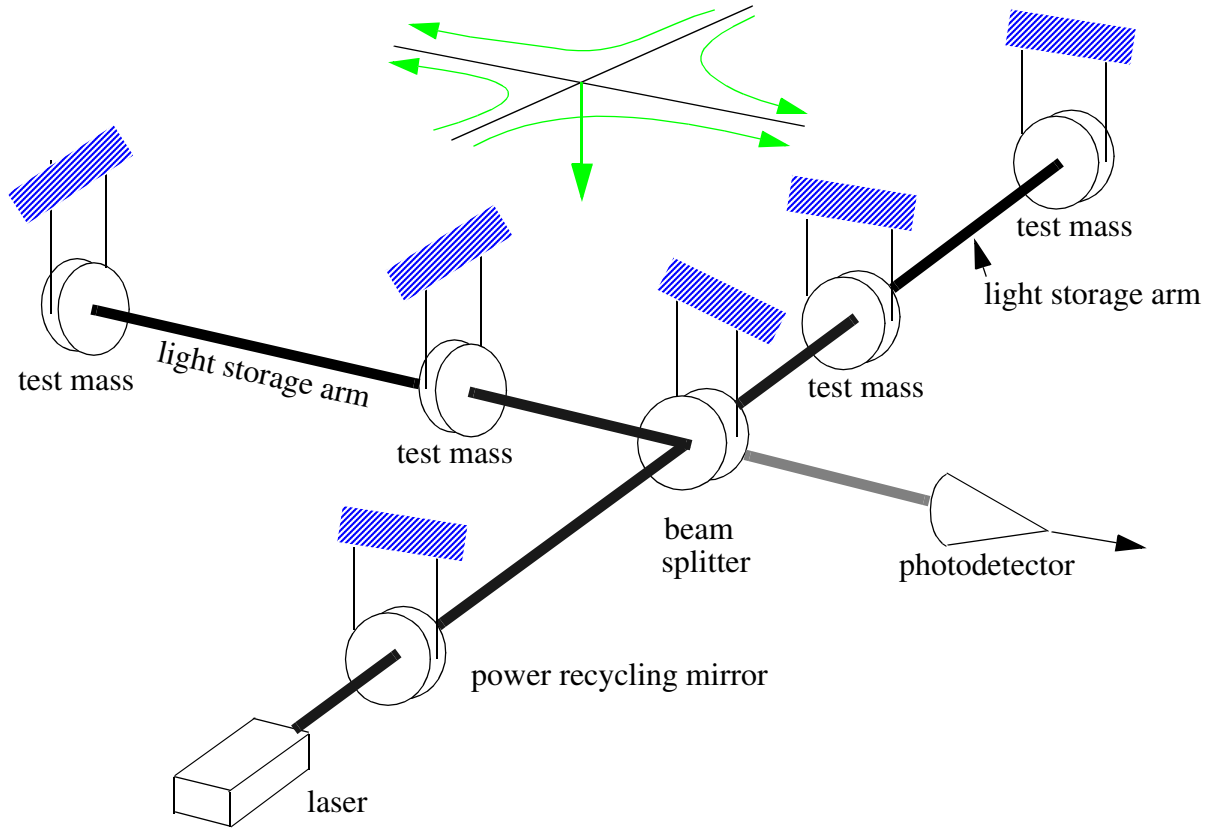


Measurement challenge

- Needed technology development to measure:

