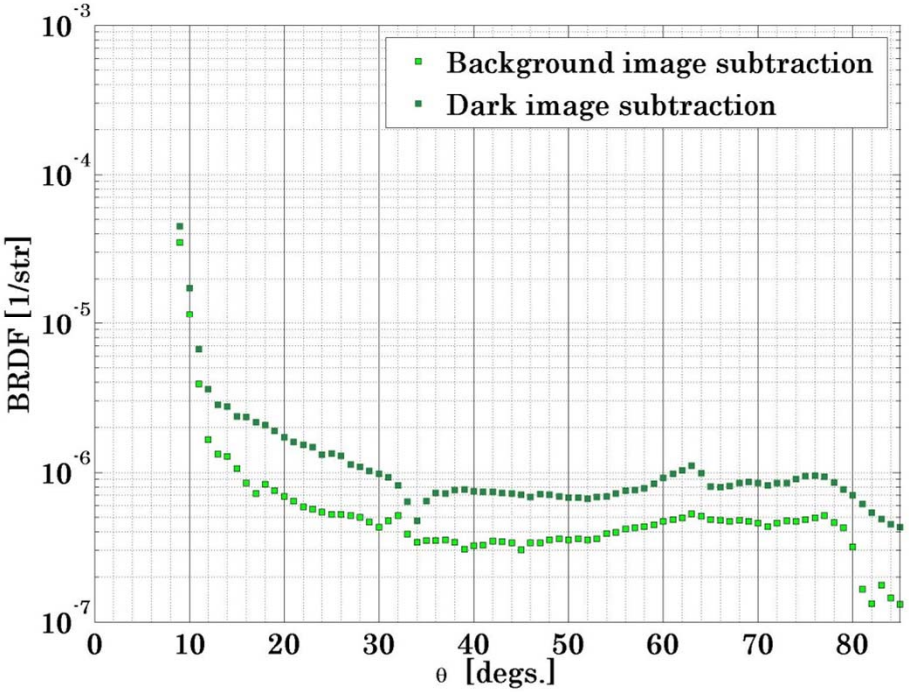
<u>Previous setup</u>

$$\mathrm{BSDF}(45^{\circ}) \sim 6 \times 10^{-7} 1/\mathrm{sr}$$

Gooch & Housego HR optic

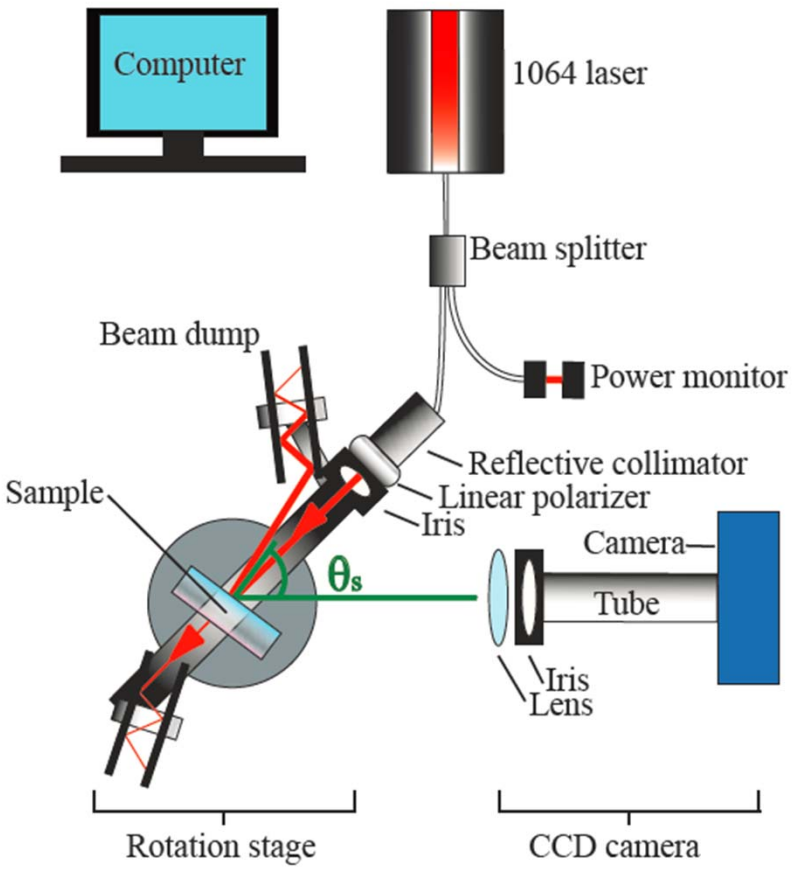
BSDF Experiment II

Gooch & Housego HR optic

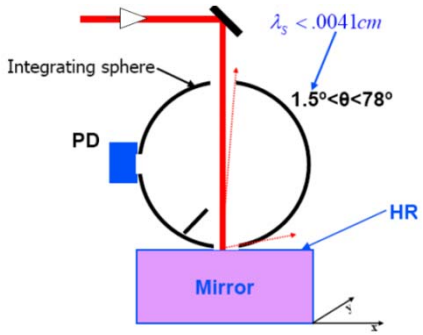


