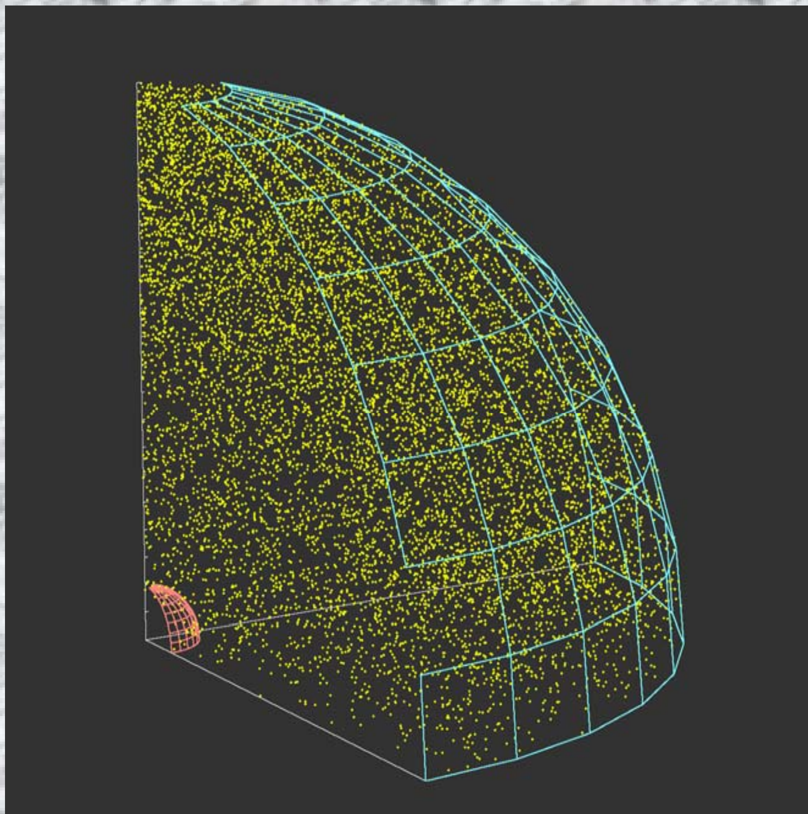
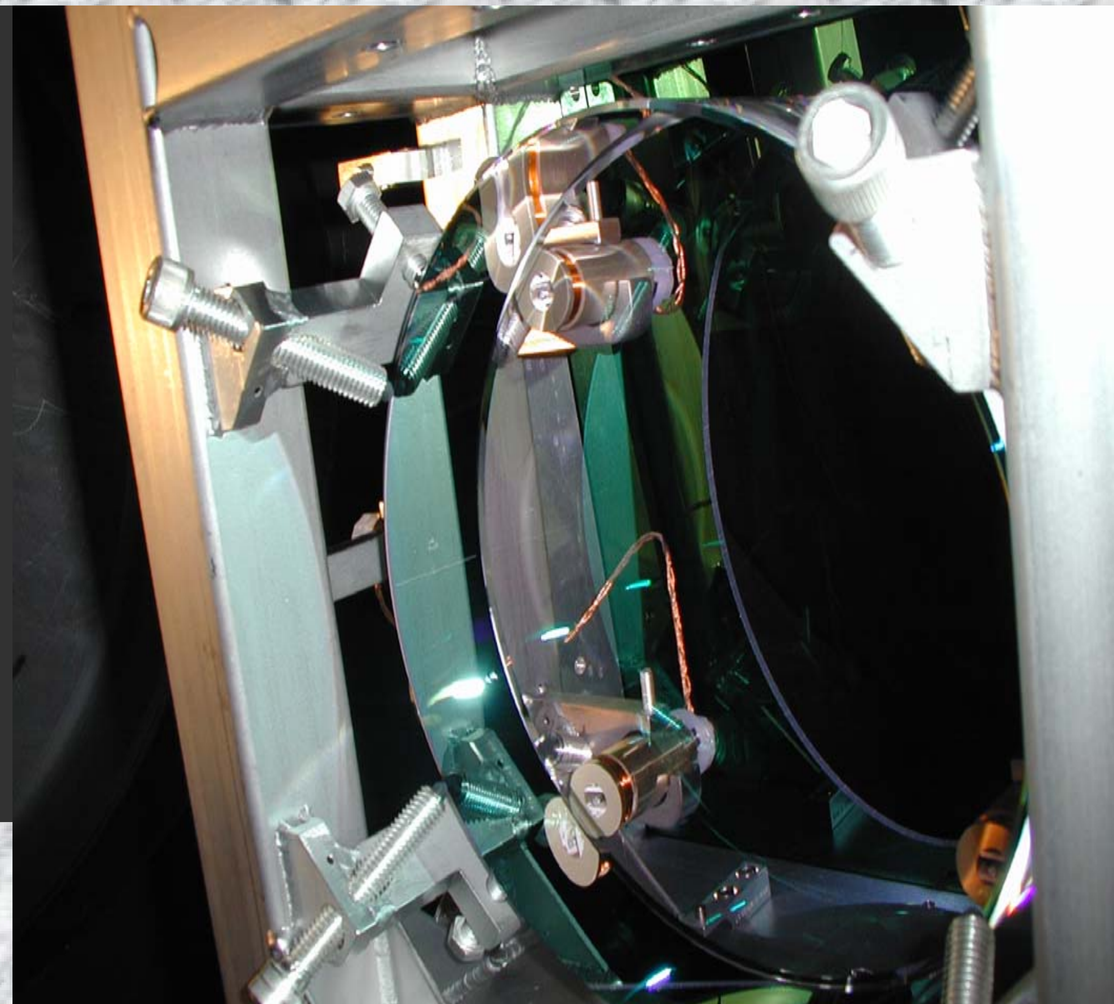
Future LIGO Interferometers





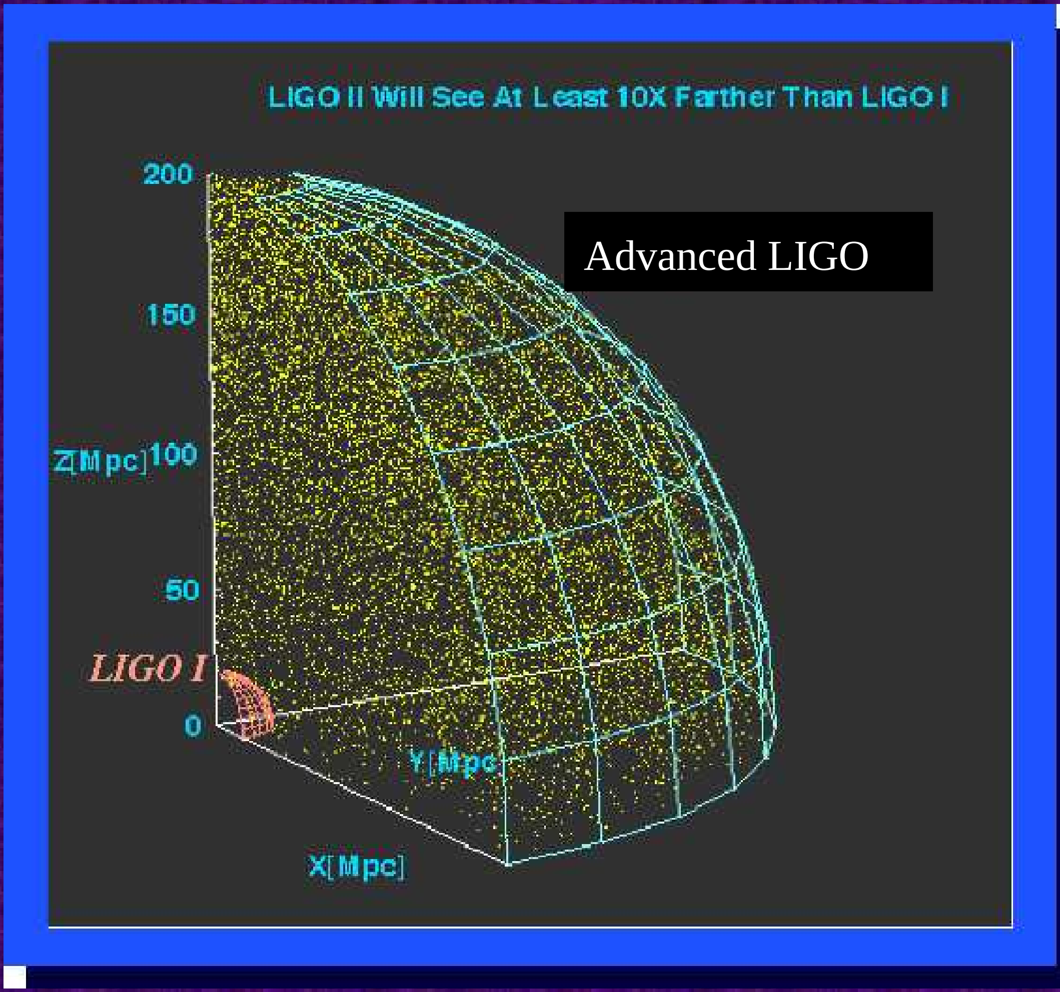
Moriond 07
La Thuille, Italy

Rana Adhikari
Caltech

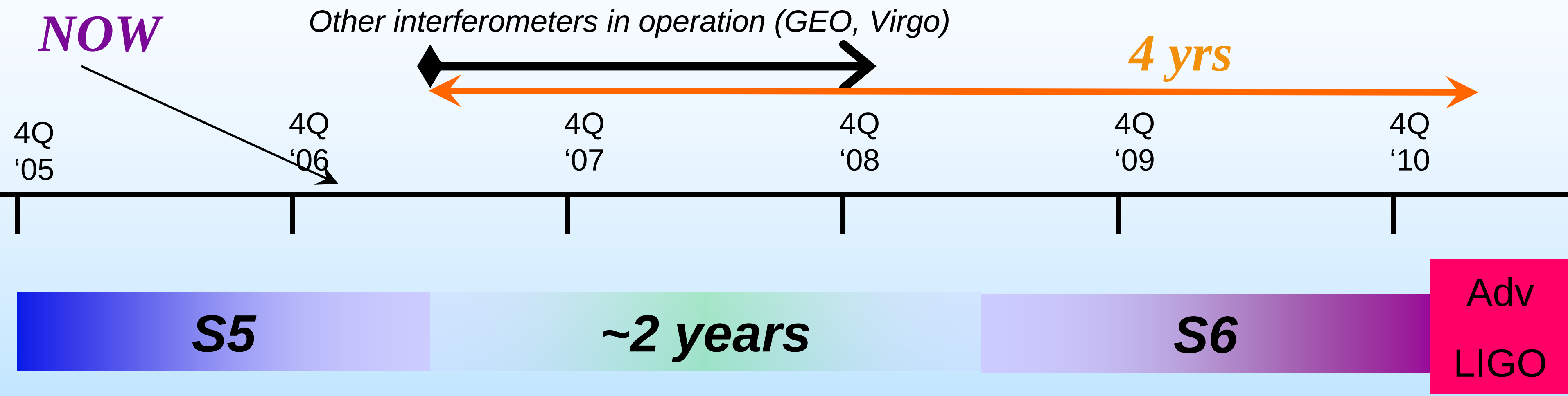
Advanced LIGO

- LIGO mission: detect gravitational waves and
  initiate GW astronomy
- Next detector
  - Should have assured detectability of known sources
  - Should be at the limits of reasonable extrapolations of detector physics and technologies
  - Must be a realizable, practical, reliable instrument
  - Daily gravitational wave detections

