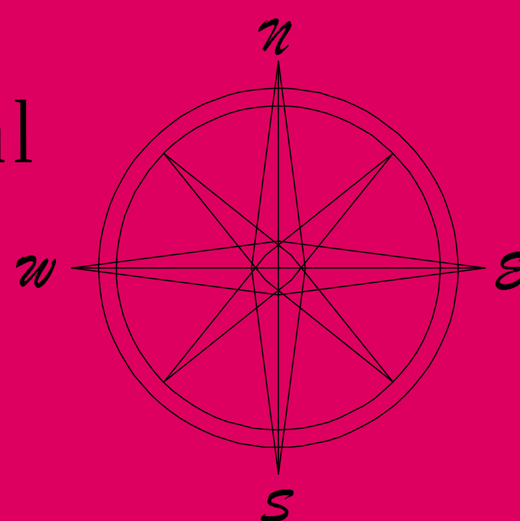
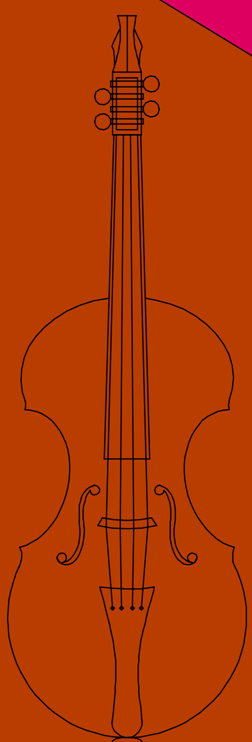
LIGO-G980123-00-D

Little Things That Can Increase Thermal Noise

-a talk in two parts

Magnet-induced test mass thermal noise

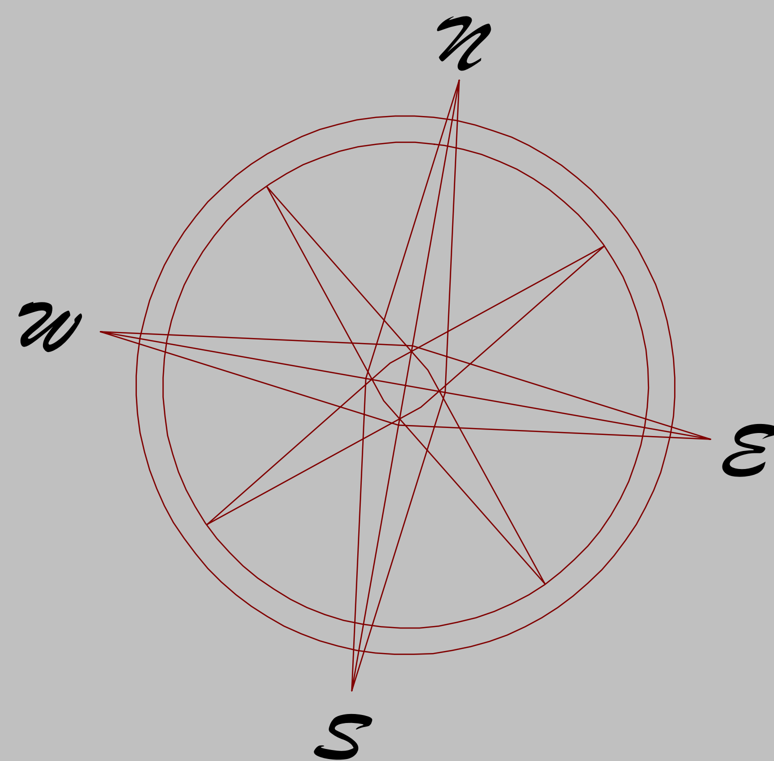




Q-reduction in nonuniform fused silica suspension wires

Phil Willems
LIGO Seminar, Oct. 6 1998

Magnet Losses Revisited

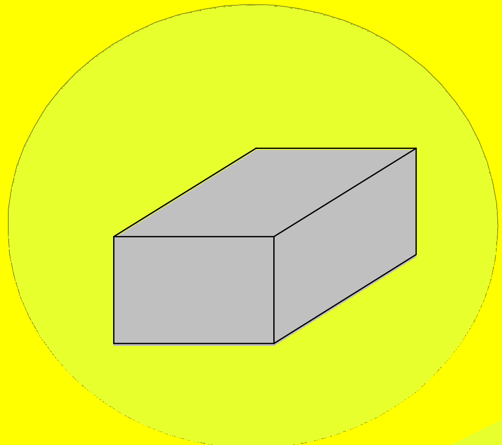


Magnet Loss Measurements

1994: Gillespie & Raab
1996: Carri
1997: Kawamura & Hazel
1998: current work

why do this measurement once again?

Indium or Epoxy?



Epoxy:

-strong bonding
(LIGO qualified)