TIS ~ 4ppm
(using conservative calibration)

Fabian Magana-Sandoval,
Josh Smith (Fullerton)



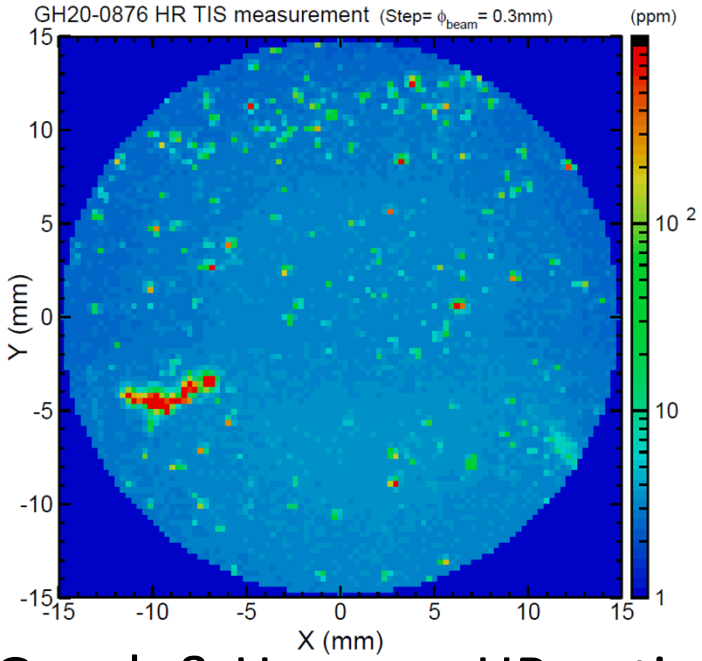
Integrating Sphere



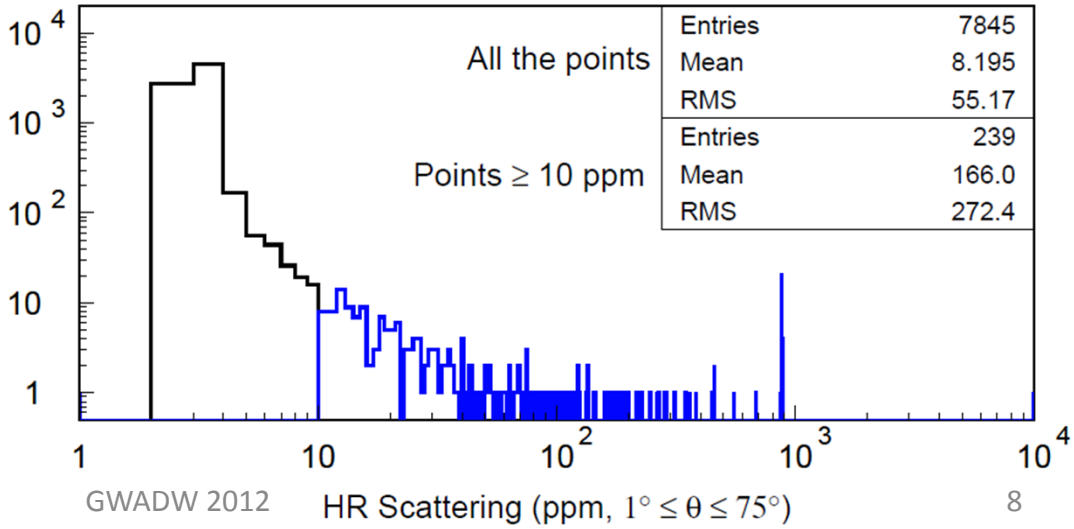
Liyuan Zhang (Caltech)

Central 1cm x 1cm square:
TIS = 3.8ppm (uniform irradiance)