→ ***Advanced* LIGO**



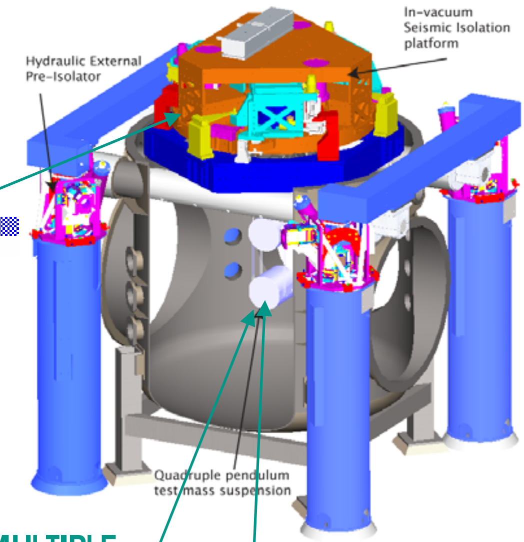
The next several years

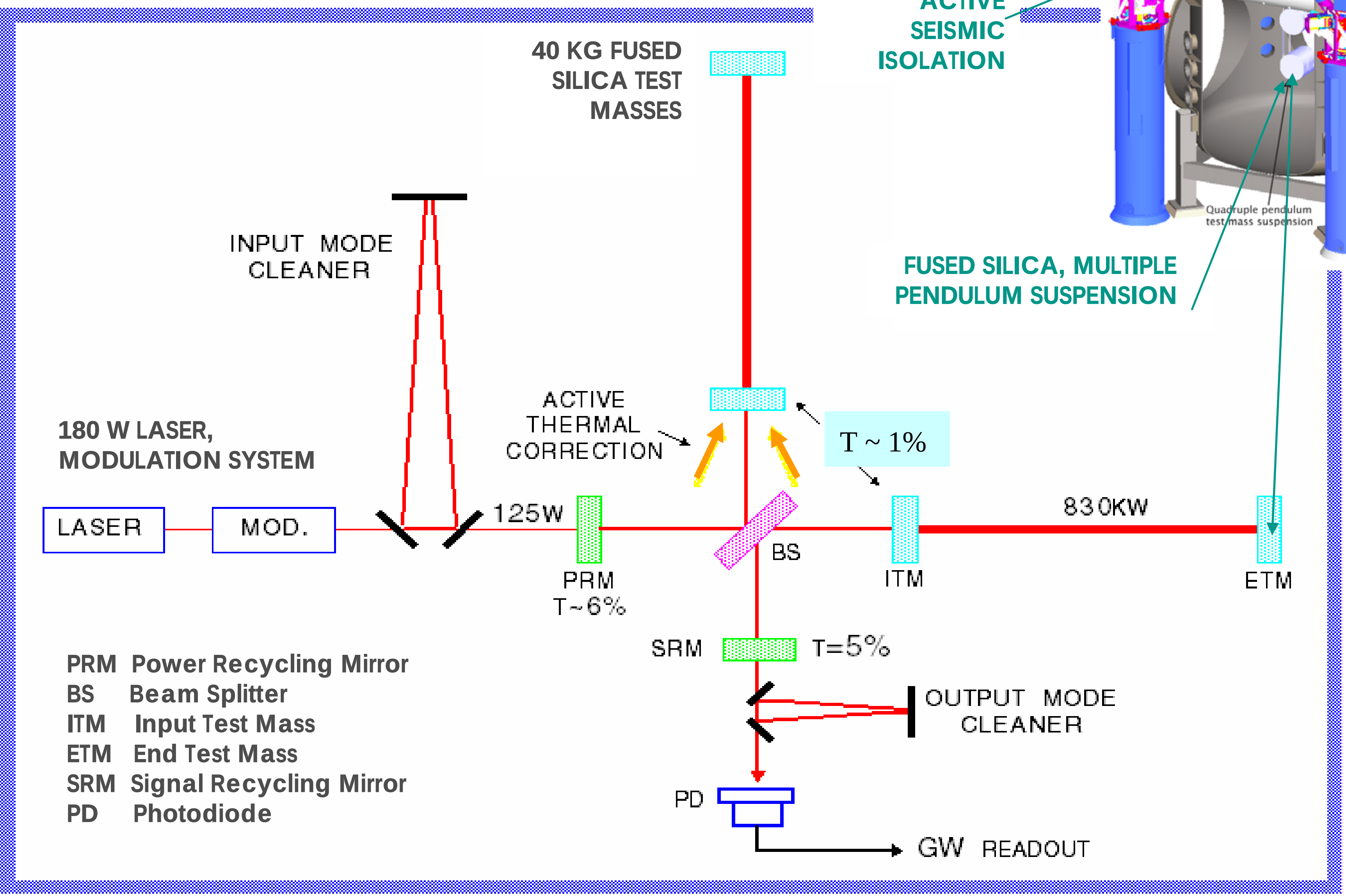


- Between now and AdvLIGO, there is some time to improve…
  1) ~Few years of hardware improvements + 1 ½ year of observations.
  1) Factor of ~2.5 in noise, factor of ~10 in event rate.
  2) *3-6 interferometers running in coincidence !*

Enhanced LIGO details in “Lessons from LIGO-I” talk on Thursday

Advanced LIGO Sketch

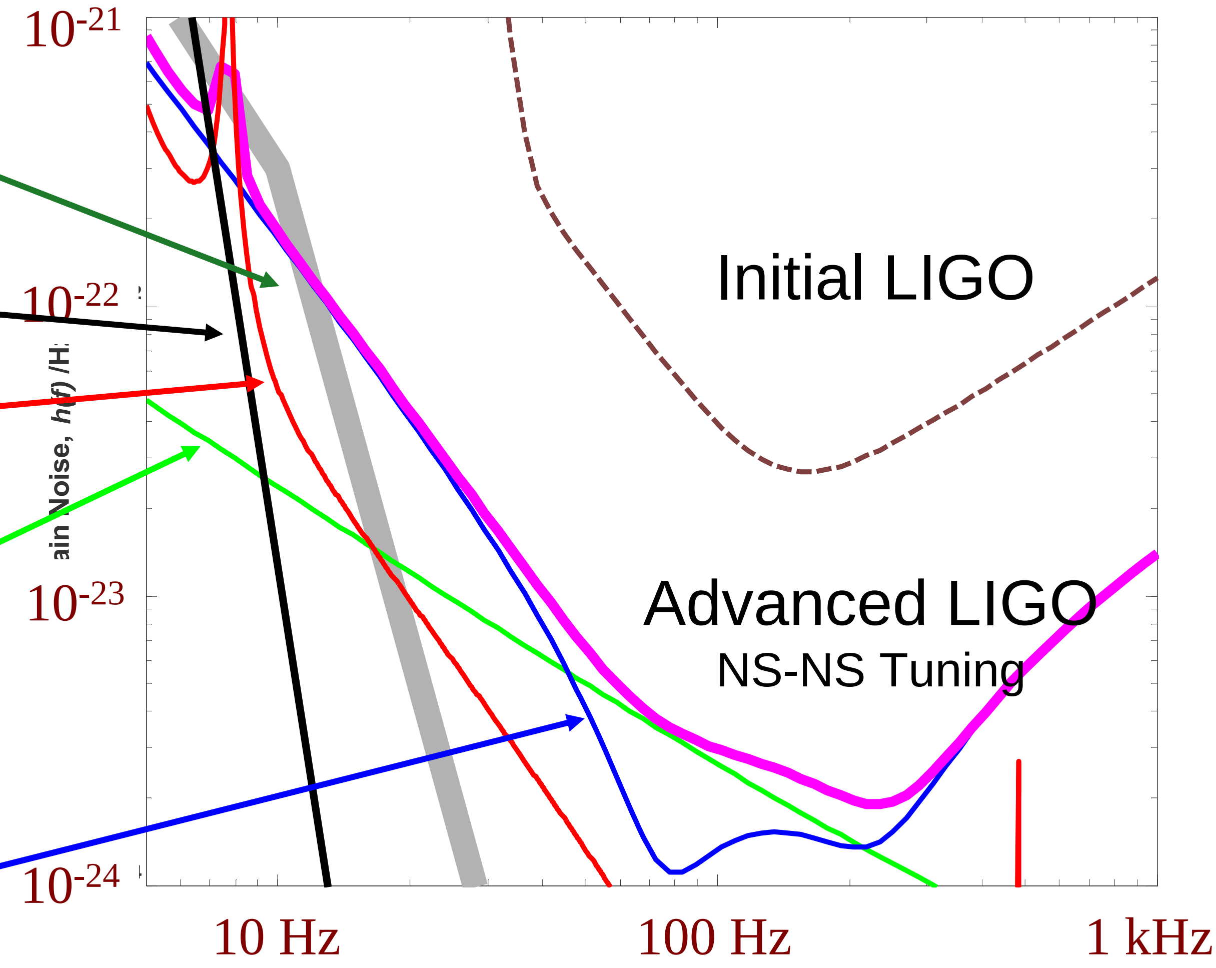




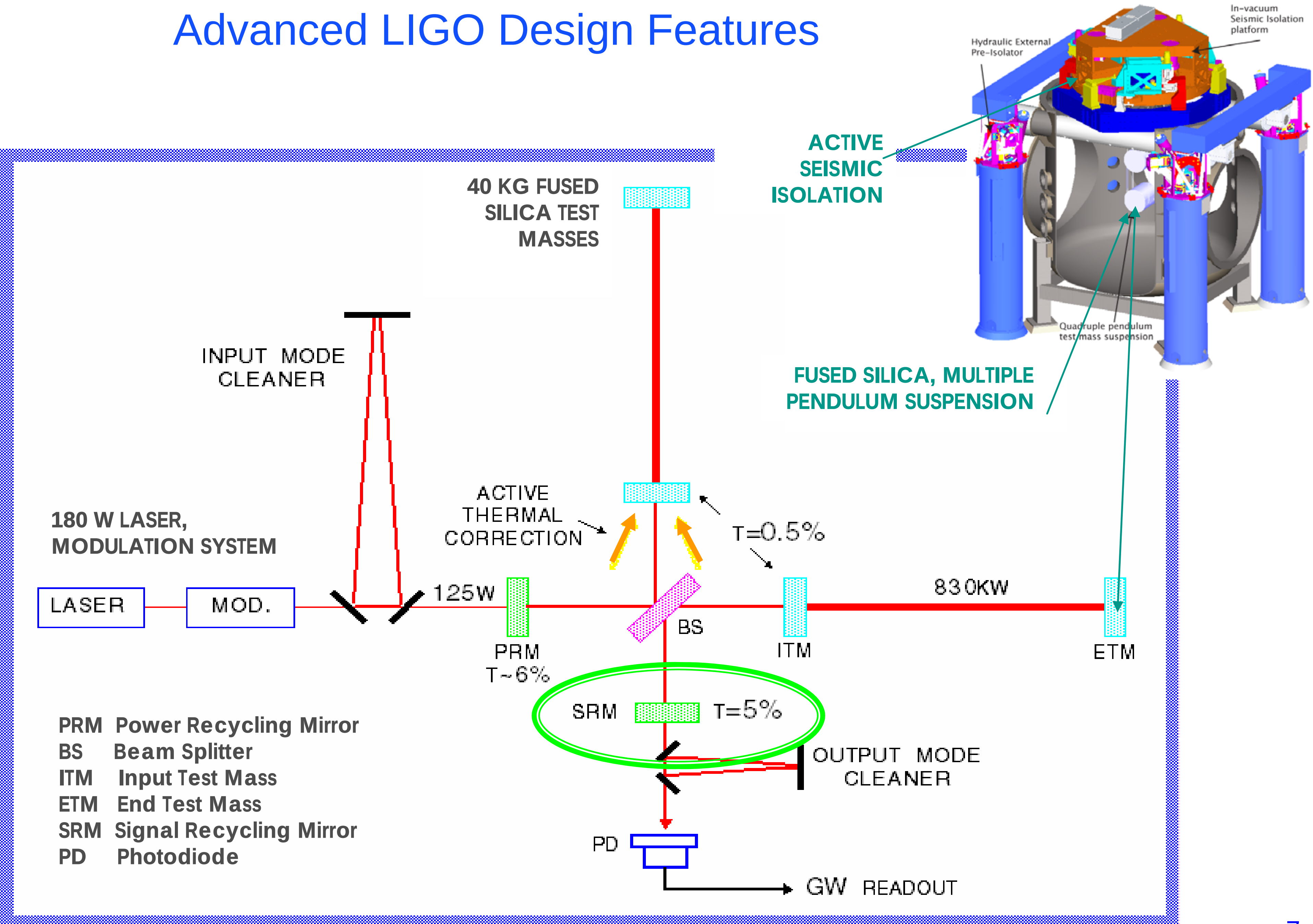
Parameter	LIGO I	Adv LIGO
Equivalent strain noise, minimum	$3x10^{-23}$/rtHz	$2x10^{-24}$/rtHz
Neutron star binary inspiral range	15 Mpc	175 Mpc
Omega GW	$3x10^{-6}$	$1.5\text{-}5x10^{-9}$
Interferometer configuration	Power-recycled MI w/ FP arm cavities	LIGO I, plus signal recycling
Laser Power in Arm Cavities	15 kW	800 kW
Test masses	Fused silica, 10 kg	Fused Silica, 40 kg
Seismic wall frequency	40 Hz	10 Hz
Beam size	4 cm	6 cm
Test mass Q	Few million	200 million
Suspension fiber Q	Few thousand	~30 million