-not very vacuum
compatible

-proven low-loss
attachment
technique

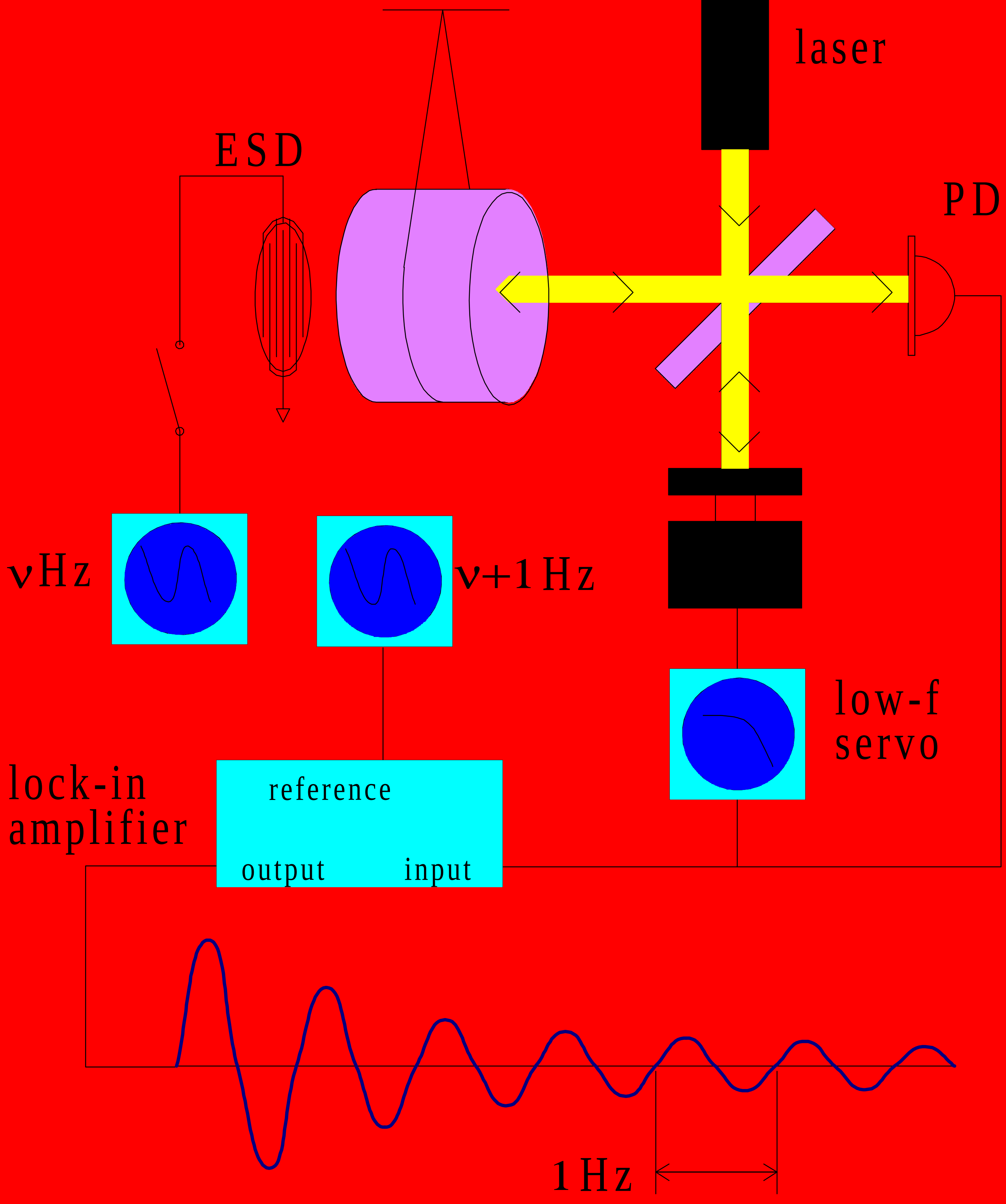
Indium:

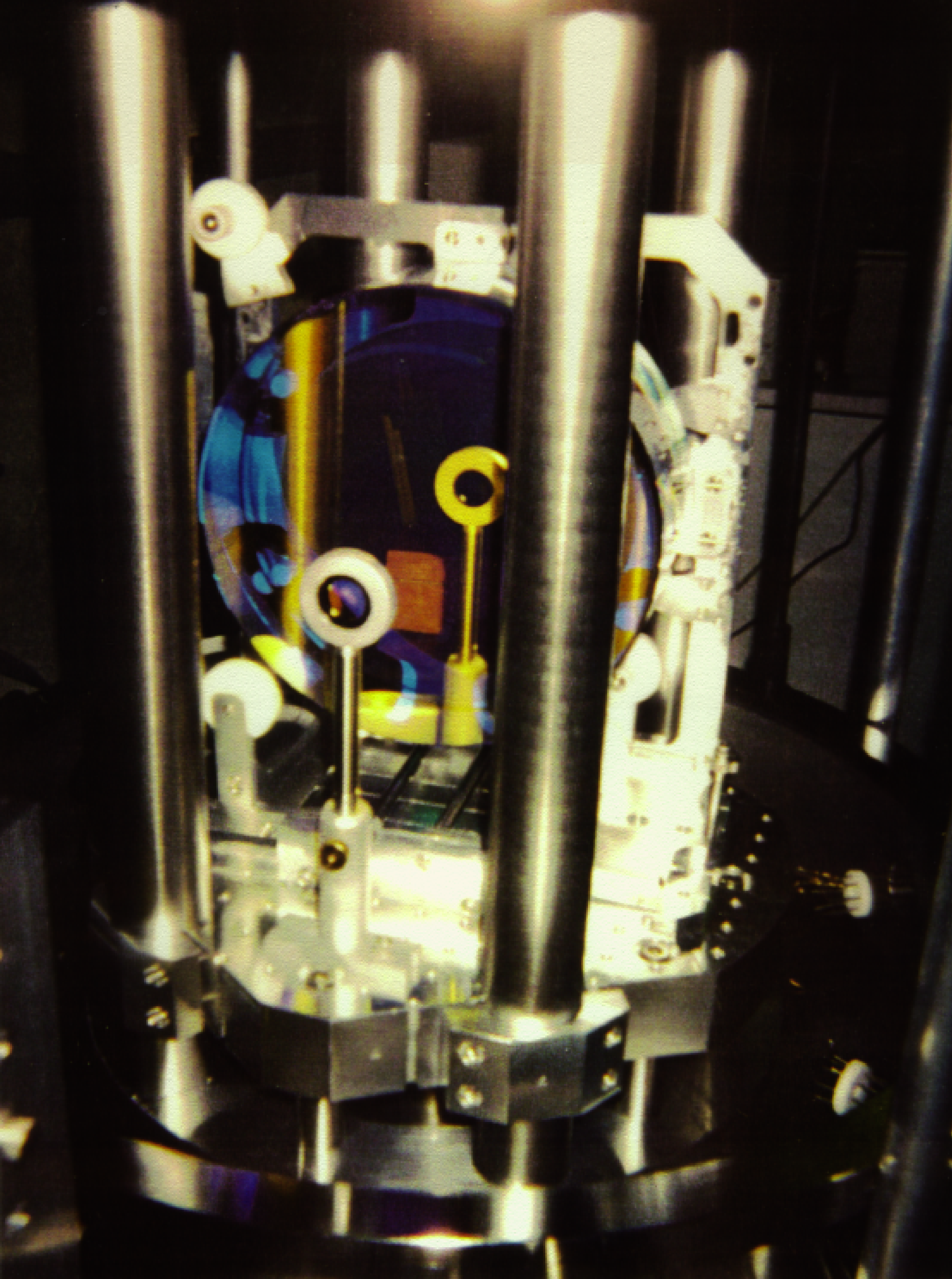
-strong bonding
(but still needs
LIGO qualifica-
tion)