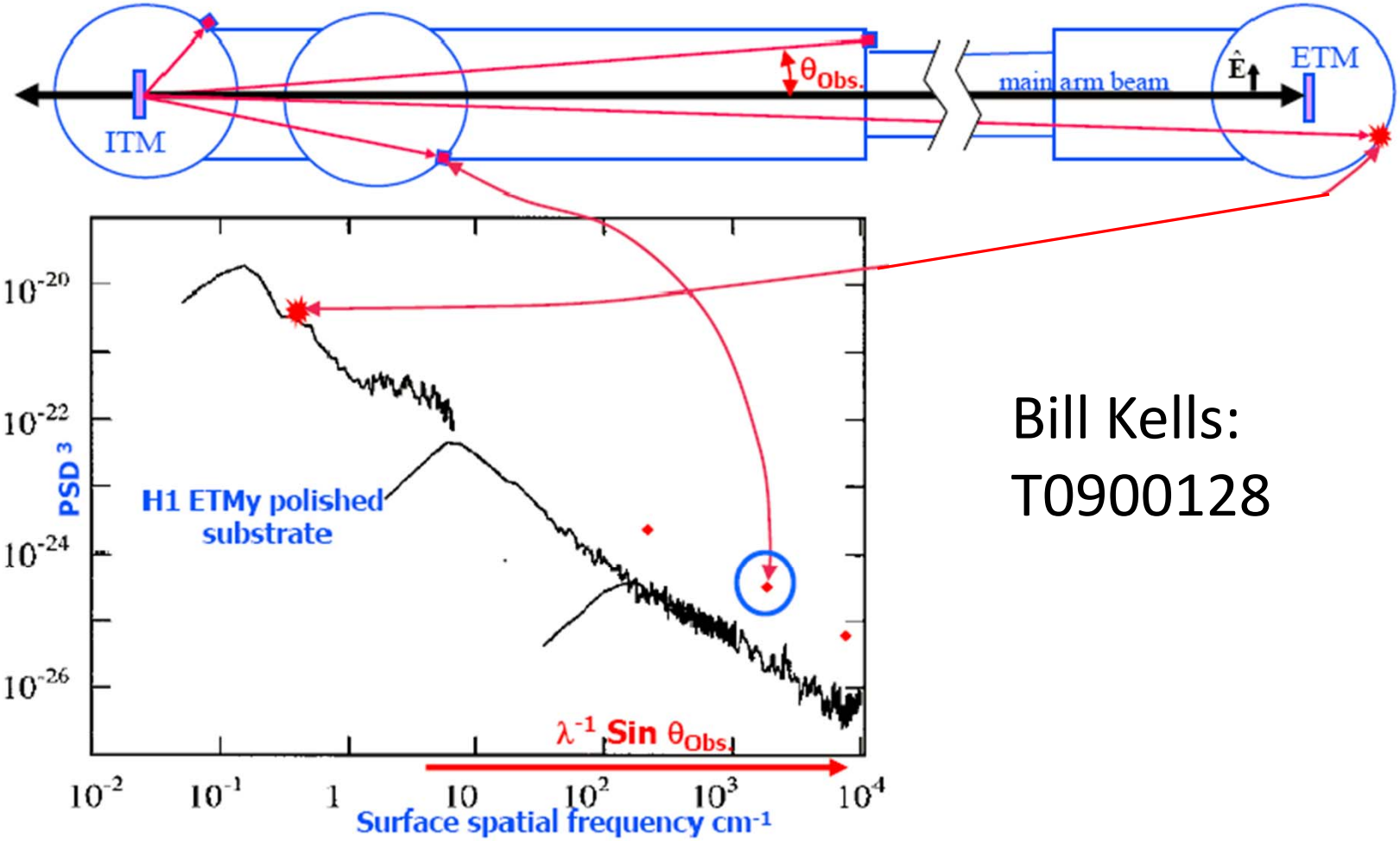
Central 2cm x 2cm square:
TIS = 9.5ppm (uniform irradiance)
(includes part of large defect)