$$h = \Delta L/L < 10^{-21}$$

$$\Delta L < 4 \times 10^{-18} \text{ meters}$$



NOISE SOURCES

Noise Terms Influencing the Strain Measurement

* Shot (Poisson) Noise

Light Amplitude Noise

Laser Frequency Fluctuations

Scattering of Light by

1) Moving Sources

2) Stationary Sources

Laser Beam Position and Angle Jitter

Residual Gas Column Density Fluctuations

Fluctuation Forces Moving the End Points

* Seismic Noise

* Thermal Noise in the Suspension Elements

Thermal Noise Driving the Mirror Normal Modes

Optical / Mechanical Imbalance Radiation Pressure Force

“Radiometer” Force Driven by Light Amplitude Noise

Fluctuating External Gravitational Gradients

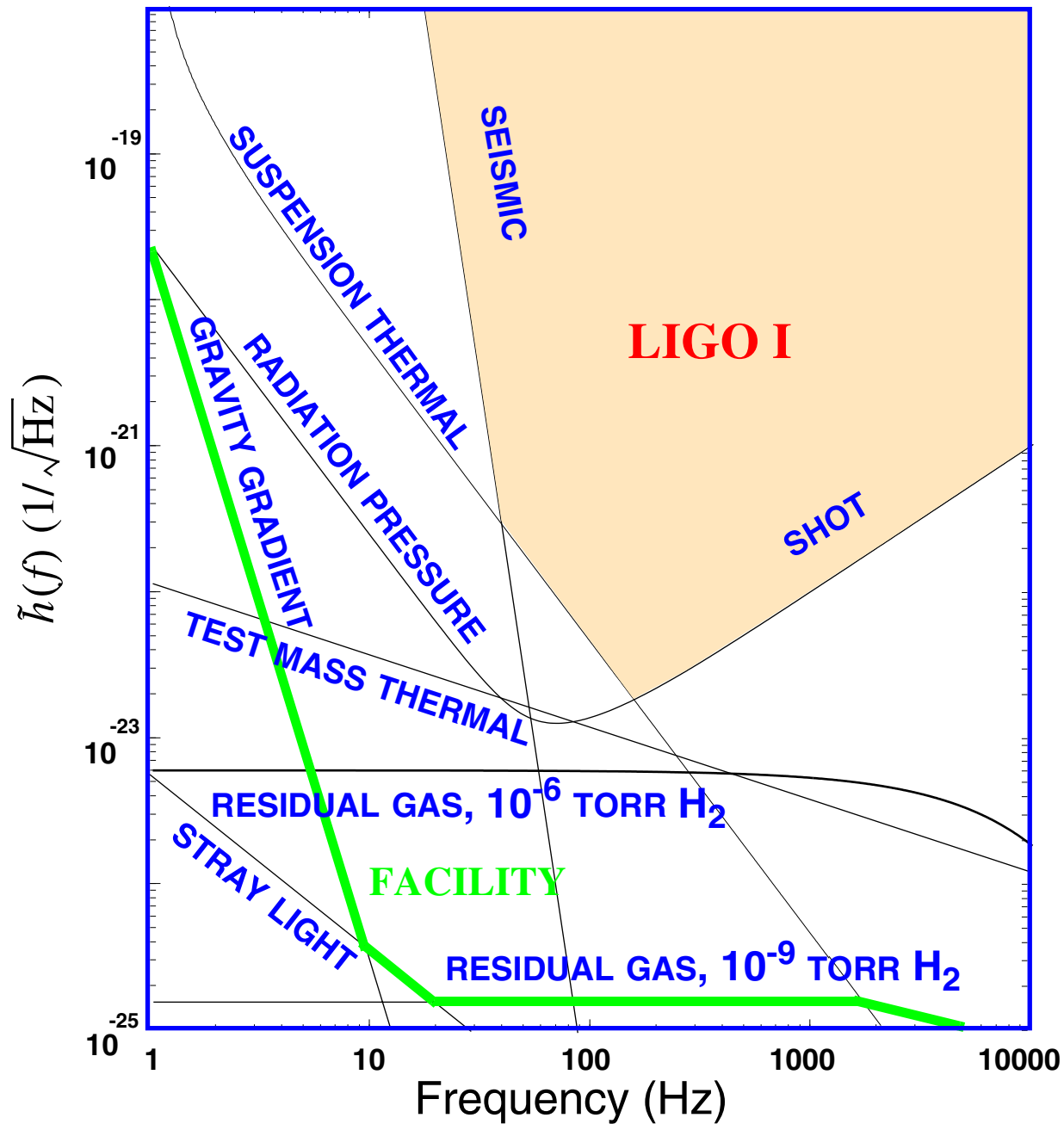
Fluctuating “Patch” Electric Fields

Fluctuating Magnetic Fields Acting on Iron Impurities

Cosmic Ray Muons

The “Naive” Quantum Limit

* Important Terms Influencing *Initial* Sensitivity Goals



FRINGE SENSING

wavelength $1 \times 10^{-6} \text{ m}$

$$h = \frac{x}{L} \sim \frac{\lambda}{Lb \sqrt{N\tau}}$$

arm length = 4000 m

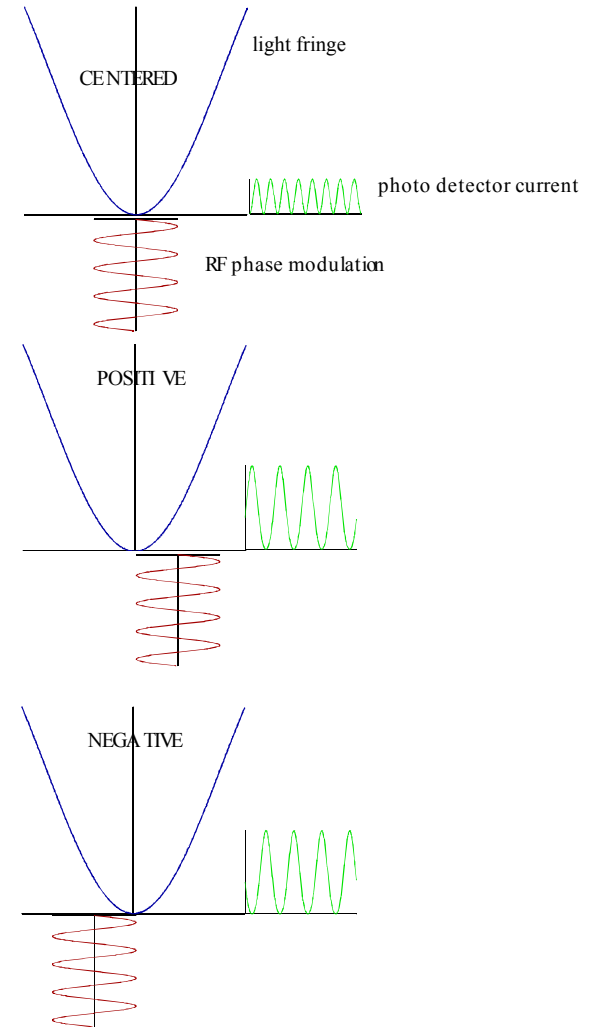
equivalent # of passes = 100

integration time

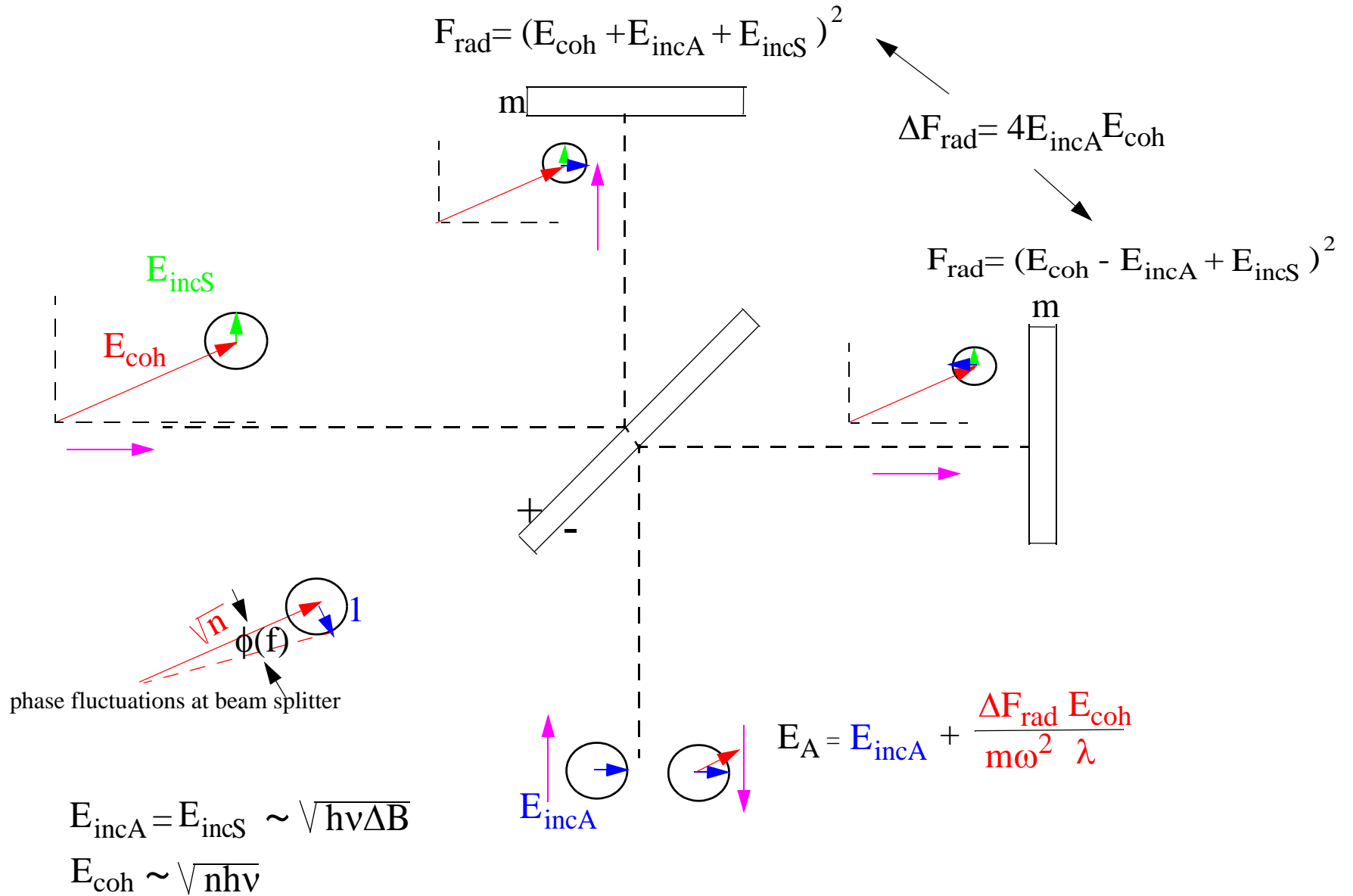
number of quanta/second at the beam splitter