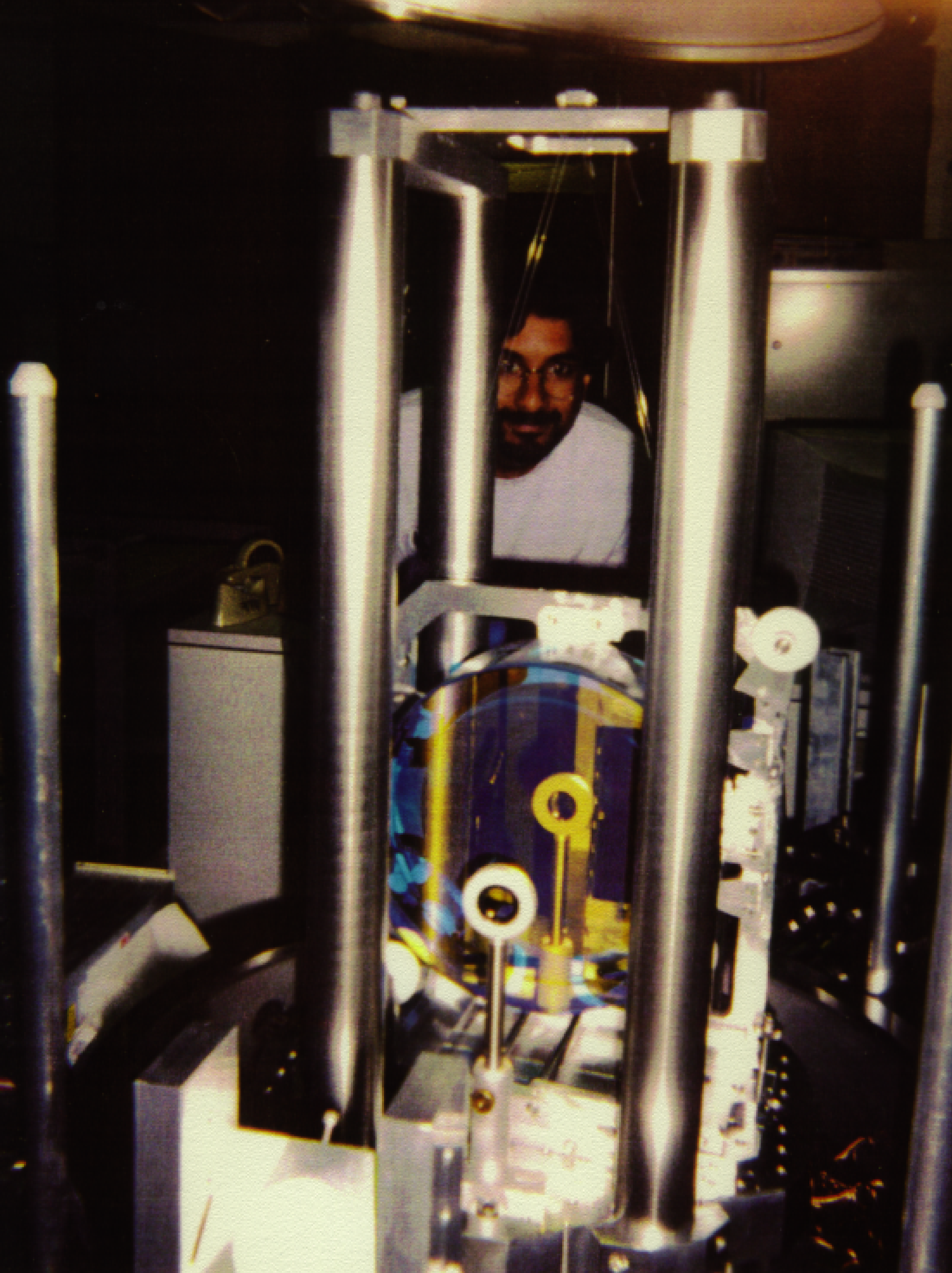
-vacuum
compatible

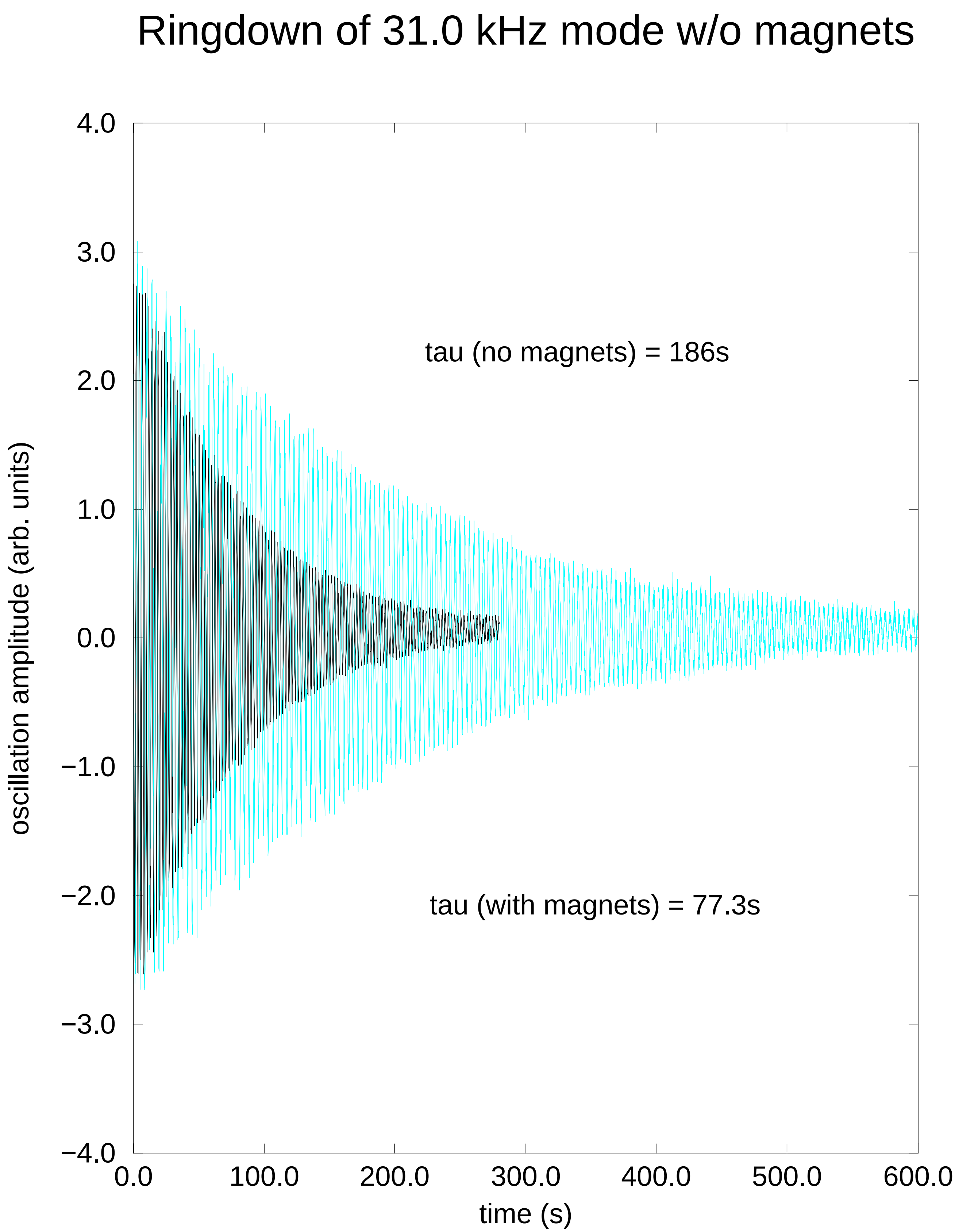
-???