Gooch & Housego HR optic



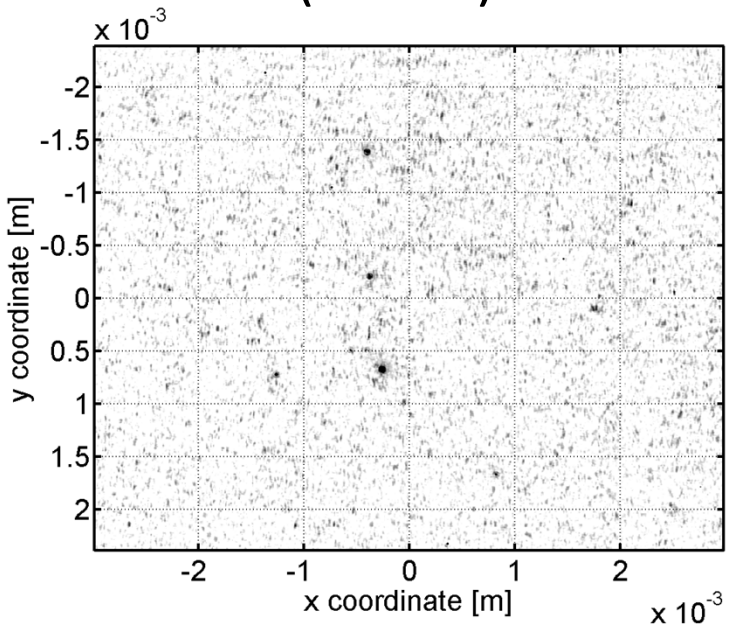
Observed Discrepancies



Bill Kells: T0900128

Point-Defect Scattering

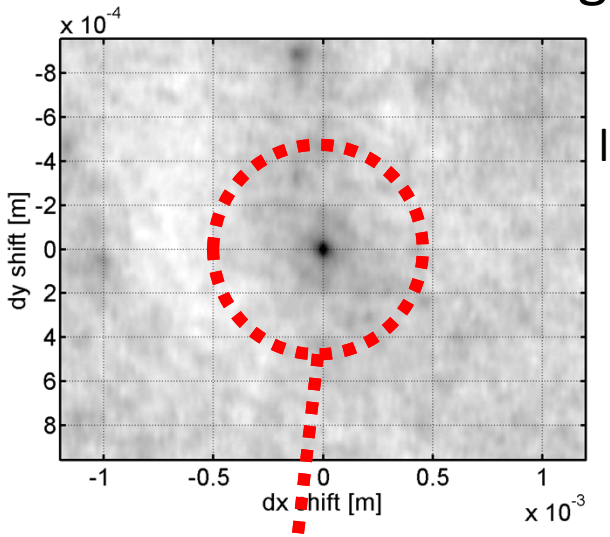
Scatter image from 45deg (Valera)