Anatomy of the projected Adv LIGO detector performance

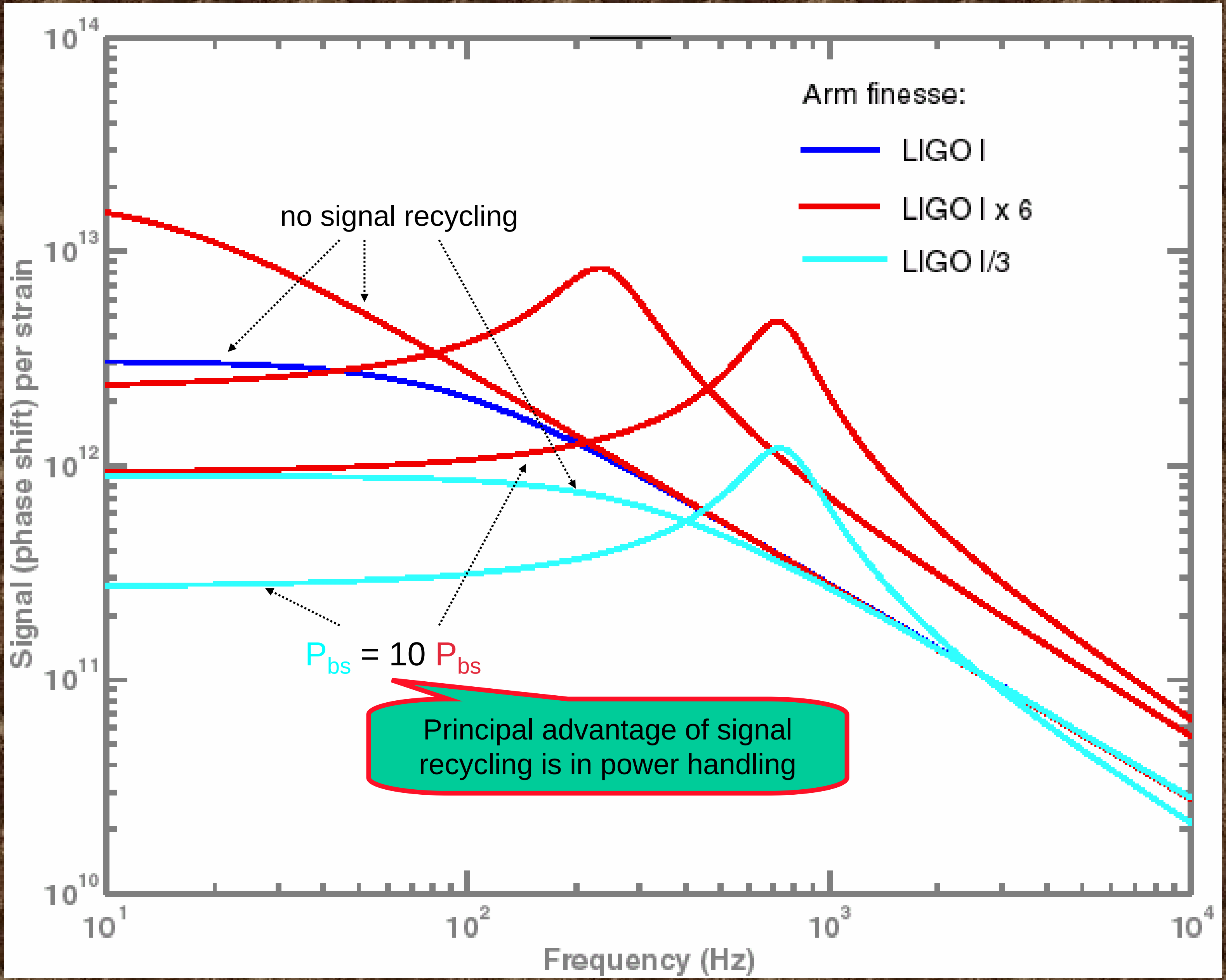
- Newtonian background, estimate for LIGO sites
- Seismic ‘cutoff’ at 10 Hz
- Suspension thermal noise
- Test mass thermal noise
- Unified quantum noise dominates at most frequencies for full power, broadband tuning



Advanced LIGO Design Features

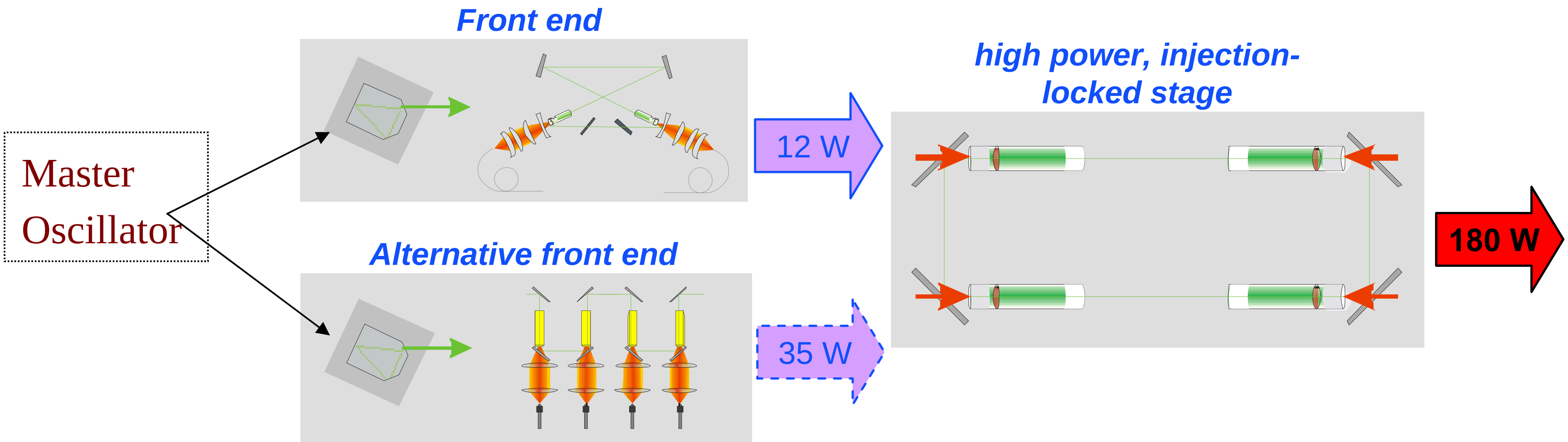


Why use Signal Recycling?