Ringdown Measurement







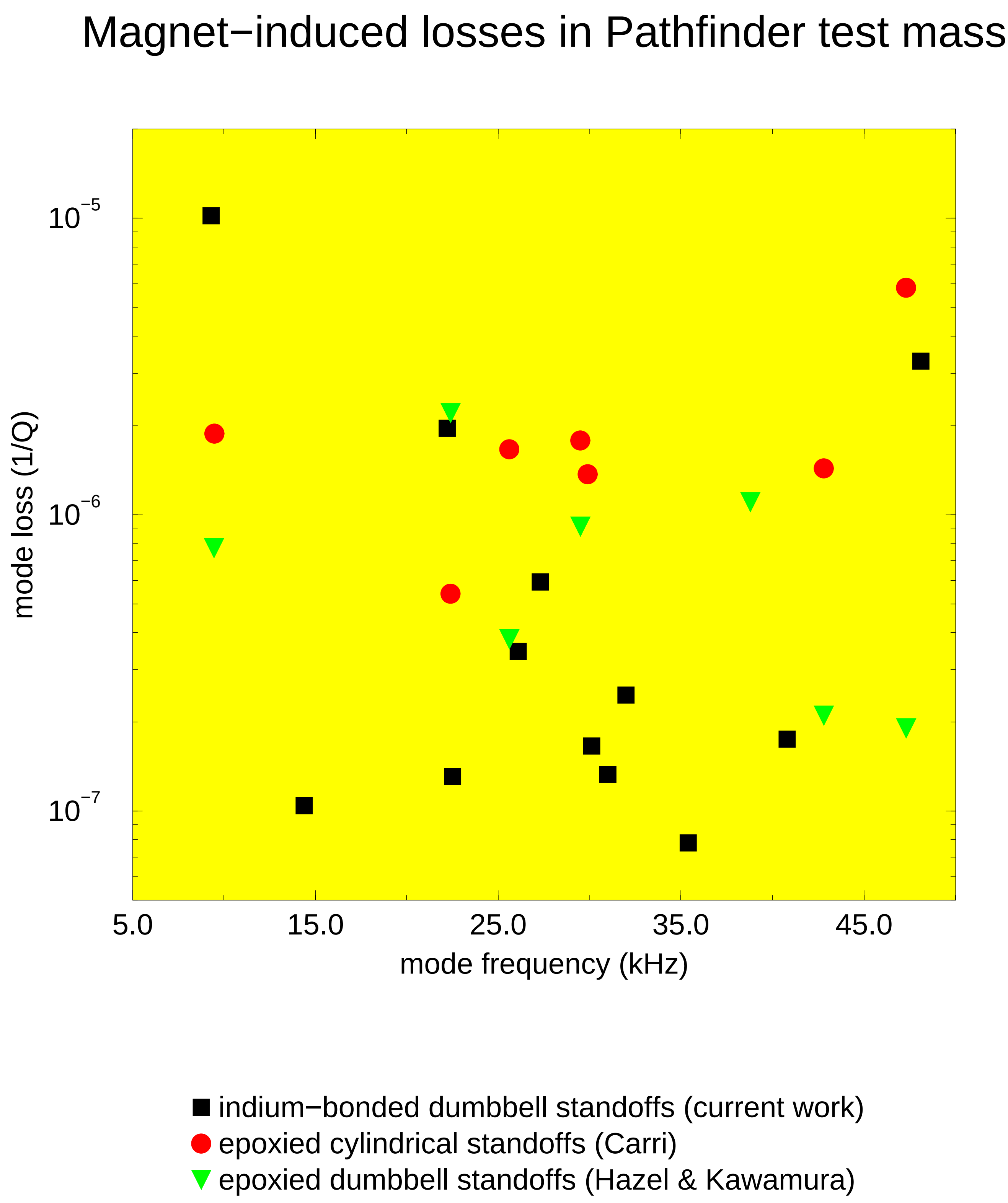


Ringdown of 31.0 kHz mode w/o magnets
tau (no magnets) = 186s
tau (with magnets) = 77.3s
oscillation amplitude (arb. units)
time (s)
4.0
3.0
2.0
1.0
0.0
−1.0
−2.0
−3.0
−4.0
0.0
100.0
200.0
300.0
400.0
500.0
600.0

.

Table 1: Measured Mechanical Losses

Mode Freq (kHz)	ϕ, without magnets ($x10^{-7}$)	ϕ, with magnets ($x10^{-7}$)
9.31	71.9	102
14.43	1.02	1.04
22.22	19.2	19.6
22.49	.775	1.31
26.11	2.86	3.45
27.28	3.65	5.92
30.07	.637	1.66
31.02	.565	1.33
31.99	1.20	2.46
35.41	.529	.78
40.76	.787	1.75
48.13	1.12	33



Magnet−induced losses in Pathfinder test mass
mode loss (1/Q)
10^{-5}
10^{-6}
10^{-7}
5.0
15.0
25.0
35.0
45.0
mode frequency (kHz)
indium−bonded dumbbell standoffs (current work)
epoxied cylindrical standoffs (Carri)
epoxied dumbbell standoffs (Hazel & Kawamura)

Current Status of Indium Bonding and Magnet Losses

1. Indium bonding losses are acceptably low for LIGO

2. Bonding strength is currently being characterized (magnet/indium bond is the weak link)

3. New fixturing for attaching magnets being designed (big advantage: indium 'cures' instantly, unlike epoxy, saving lots of time)

Q Reduction in Tapered Suspension Fibers

Mukund Thattai;
Cornell, Caltech SURF
Phil Willems;
Caltech

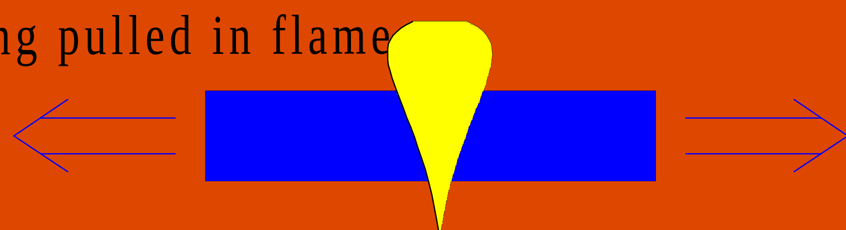
Uniform wire suspension is well understood, and probably ideal; losses are concentrated at ends according to the equation

$$\Phi = \Phi_{mat} \frac{2}{kL}\left(1 + \frac{(n\pi)^2}{2kL}\right)$$

n=number of excited wire mode
k=wire elastic wavenumber

Note that fibers should be narrow at the ends to minimize loss. Yet actual fused silica fibers taper to increasing diameter at the ends.