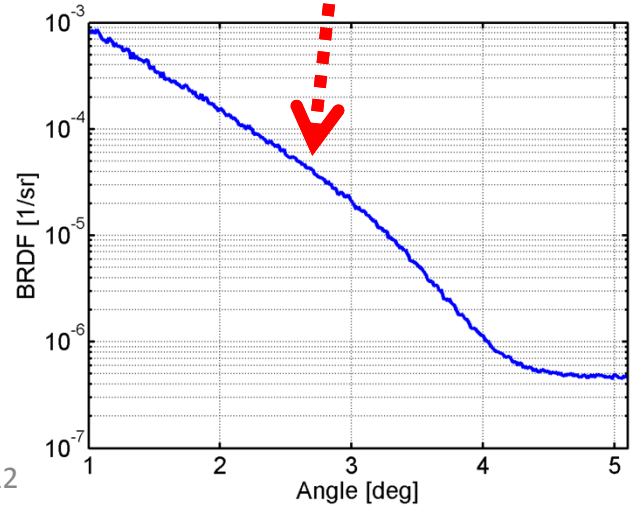
Pixel size: 5μm

Diffraction resolution limit: 20μm

Autocorrelation of image



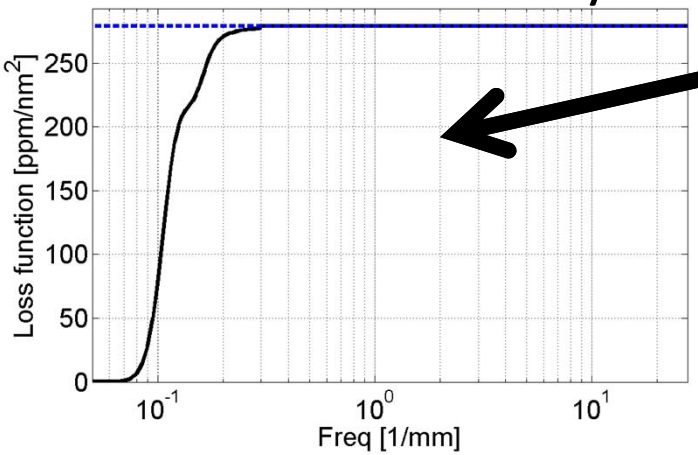
log-scale



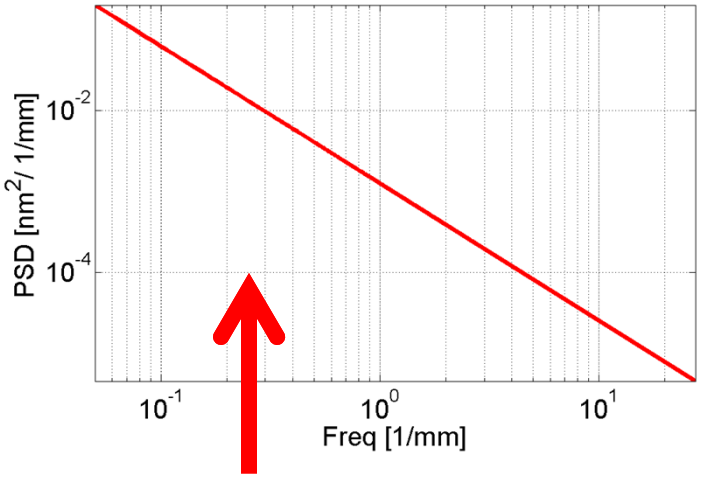
Is our understanding of point-defect scattering good enough?

Simulation of Cavity Loss

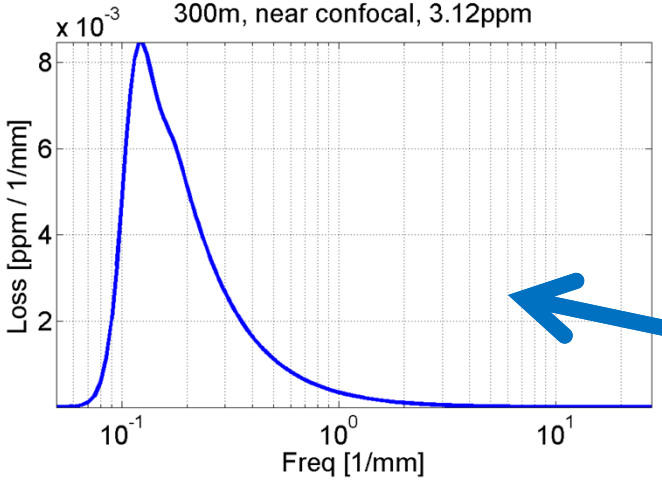
300m linear cavity



Which scatter angles lead to round-trip loss?



Surface-roughness PSD is proportional to loss.



Loss as function of scattering angle.