300 watts at beam splitter = 10^{21} identical photons/sec

$$h = 6 \times 10^{-22} \quad \text{integration time } 10^{-2} \text{ sec}$$



Quantum Noise in the Michelson Interferometer



PENDULUM THERMAL NOISE

Pendulum Brownian motion

Dissipation leads to fluctuations

τ = coherence or damping time
 = $Q \times$ period of oscillator

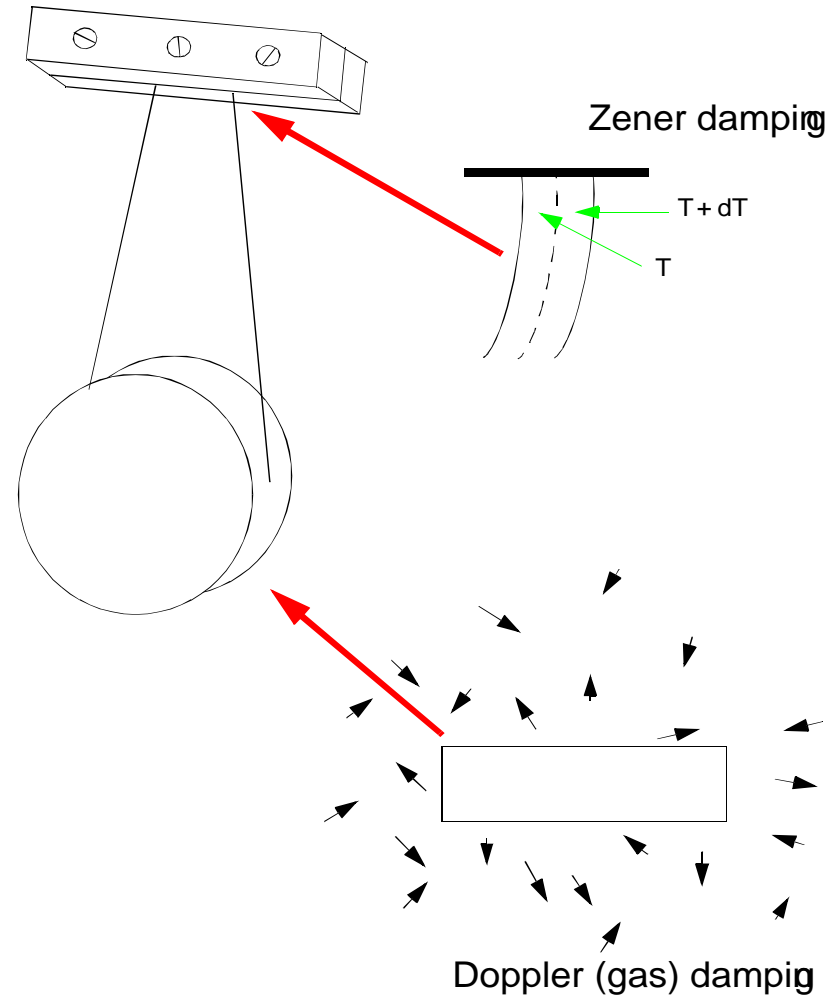
Exchange with surroundings:

$$E(\text{thermal}) = \frac{kT}{\tau}$$

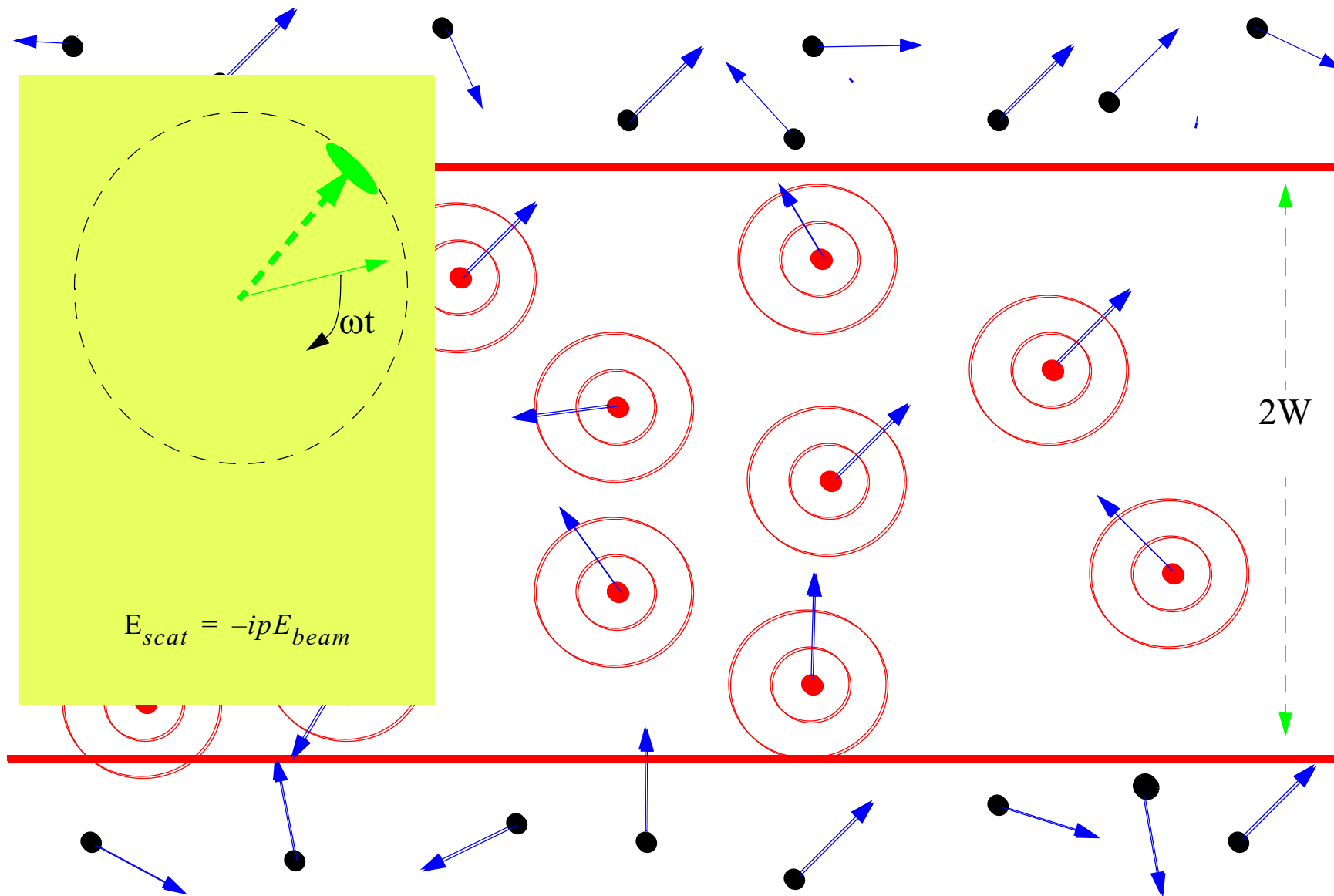
Large $\tau \Rightarrow$ smaller fluctuations