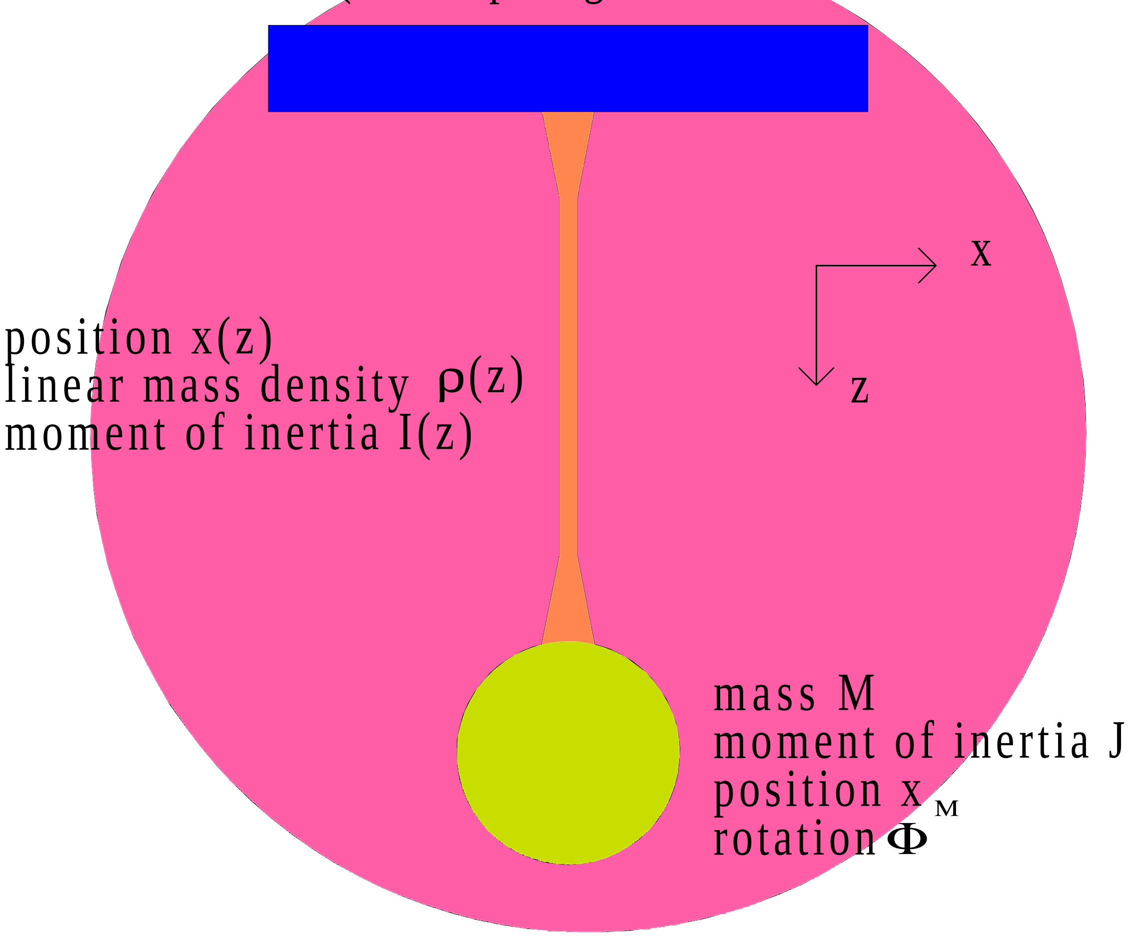
fiber being pulled in flame



finished fiber with tapered ends

The Physical Model

(with apologies to Gonzalez and Saulson)