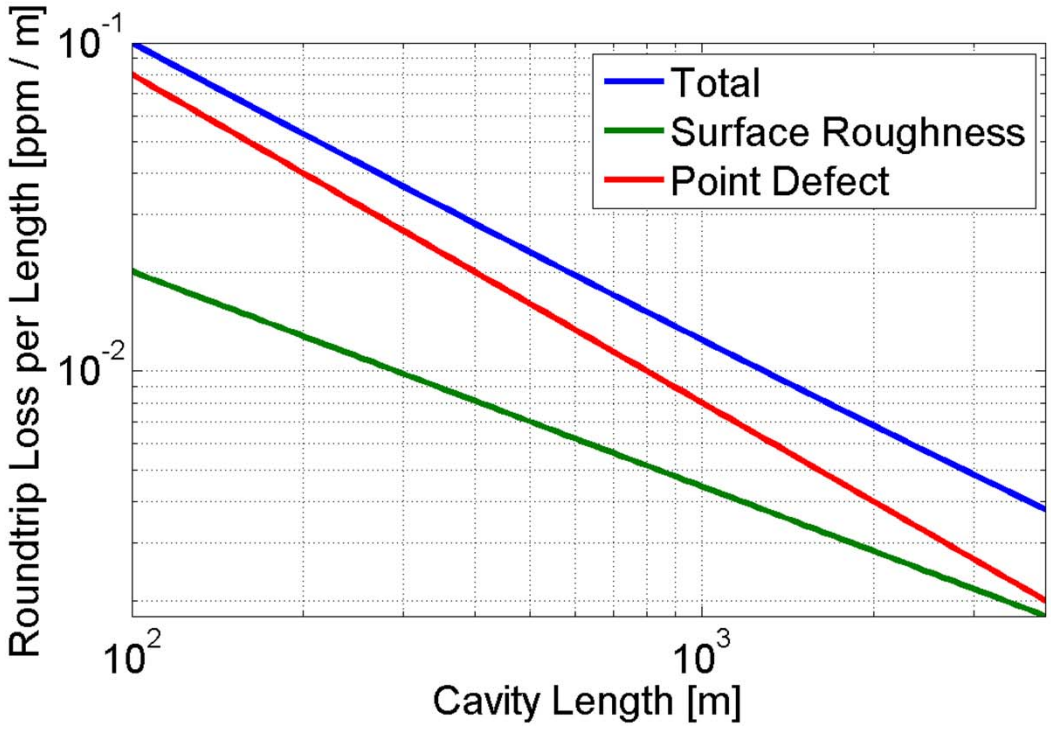
Loss as Function of Length

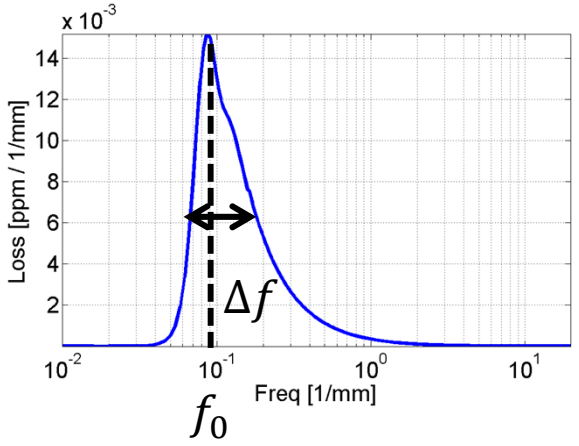
Surface roughness 1D PSD:

$$S_1(f) \propto f^{-p}$$

Cavity loss:

$$\text{loss} \propto S_1(f_0) \cdot \Delta f \propto L^{(p-1)/2}$$

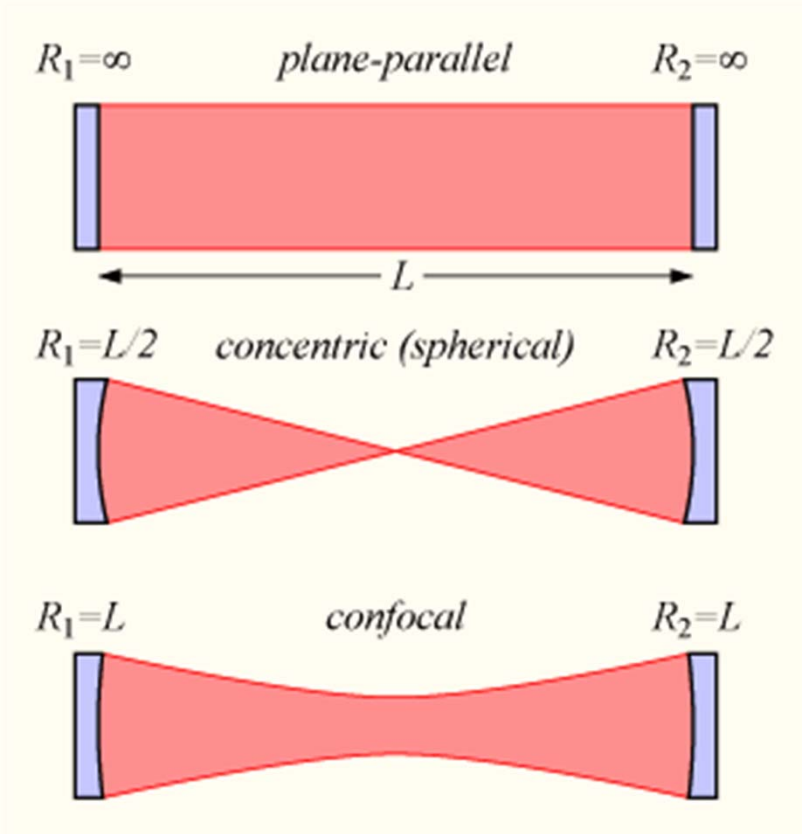




Modeling surface-roughness spectra of available optics:

The longer the better

Brief Intro into g-Factors



Plane parallel:

g-Factor: $g = 1 - \frac{L}{R_c} = 1$

Concentric:

Minimal beam size at waist

(g = -1)