Ultra Stable Laser

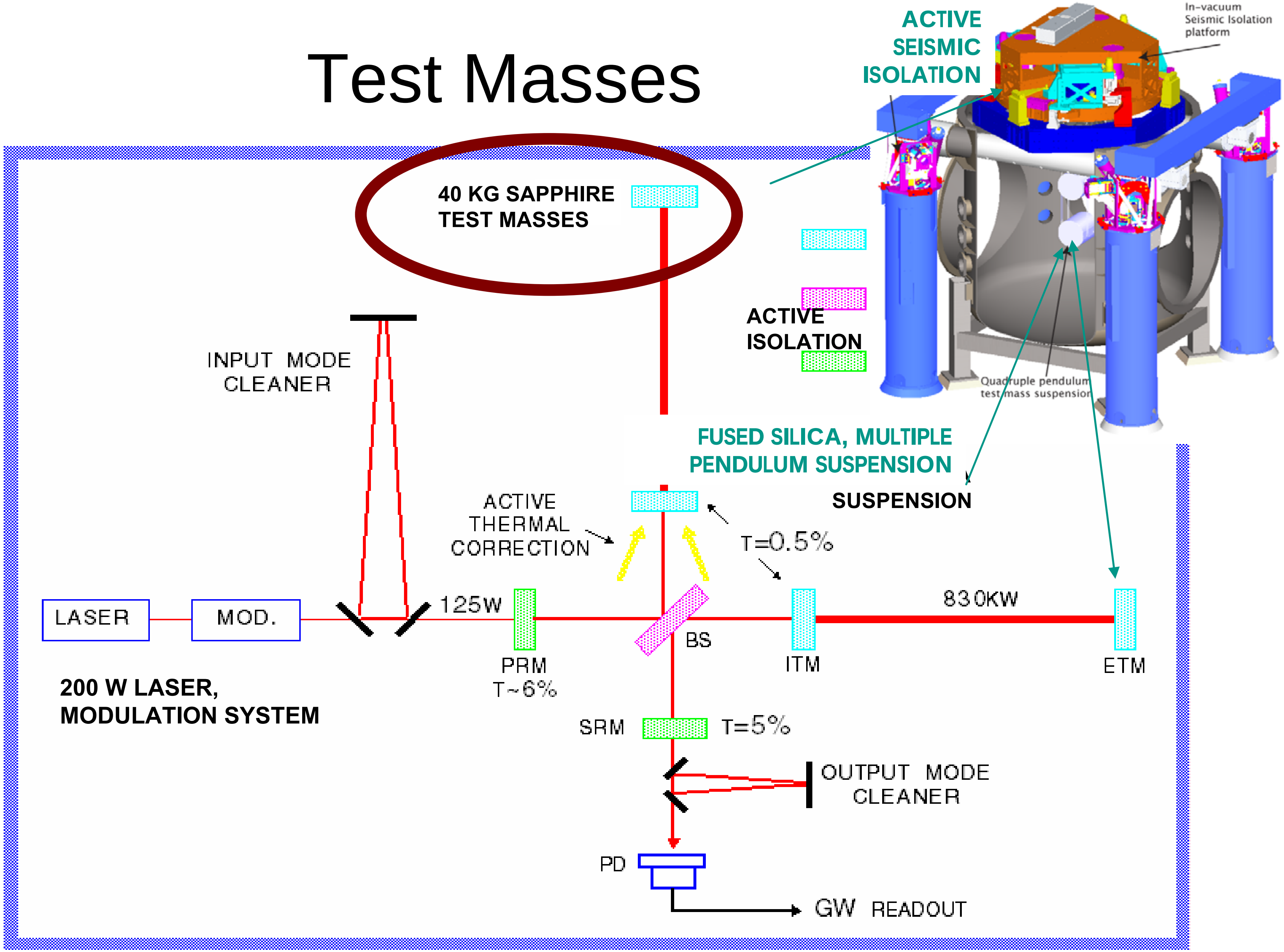
- High power laser: 180 Watts



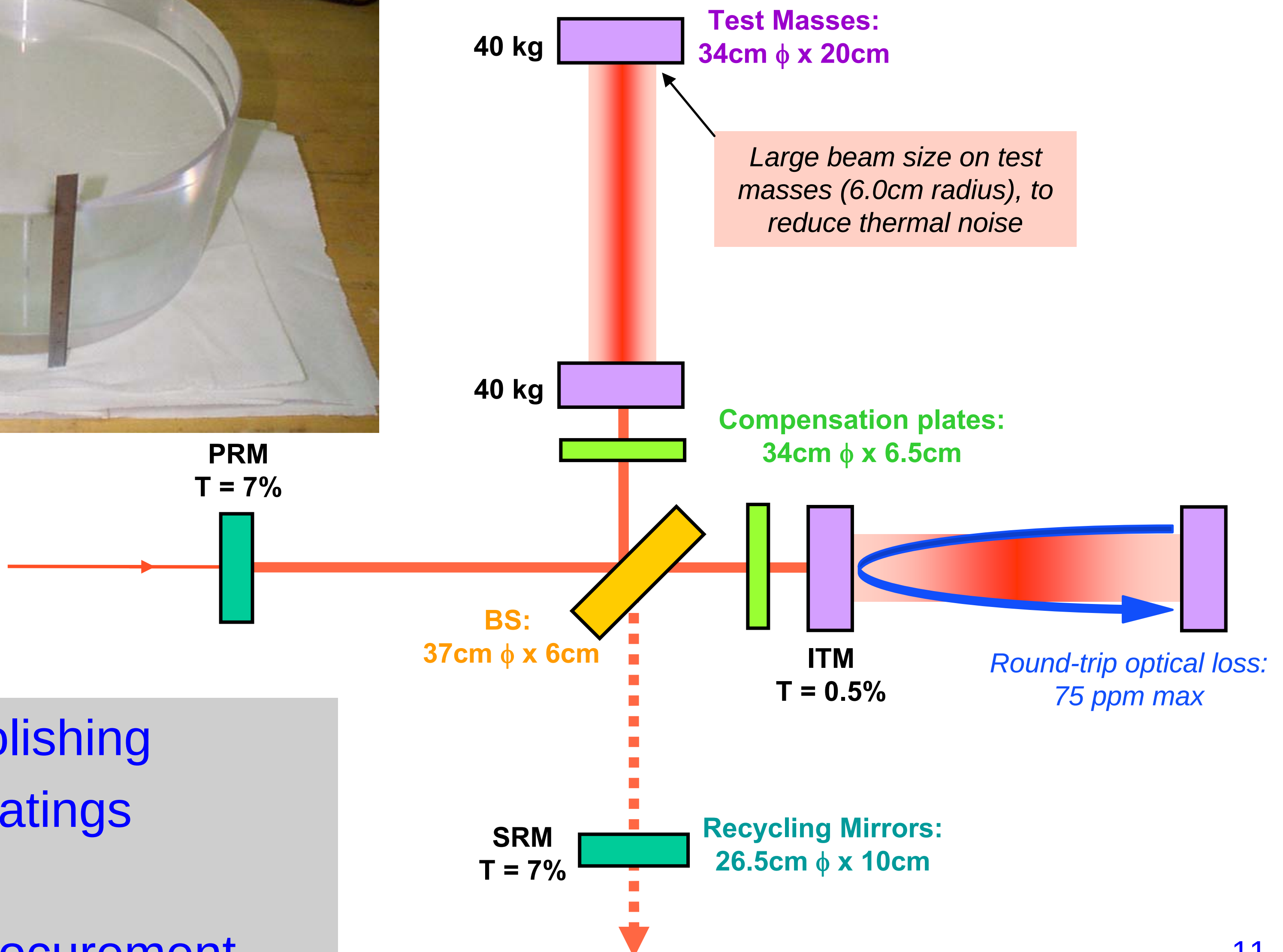
- Laser power stabilization (relative power fluctuations ~ 2 x 10^{-9})
- Laser frequency stabilization
  - » Wideband frequency actuation for further stabilization (~ 10^{-7} Hz/rHz)
- Pre-mode cleaner for spatial clean-up and high-frequency filtering

Work lead by AEI (Hanover) in collaboration with LZH (Laser Zentrum Hanover)

Test Masses


ACTIVE
SEISMIC
ISOLATION
In-vacuum
Seismic Isolation
platform
40 KG SAPPHIRE
TEST MASSES
ACTIVE
ISOLATION
Quadruple pendulum
test mass suspension
INPUT MODE
CLEANER
FUSED SILICA, MULTIPLE
PENDULUM SUSPENSION
SUSPENSION
ACTIVE
THERMAL
CORRECTION
T=0.5%
LASER
MOD.
125W
830KW
BS
PRM
T~6%
ITM
ETM
200 W LASER,
MODULATION SYSTEM
SRM
T=5%
OUTPUT MODE
CLEANER
PD
GW READOUT

Core Interferometer Optics



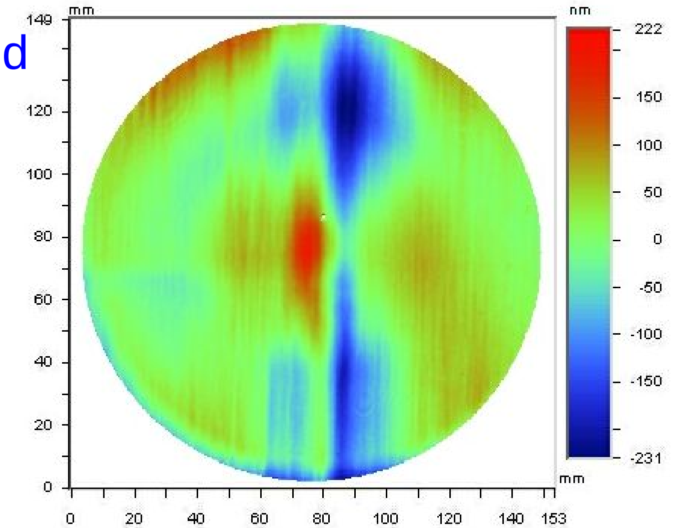
Challenges:

- Substrate polishing
- Dielectric coatings
- Metrology
- Substrate procurement

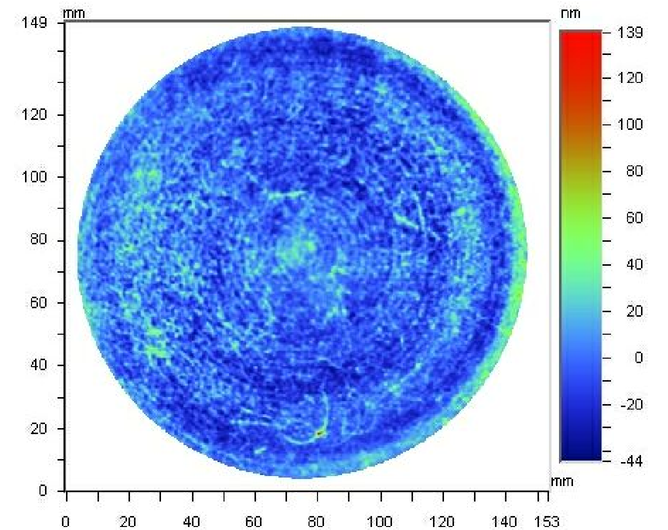
Core Optics

- Substrates
  - » Fused silica: Heraeus (for low absorption) or Corning
  - » Specific grade and absorption depends on optics
  - » ITMs and BS most critical (need low absorption and good homogeneity)
- Polishing
  - » Low micro-roughness (< 1 angstrom-rms)
  - » Low residual figure distortion (< 1 nm-rms over central 120mm diameter)
  - » Accurate matching of radii-of-curvature
  - » Surfaces for attachment of suspension fibers
- Dielectric coatings
  - » Low absorption (0.5 ppm or smaller)
  - » Low scatter (< 30 ppm)
  - » Low mechanical loss (< 2e-4)
- In-house Metrology
  - » ROC, figure distortion, scattering, absorption