$$-E[I(z)\,x'''' + 2I'(z)x''' + I''(z)x''] + Tx'' = -\rho(z)\,\omega^2 x$$

string equation of motion

$$x(0)=x'(0)=0$$

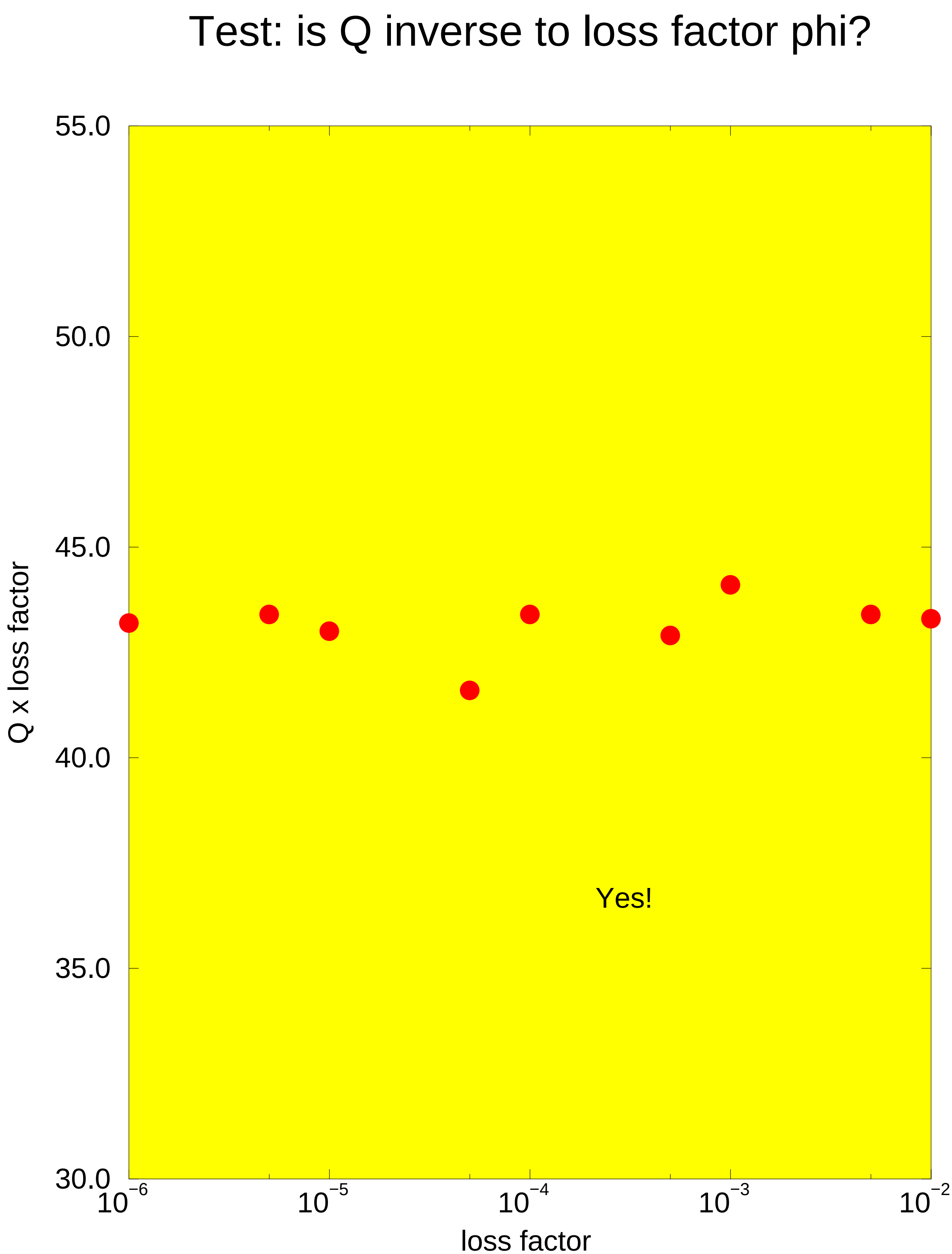
boundary conditions, top of string

$$E[I(L)\,x(L)''' + I'(L)x''(L)] - Tx'(L) = -\omega^2 M x_M$$

mass force equation

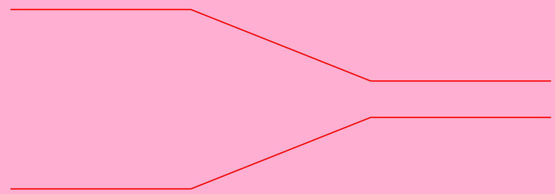
$$-E[I(L)x''(L) + hI'(L)x''(L) + hI(L)x'''(L)] = -J\omega^2\Phi$$

mass torque equation


Test: is Q inverse to loss factor phi?
55.0
50.0
45.0
40.0
35.0
30.0
Q x loss factor
Yes!
10^−6
10^−5
10^−4
10^−3
10^−2
loss factor

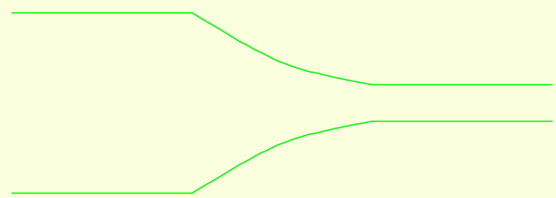
Diameter Profiles Used in the Simulation

Linear:



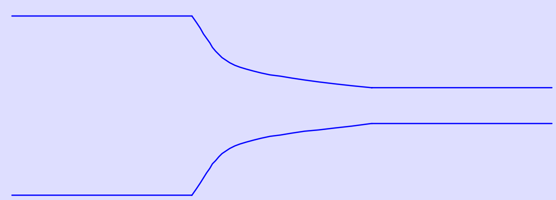
-heating zone grows half as fast as fiber is pulled (described by Birks et al.)
-useful approximation since all tapers shown are linear to first order

Exponential:

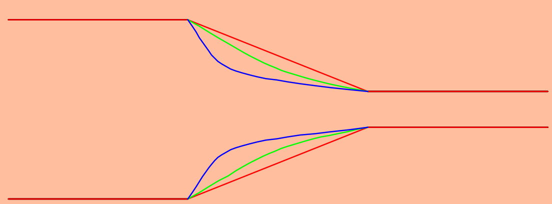


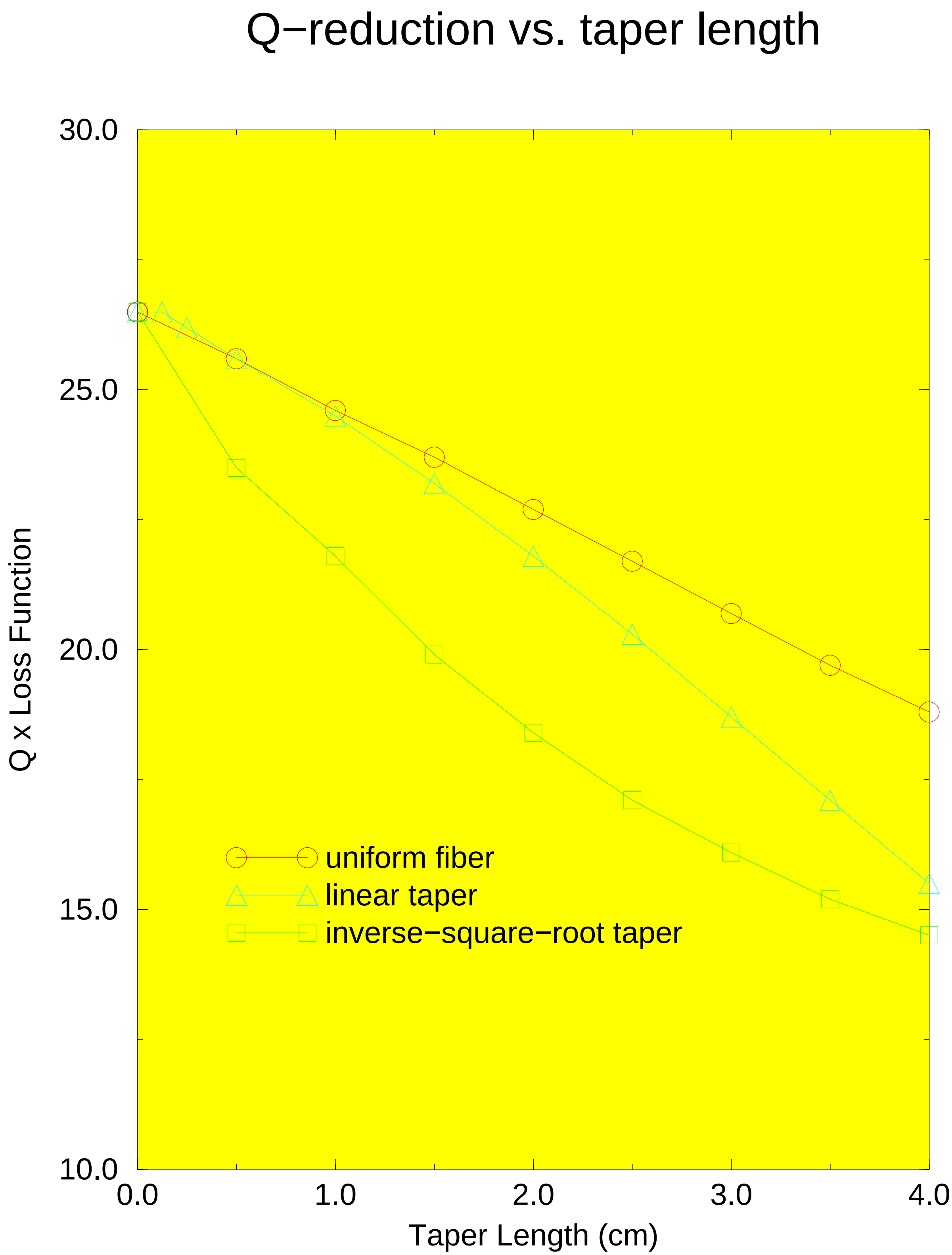
-heating zone constant as fiber is pulled
-approximation of hand-pulled fibers