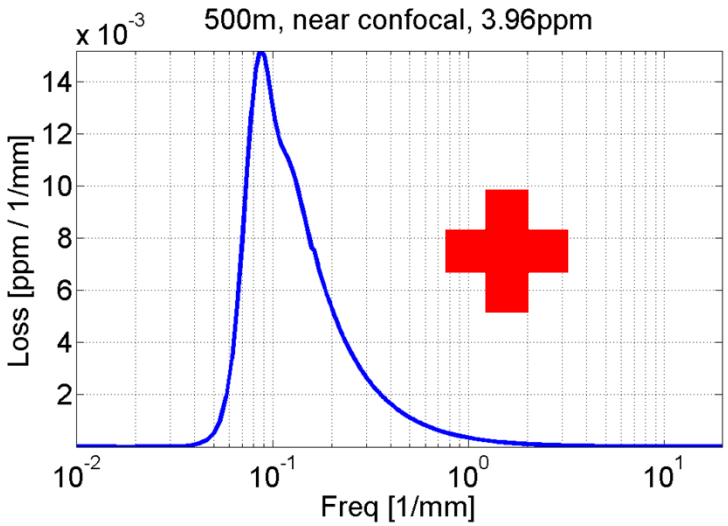
Confocal:

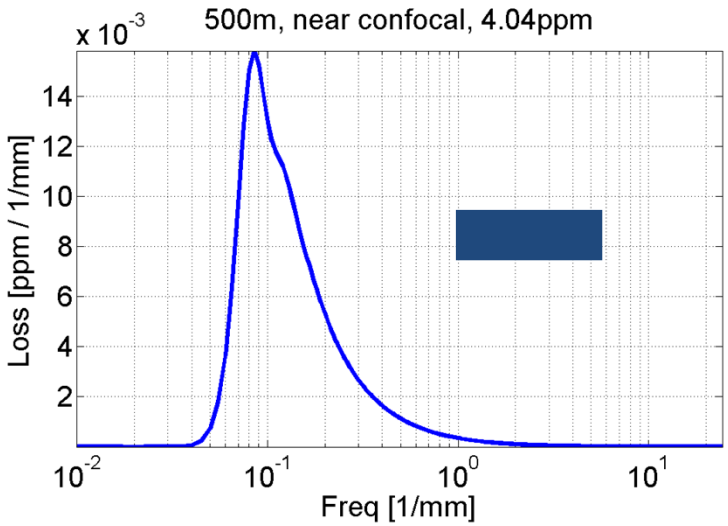
Minimal beam size on mirrors

(g = 0)

g-Factors and Quantum Filters

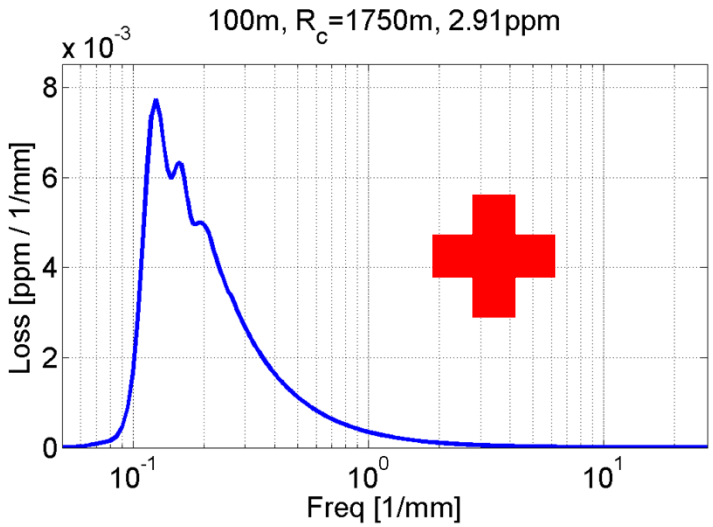
Cavity length	L = 500m
Towards parallel	R_{pos} = 600m
Towards concentric	R_{neg} = 430m
Beam radius	w = 13mm