Compensation Polish

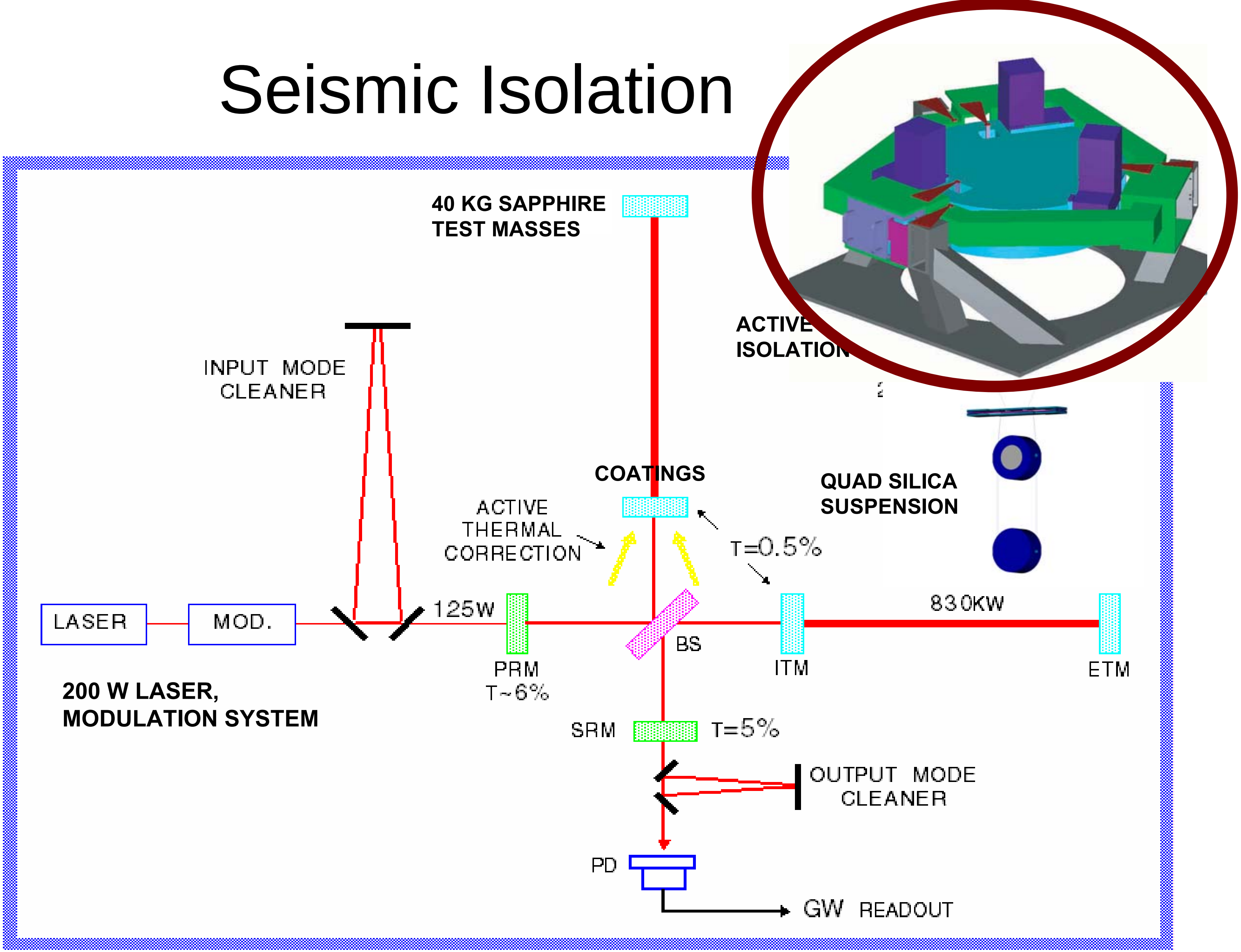


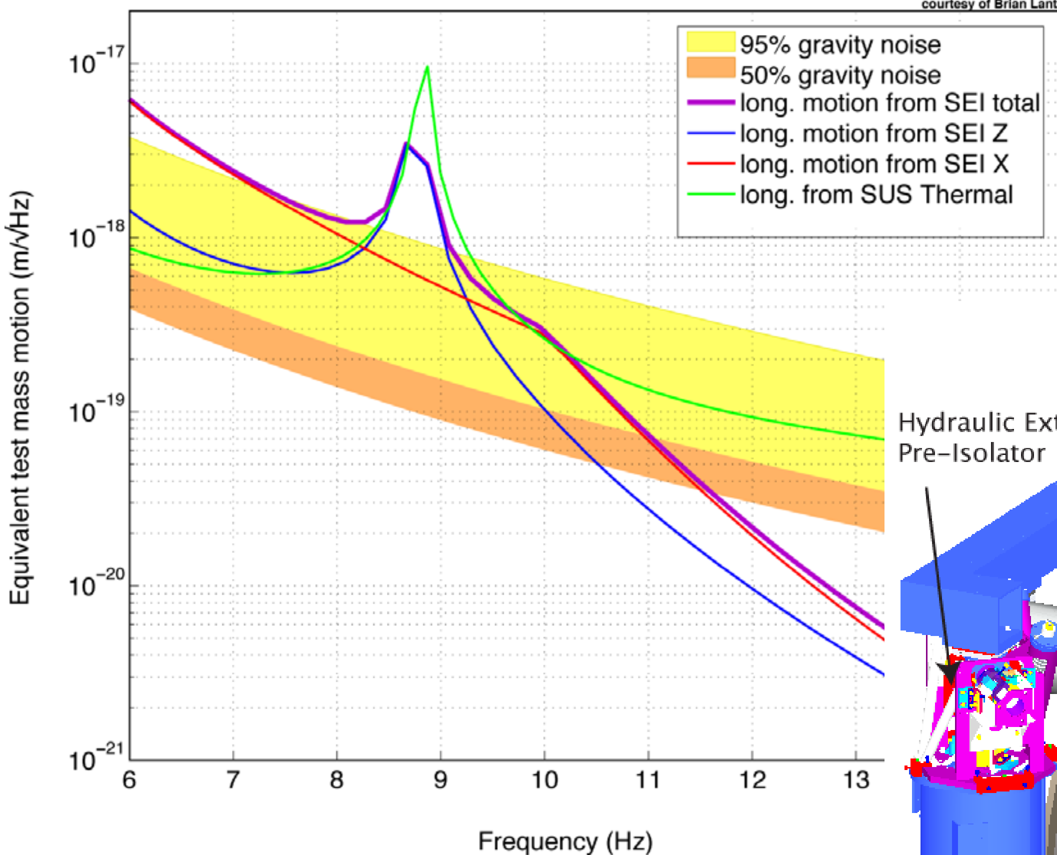
before

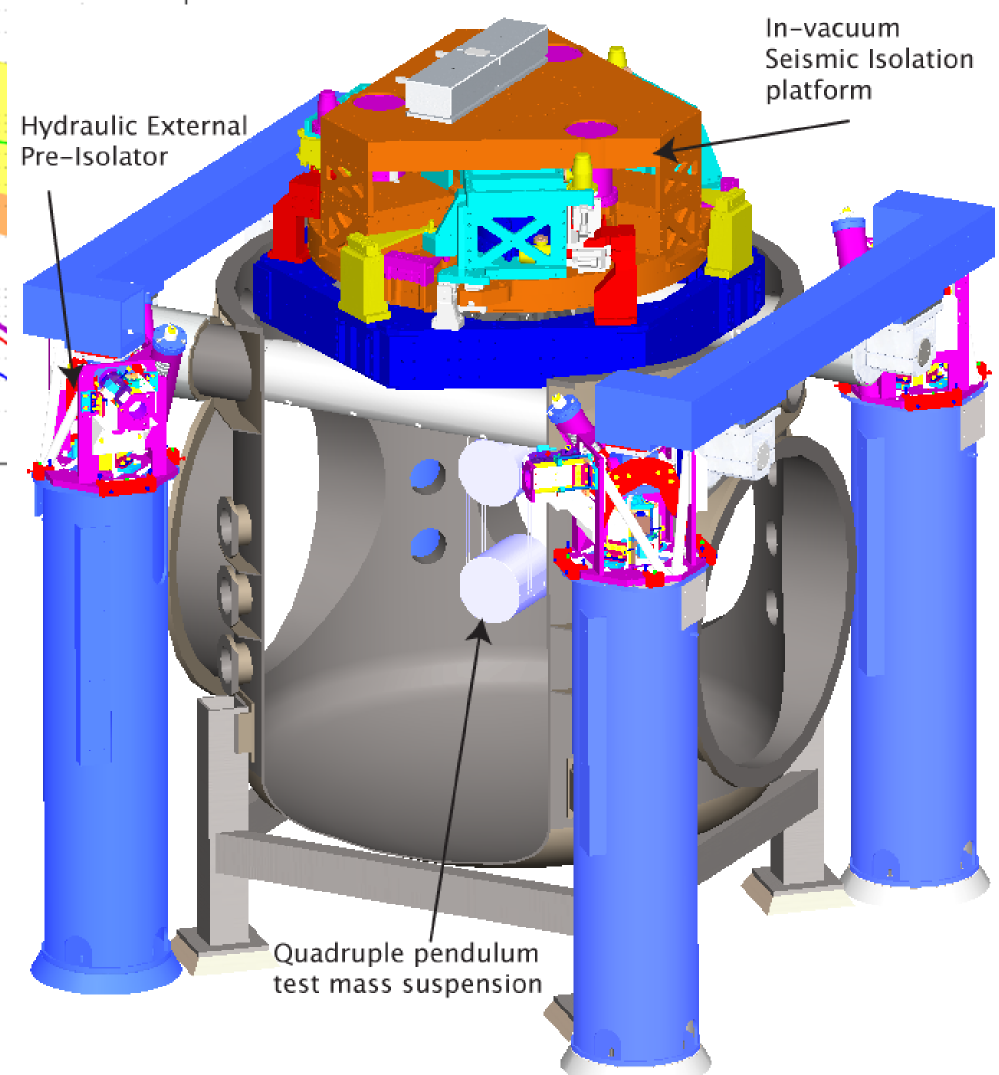


after

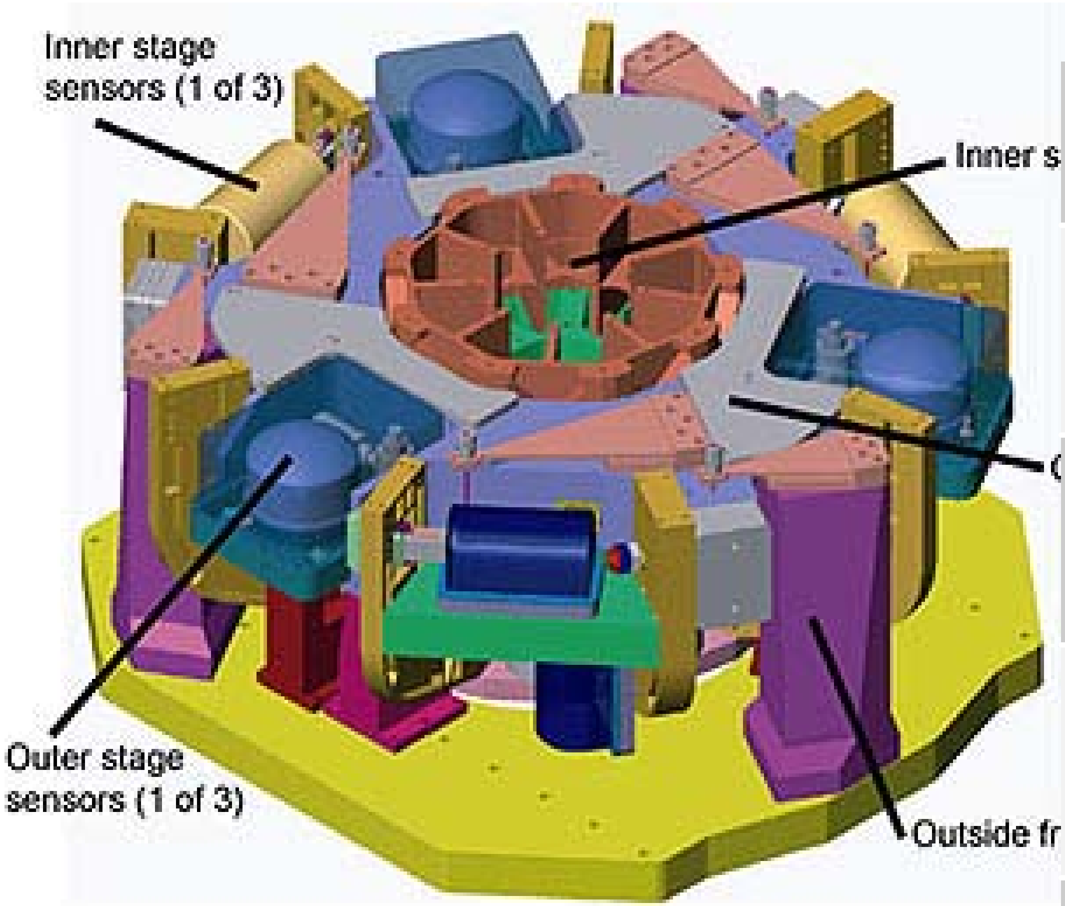
Seismic Isolation




courtesy of Brian Lantz
95% gravity noise
50% gravity noise
long. motion from SEI total
long. motion from SEI Z
long. motion from SEI X
long. from SUS Thermal
Equivalent test mass motion (m/√Hz)
Frequency (Hz)

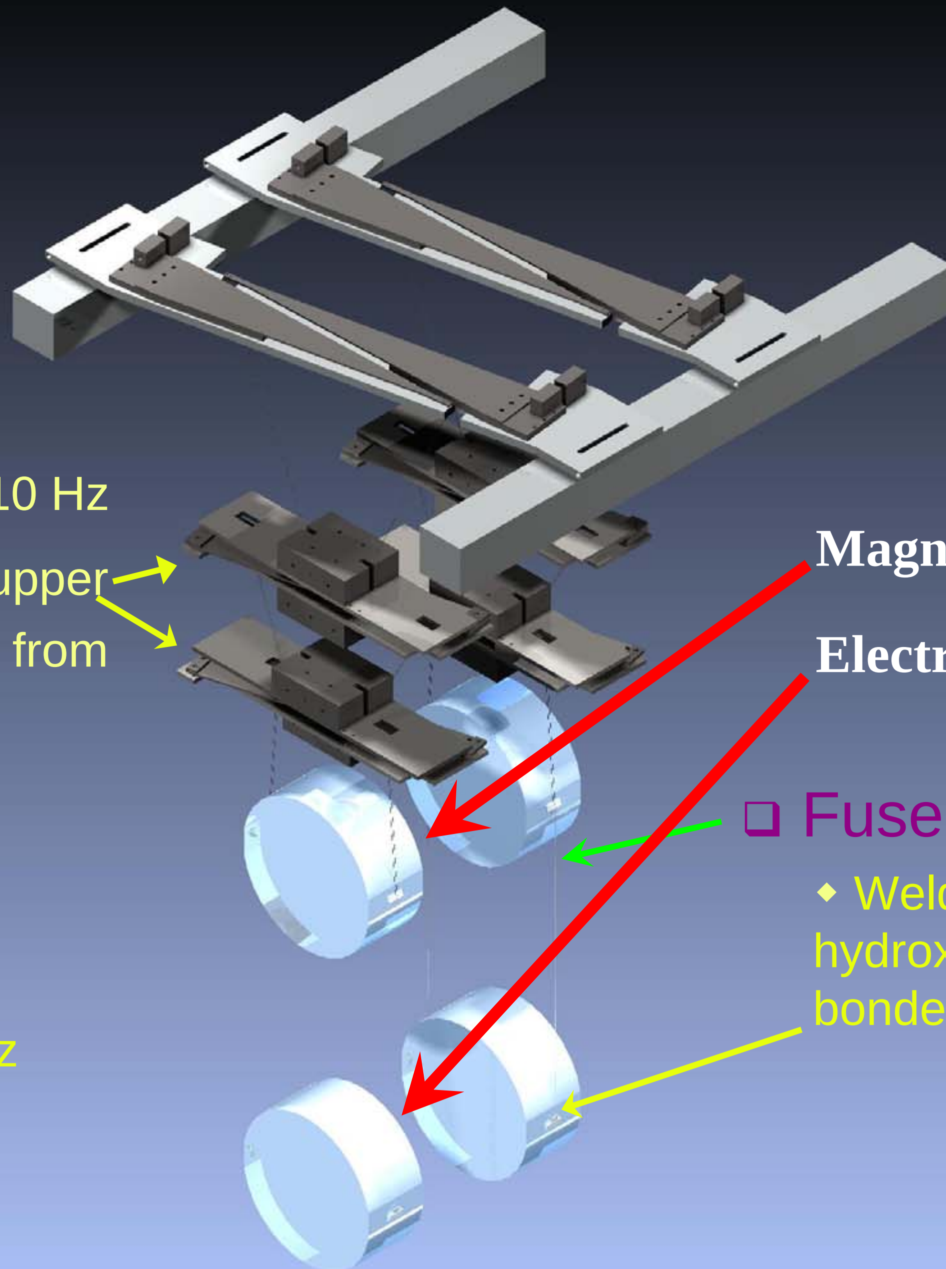

In-vacuum
Seismic Isolation
platform
Hydraulic External
Pre-Isolator
Quadruple pendulum
test mass suspension