Mechanisms

- velocity dependent – viscous
- position dependent lag – structure
- thermo-elastic - Zener



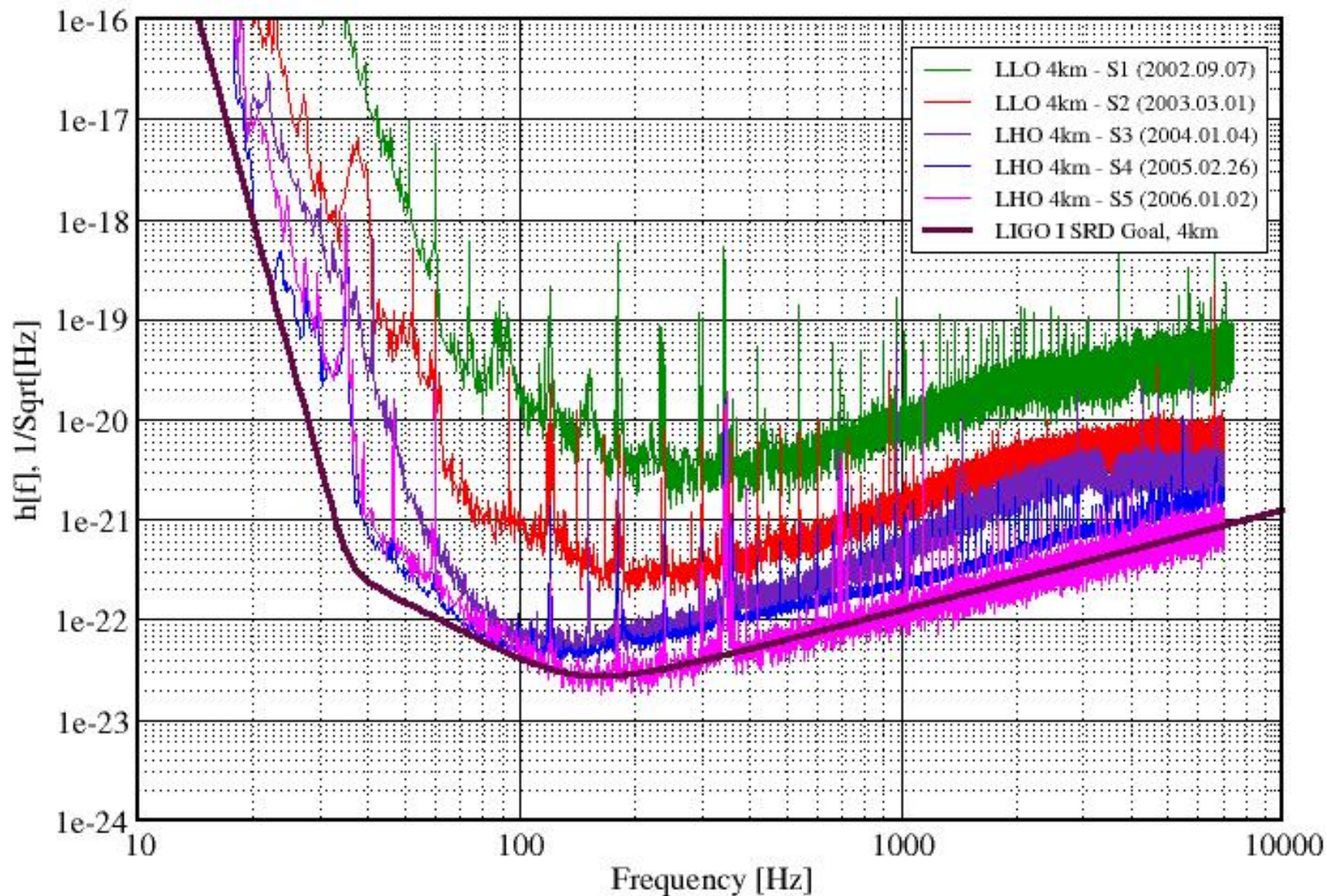
Phase noise from molecular scattering



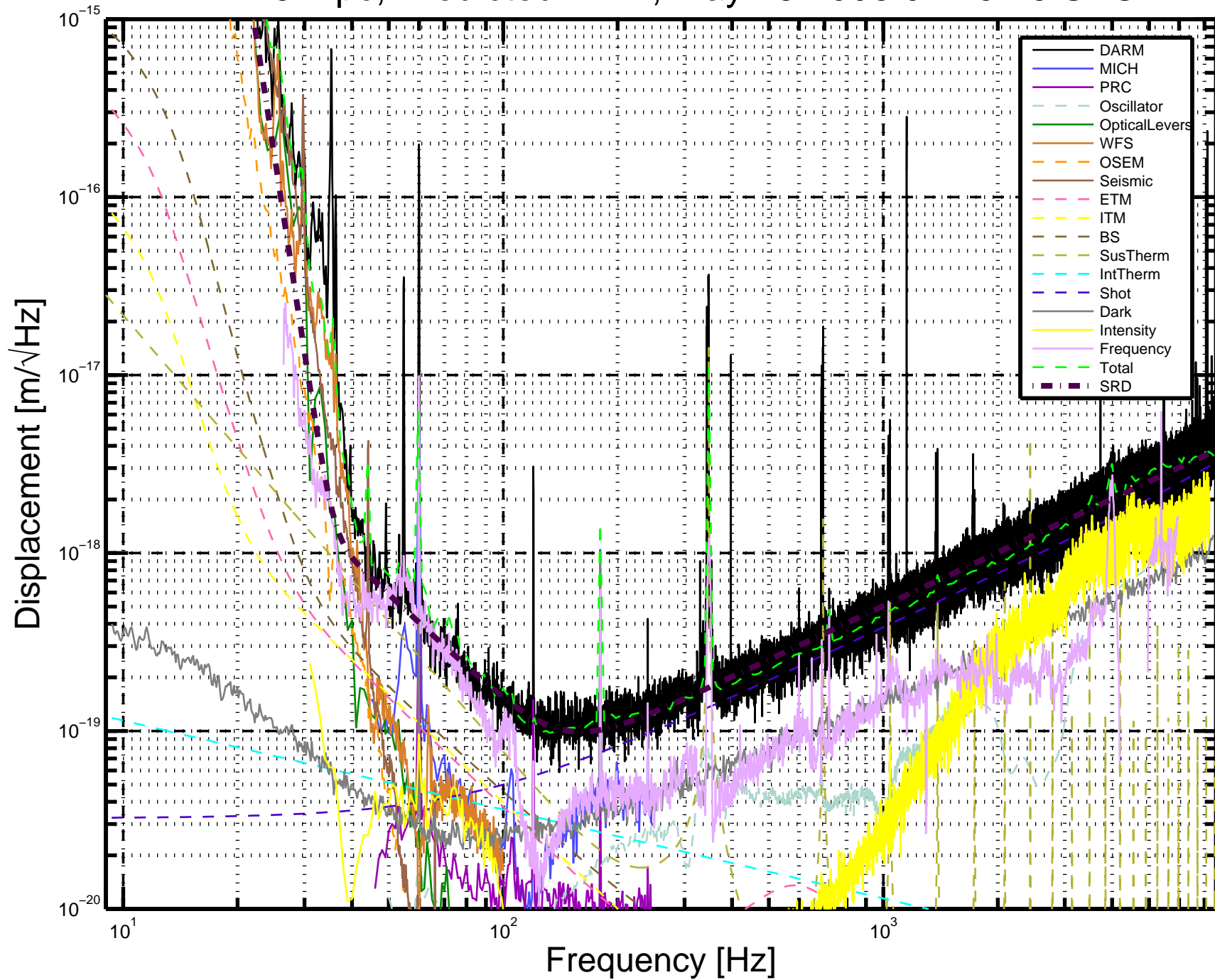
Best Strain Sensivities for the LIGO Interferometers

Comparisons among S1 - S5 Runs

LIGO-G060009-01-Z



L1: 15 Mpc, Predicted: 14.1, May 13 2006 02:19:46 UTC



Strain sensitivity initial, enhanced and advanced LIGO