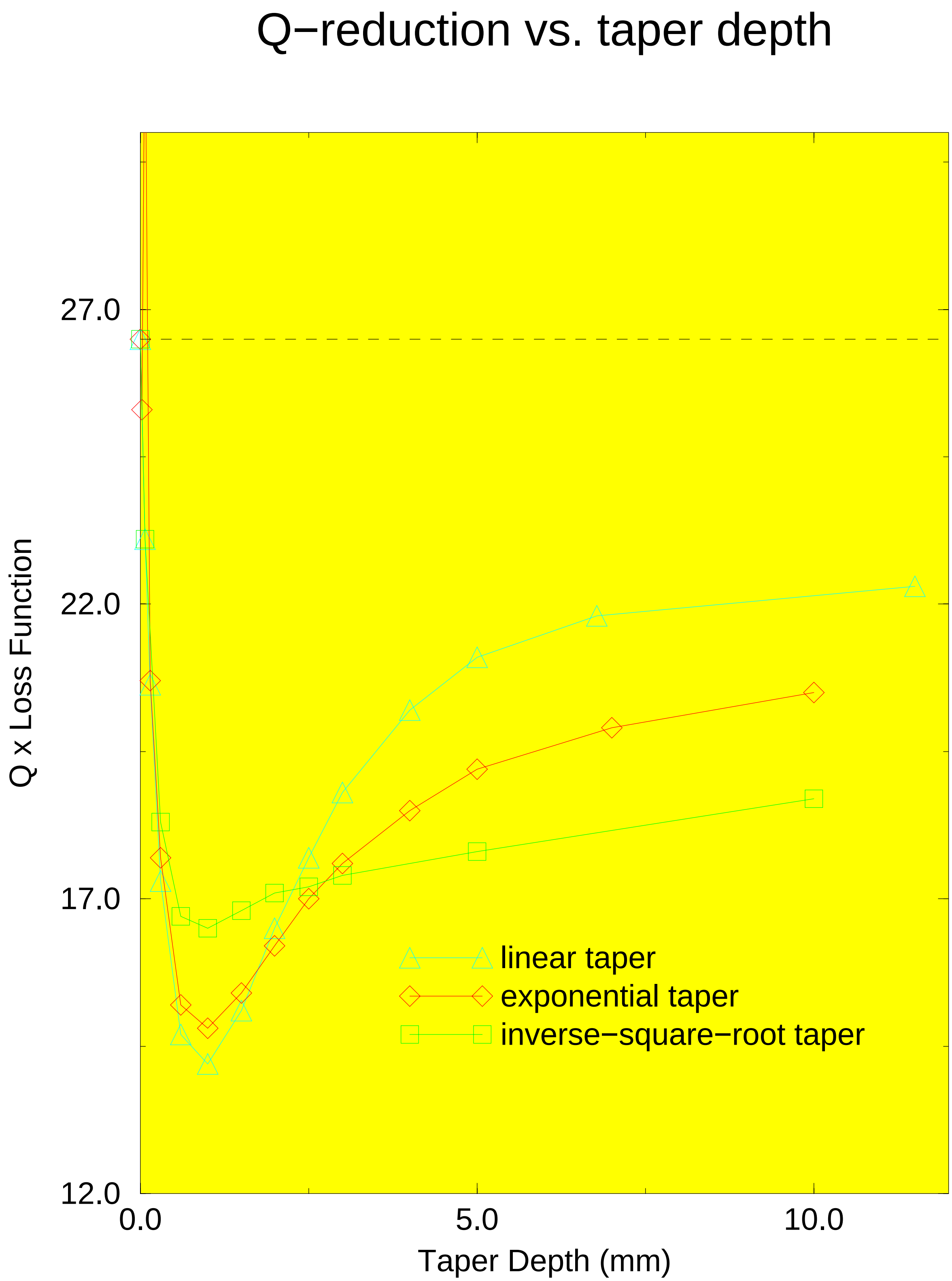
Inverse Square Root:



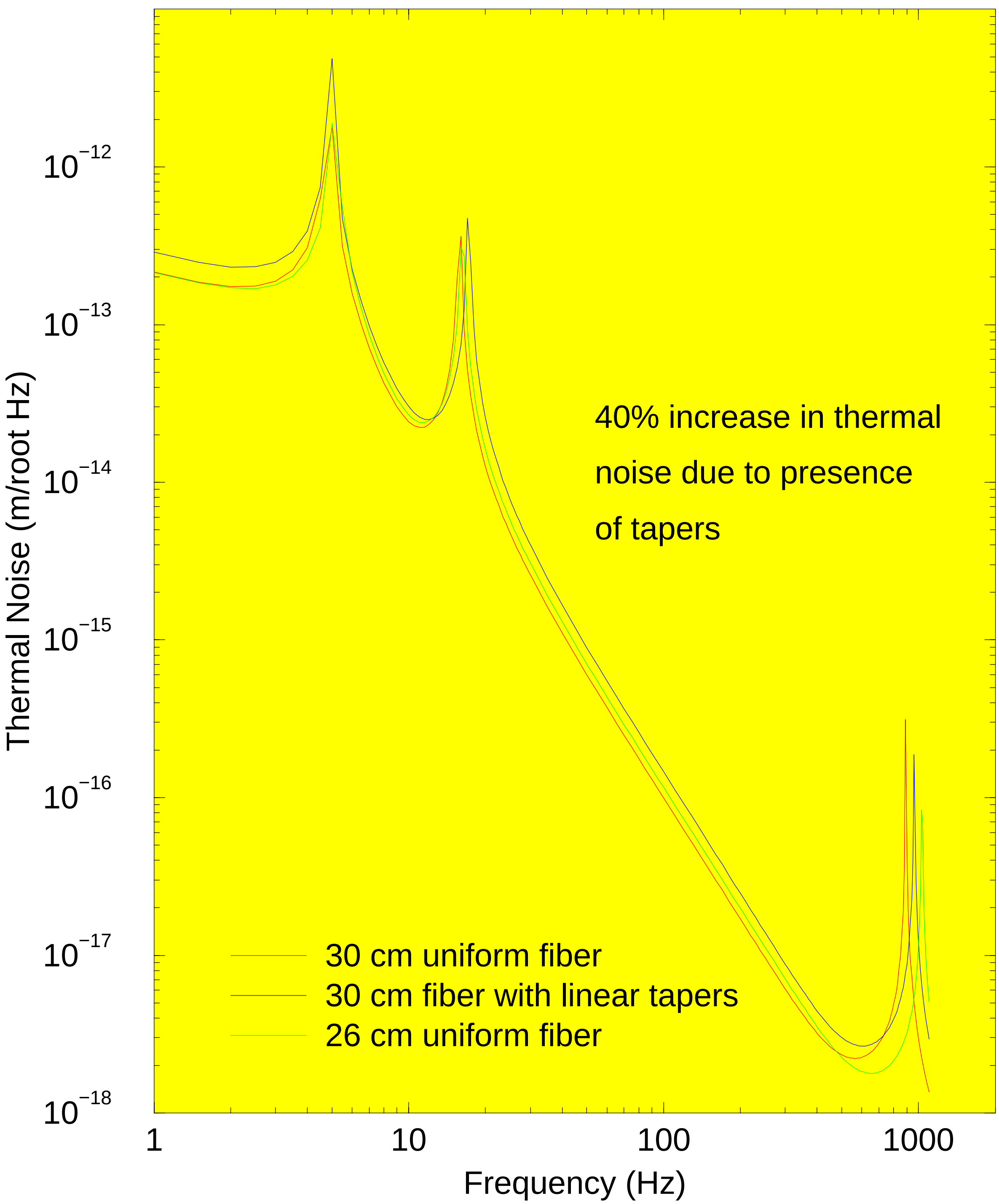
-rod fed into heating zone at low speed and fiber drawn out at high speed
-approximation of draw tower fibers