Seismic Isolation: Active Platform



Requirement		BSC Chamber Value
Payload Mass		**800 kg**
Range		**± 1 mm, ± 0.5 mrad**
Table Noise		**3×10^{-13} m/√Hz @10 Hz**
Angular Noise		**10 nrad RMS**

Quad Suspensions



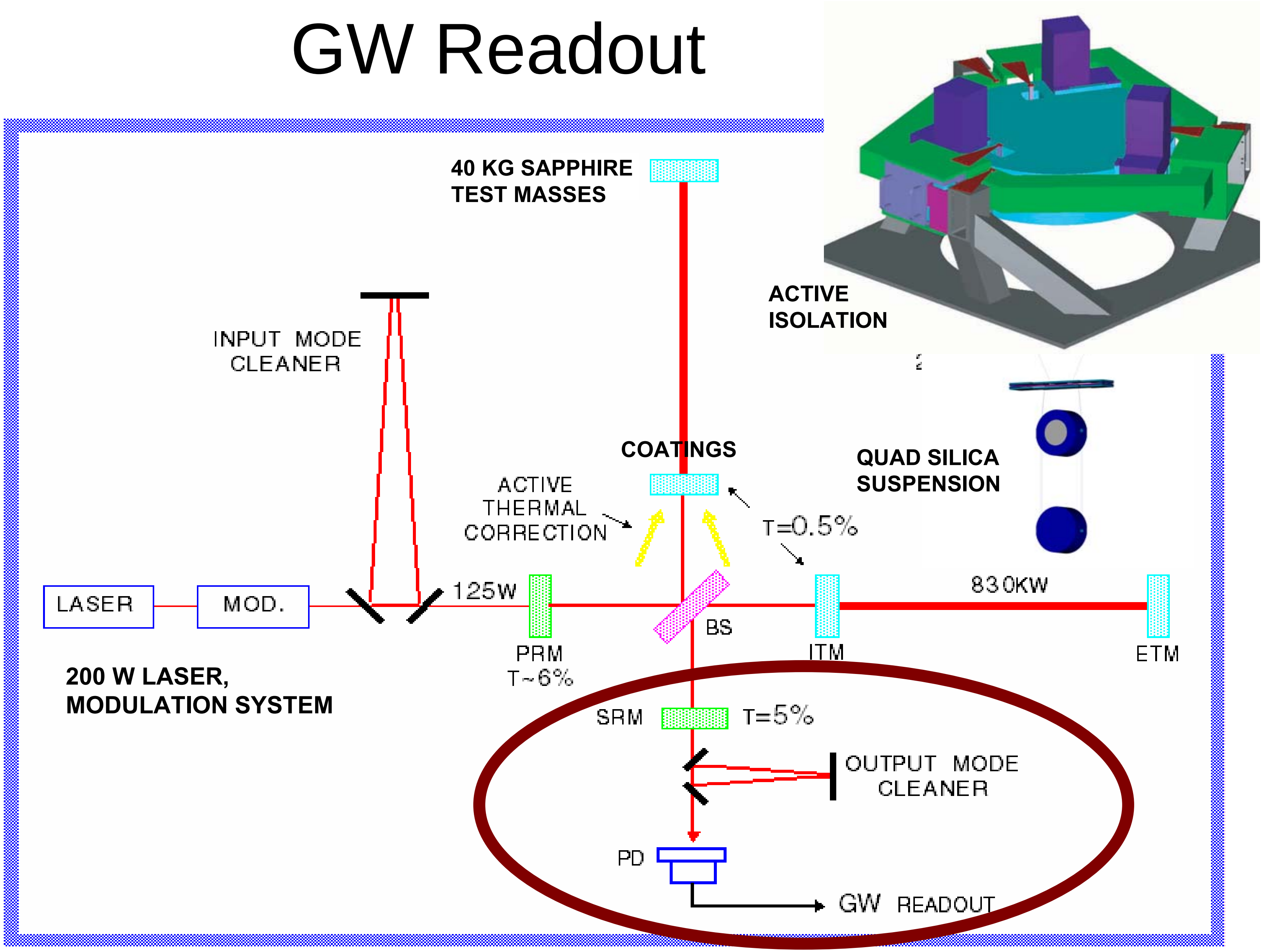
- Quadruple pendulum:
  - » ~10^7 attenuation @10 Hz
  - » Controls applied to upper layers; noise filtered from test masses
- Seismic isolation and suspension together:
  - » 10^{-19} m/rtHz at 10 Hz

Magnets

Electrostatic

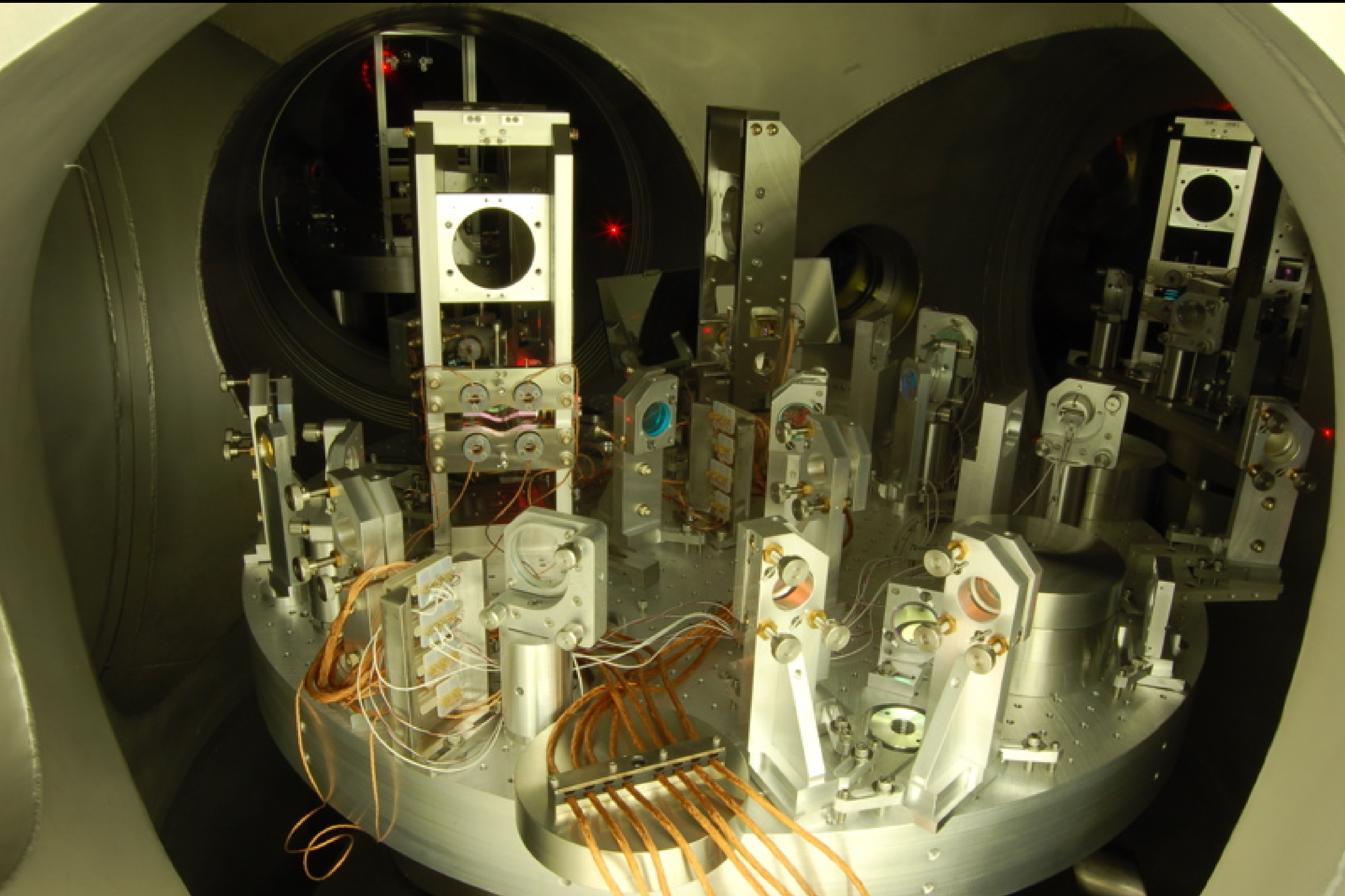
- Fused silica fiber
  - Welded to ‘ears’, hydroxy-catalysis bonded to optic

GW Readout


40 KG SAPPHIRE
TEST MASSES
ACTIVE
ISOLATION
INPUT MODE
CLEANER
COATINGS
QUAD SILICA
SUSPENSION
ACTIVE
THERMAL
CORRECTION
T=0.5%
LASER
MOD.
125W
830KW
BS
PRM
T~6%
ITM
ETM
200 W LASER,
MODULATION SYSTEM
SRM
T=5%
OUTPUT MODE
CLEANER
PD
GW READOUT