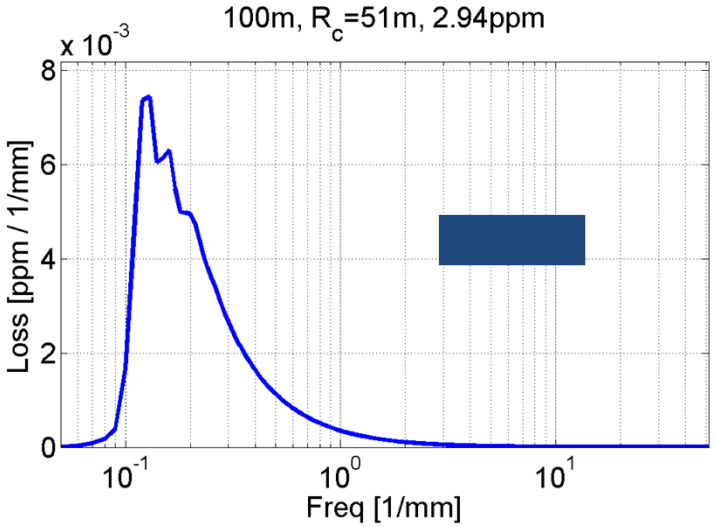




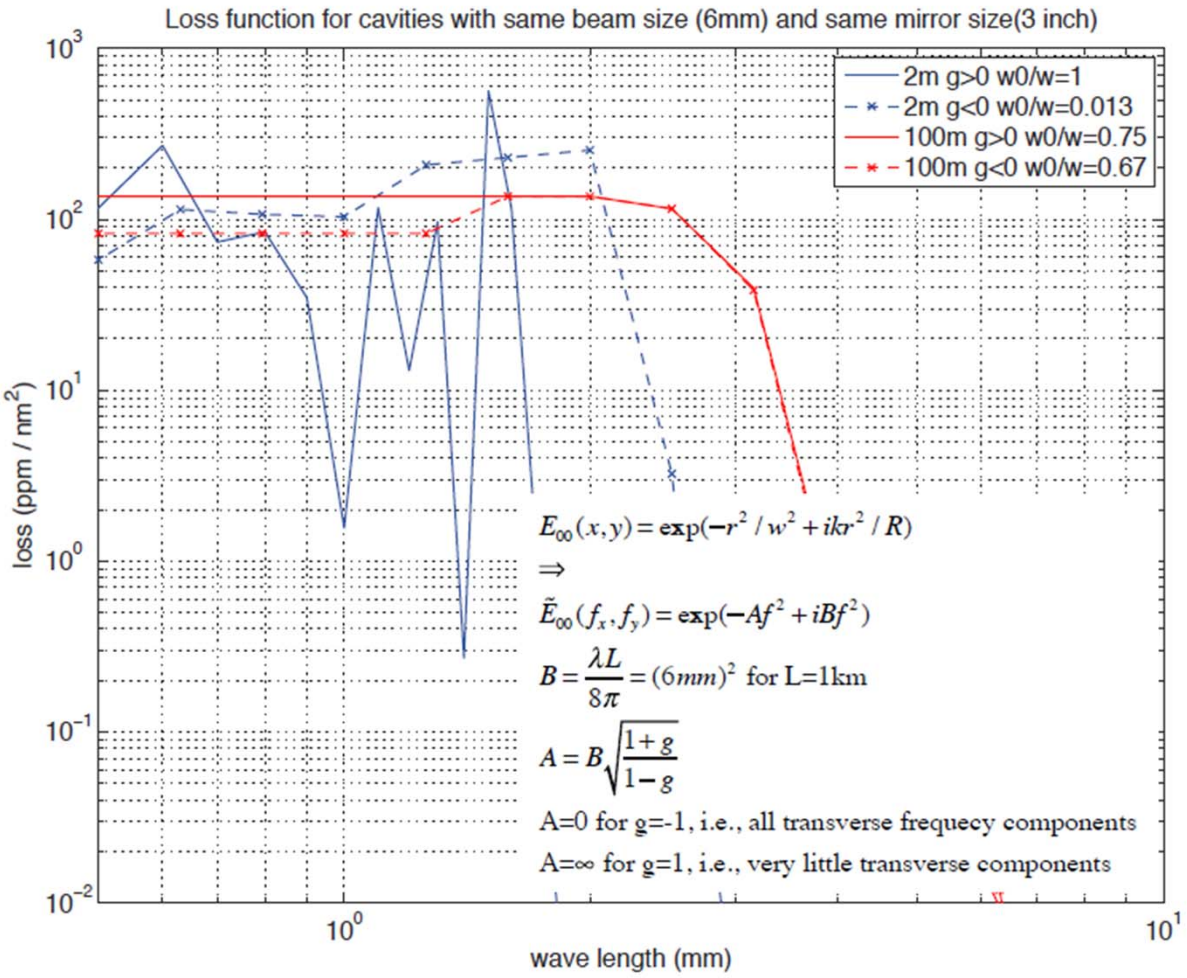
g-Factors and Cavity Loss

Cavity length	L = 100m
Towards parallel	R_{pos} = 1750m
Towards concentric	R_{neg} = 51m
Beam radius	w = 10mm (as 300m confocal)





Preliminary Results: 2m



Complicated to understand and numerically challenging to simulate because of **higher-order mode** content.

Next Steps

Combine as much as possible from the following list using the same set of high-quality optics:

1. Cavity round-trip loss measurements (see talk by Patrick Kwee)
2. TIS and BRDF measurements
3. Surface-roughness measurements
4. SIS simulations for the MIT experiment