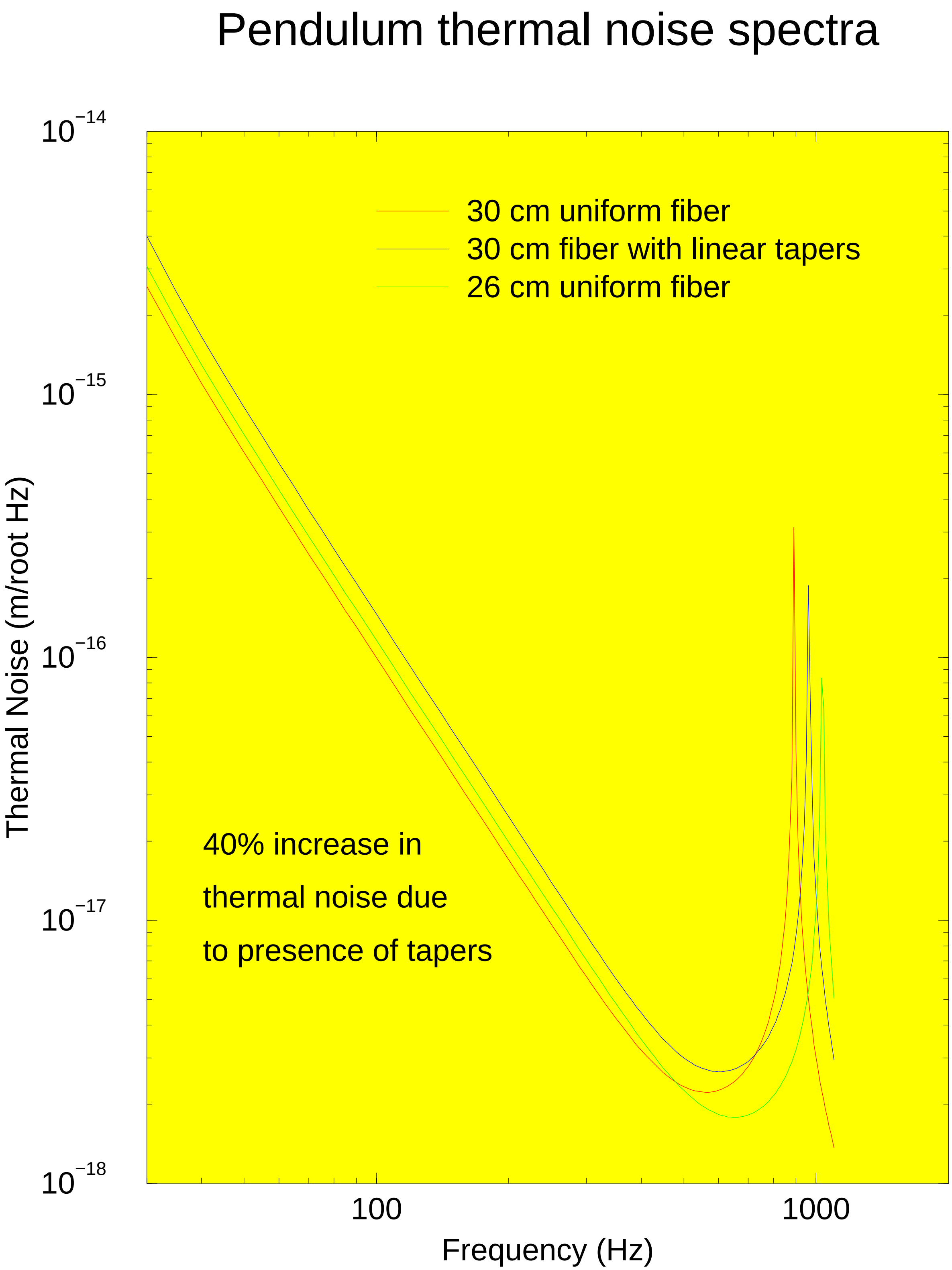



Q−reduction vs. taper length
30.0
25.0
20.0
15.0
10.0
Q x Loss Function
0.0
1.0
2.0
3.0
4.0
Taper Length (cm)
uniform fiber
linear taper
inverse−square−root taper


Q−reduction vs. taper depth
Q x Loss Function
27.0
22.0
17.0
12.0
0.0
5.0
10.0
Taper Depth (mm)
linear taper
exponential taper
inverse−square−root taper

Pendulum thermal noise spectra





Pendulum thermal noise spectra
30 cm uniform fiber
30 cm fiber with linear tapers
26 cm uniform fiber
40% increase in
thermal noise due
to presence of tapers
Thermal Noise (m/root Hz)
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
100
1000
Frequency (Hz)

Possible Improvements

a) find a way to clamp fused silica fibers in the same manner as metal wires
b) use very narrow heating zones to draw fibers (e.g. carbon dioxide lasers)
c) use torch multipass technique to tailor fiber profile

Note 1, Linda Turner, 11/02/98 11:44:09 AM
LIGO-G980123-00-D