@ the Caltech 40m Lab

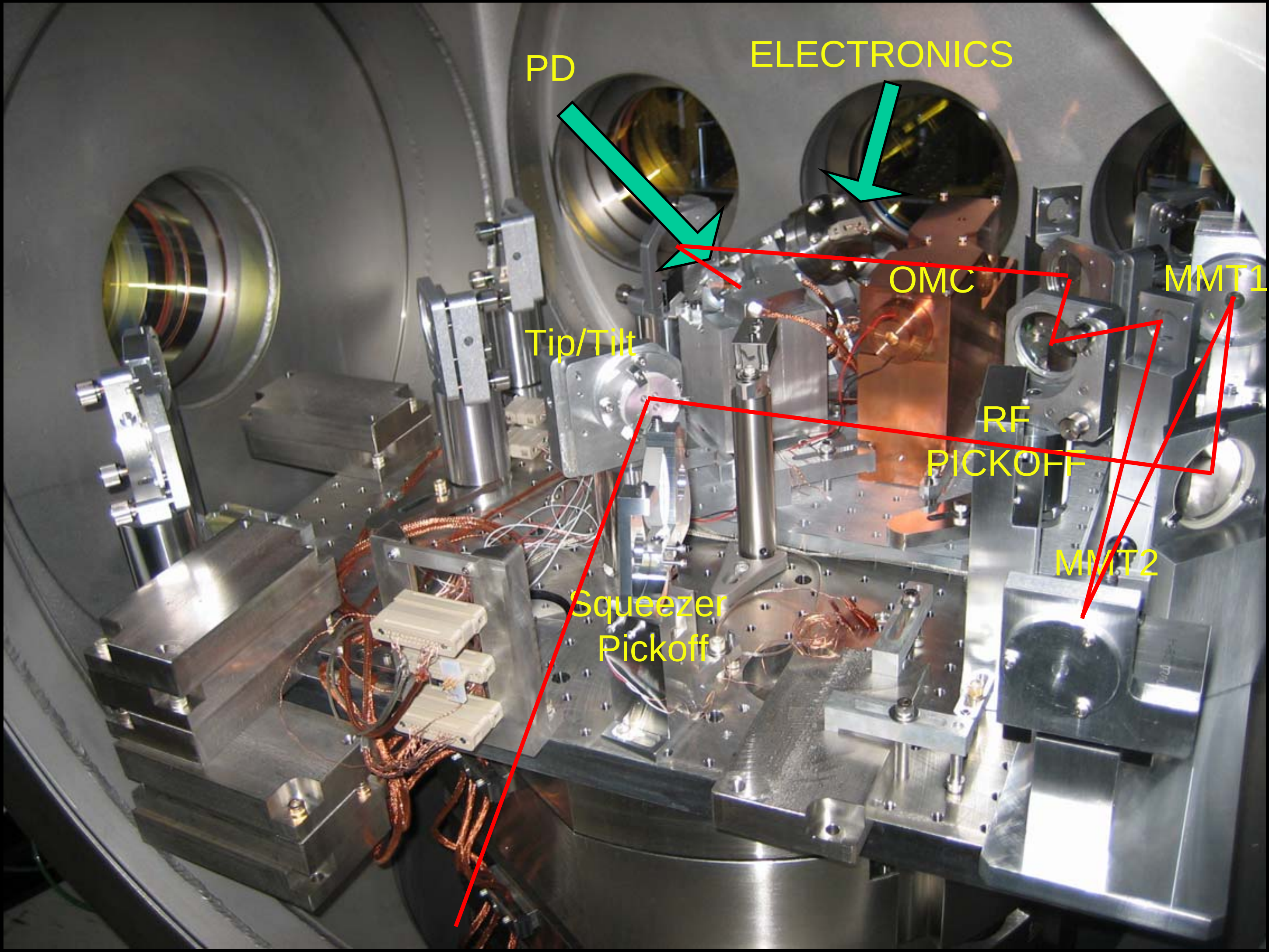
@ the Caltech 40m Lab



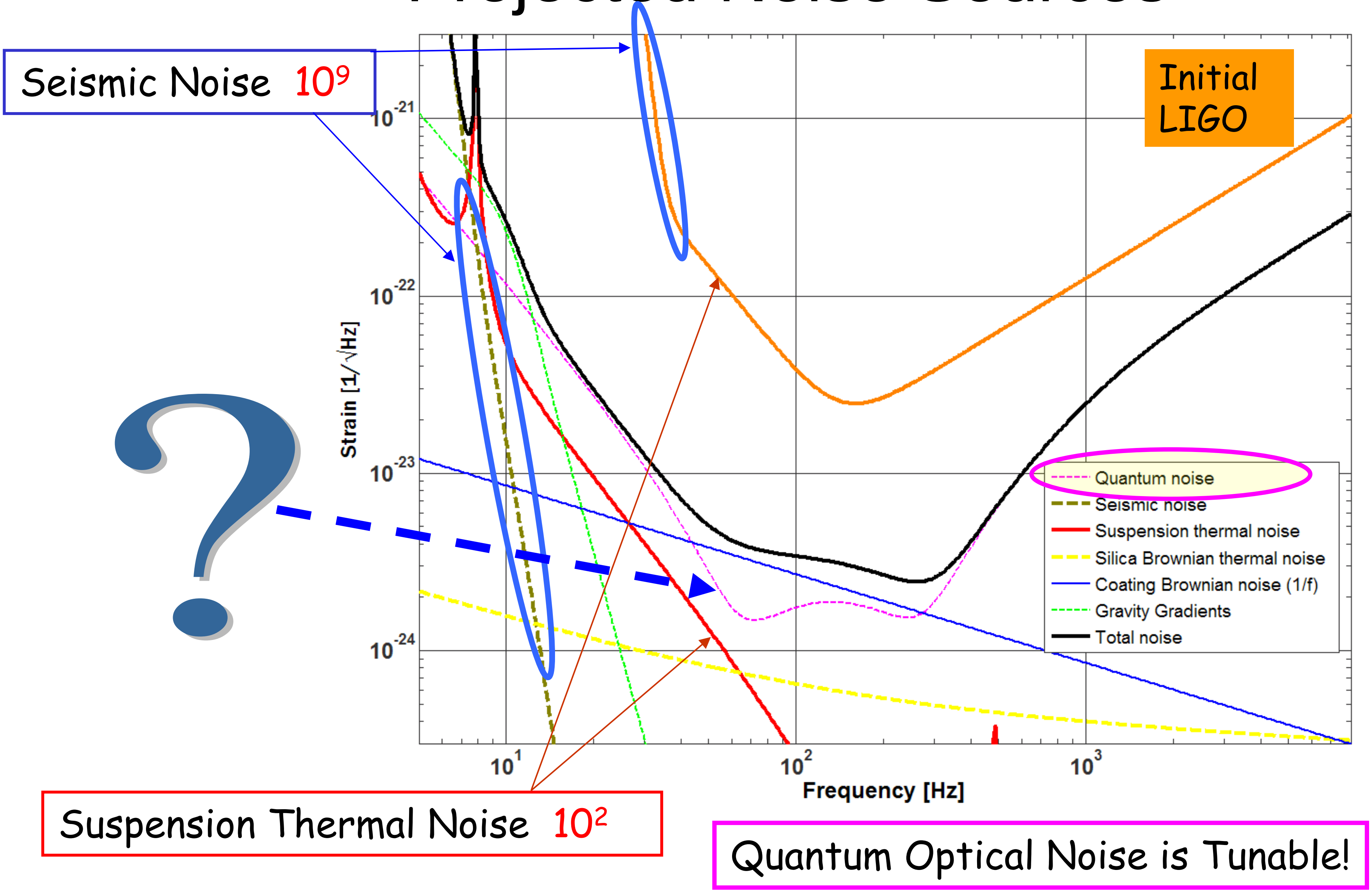
@ the Caltech 40m Lab

DC Readout Beamline

Controls and Noise Characterization Prototype



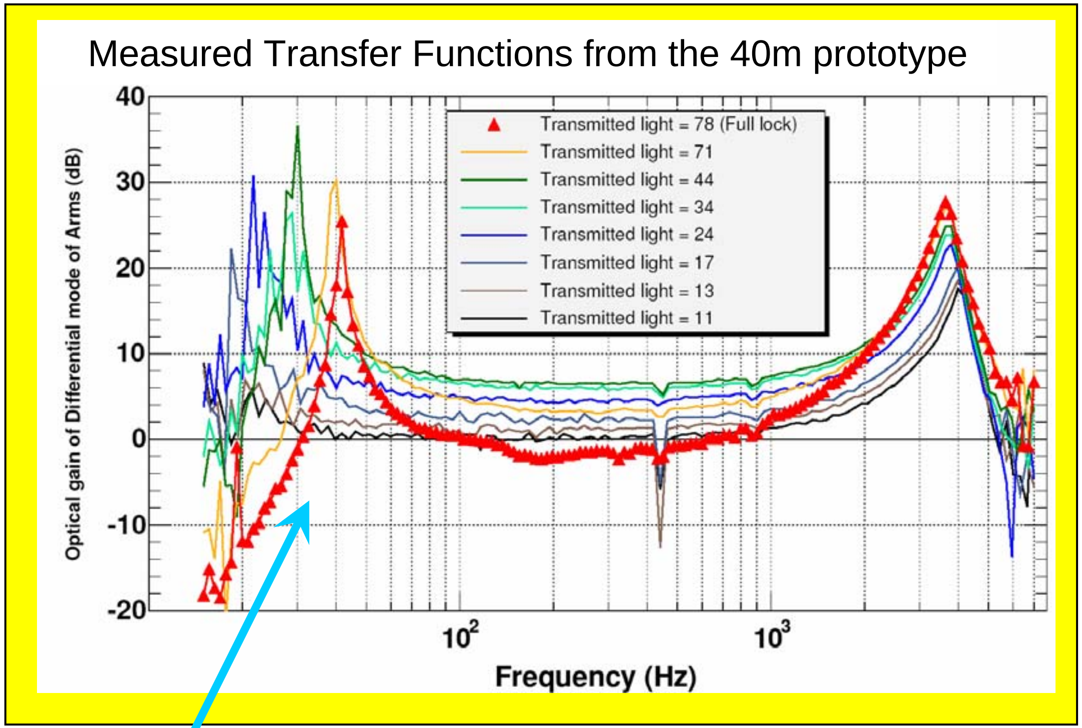
Projected Noise Sources



Opto-mechanical Spring

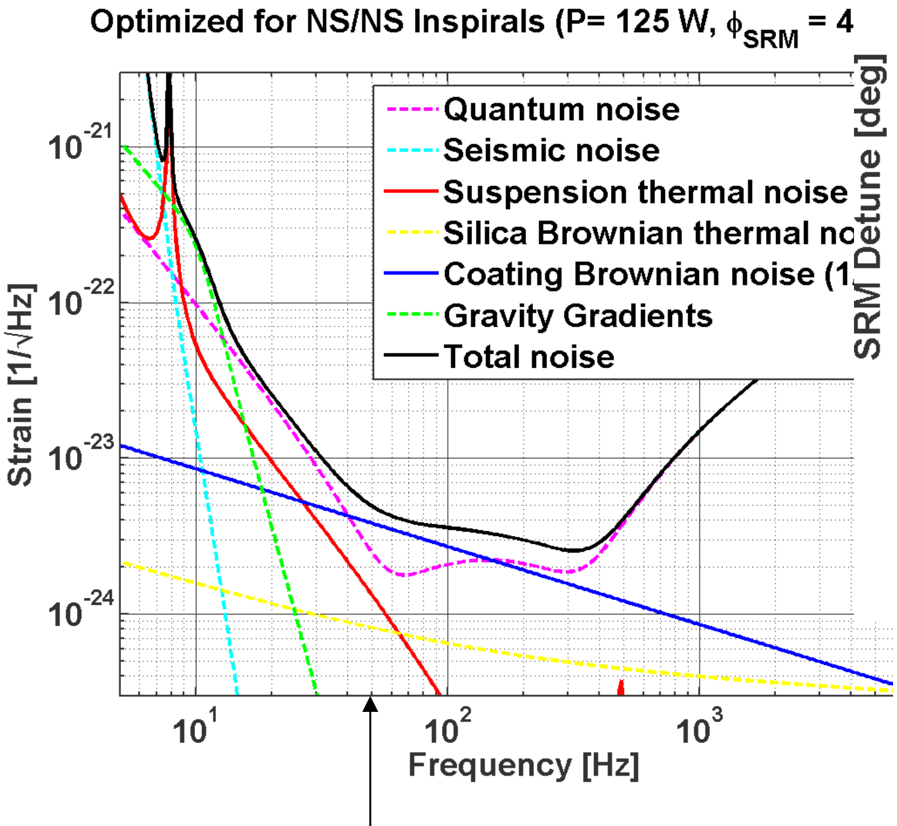
Radiation pressure:
F = 2 P / c
Detuned Cavity -> dF/dx

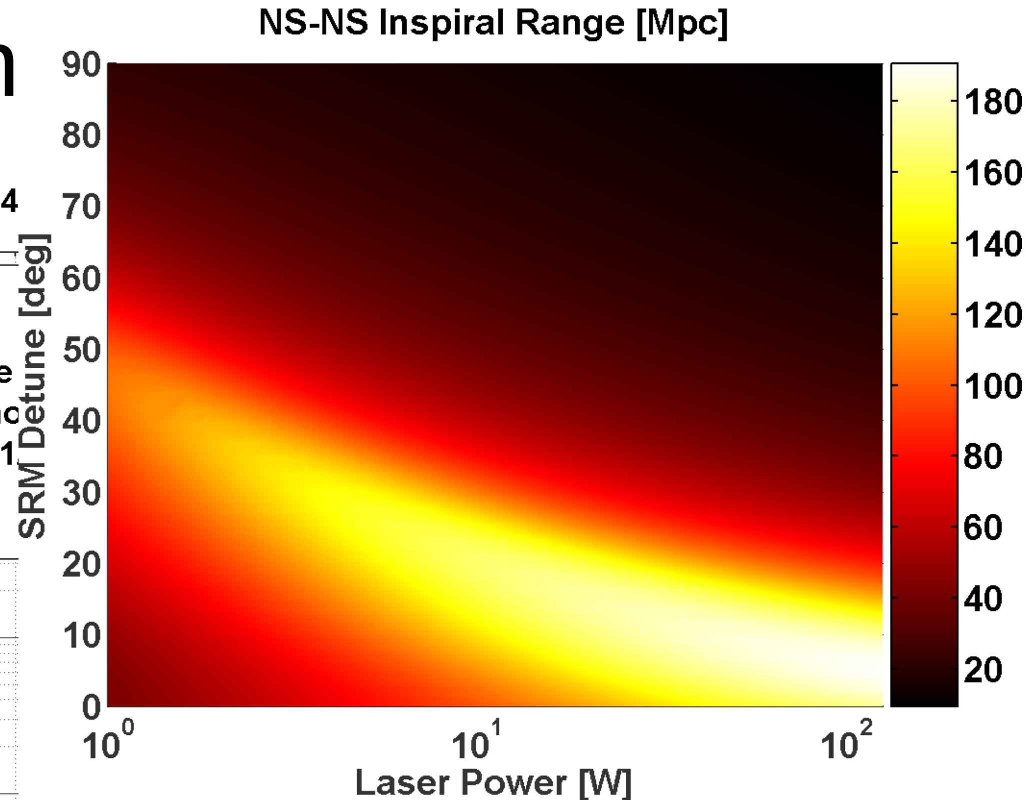
- ½ MW in the arms ->
- 'Optical Bar' detector
- ~75 Hz unstable opto-mechanical resonance
- High Bandwidth servos



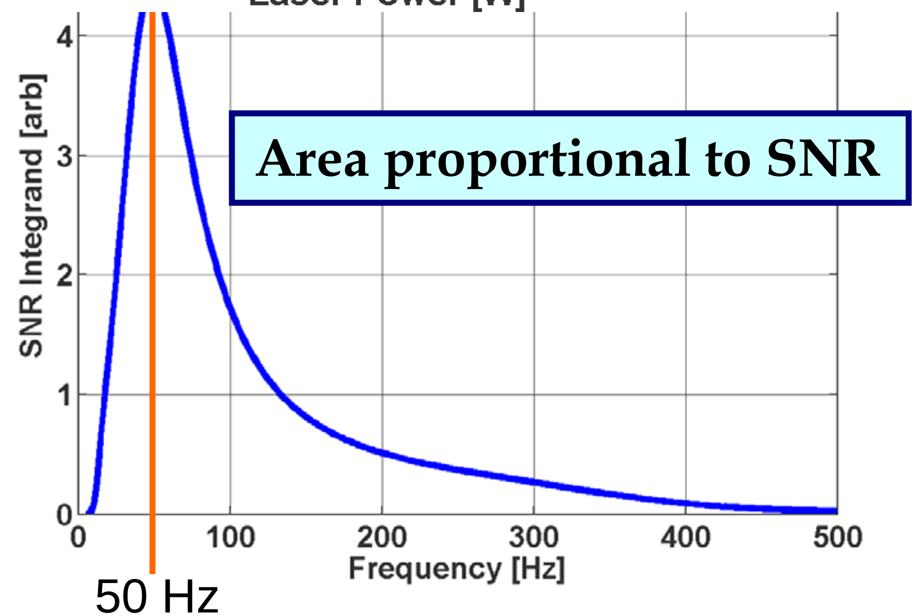
Optical Spring stiffness ~ 10^7 N/m
BMW Z4 ~ 10^4 N/m
Angular spring resonance ~ 2 Hz

NS/NS Bin

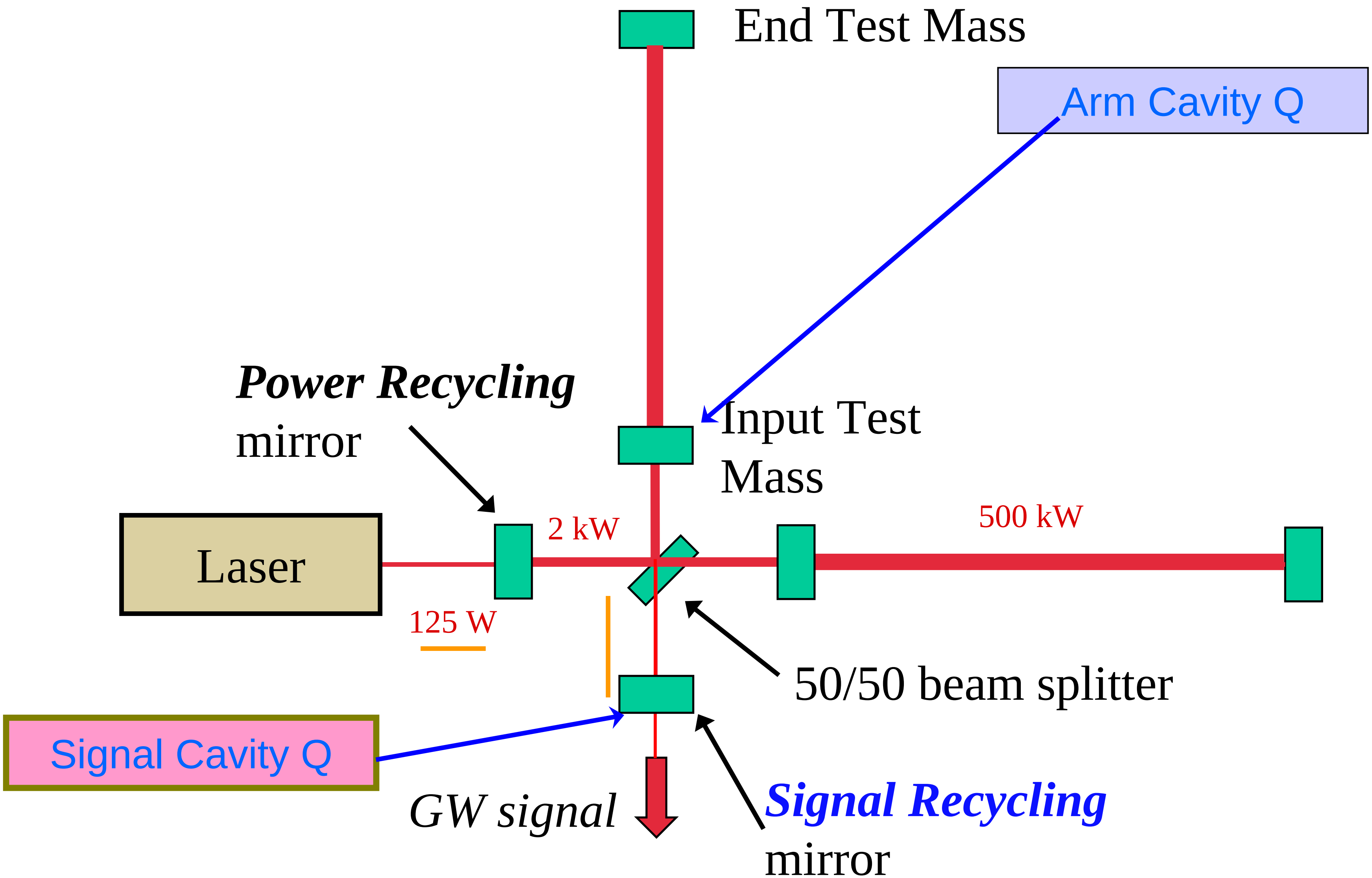




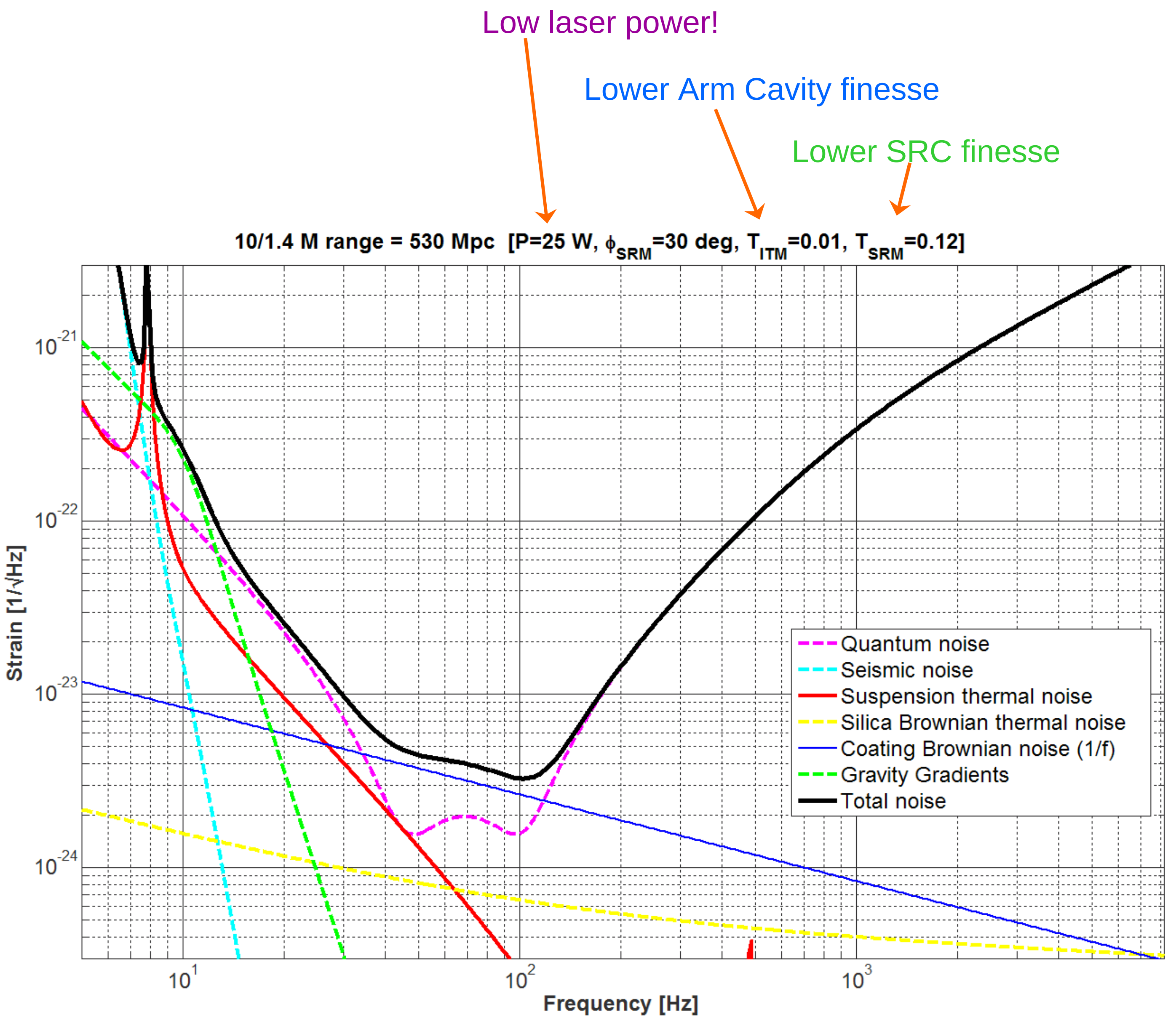
Most of the sensitivity comes from a band around 50 Hz



There’s more…


End Test Mass
Arm Cavity Q
Power Recycling
mirror
Input Test
Mass
500 kW
2 kW
Laser
125 W
50/50 beam splitter
Signal Cavity Q
GW signal
Signal Recycling
mirror

30% Sensitivity Improvement



Advanced LIGO

- Initial instruments, data helping to establish the field of interferometric GW detection
- Advanced LIGO promises exciting astrophysics
- Substantial progress in R&D, design
- Enhanced LIGO starts now!!
- Installation in 2011, Data ~2013-2014
- Steady stream of gravitational wave signals