Advanced LIGO Status Report

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On behalf of the LIGO Science Collaboration

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ESF PESC Exploratory
Workshop - Perugia Italy
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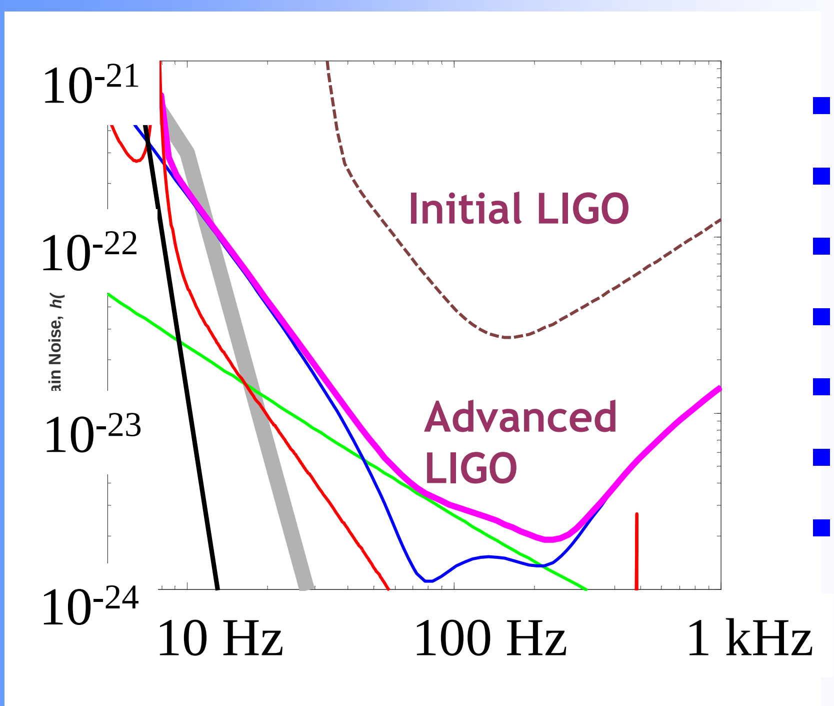
Advanced LIGO Overview

LIGO infrastructure designed for a progression of instruments

- Nominal 30 year lifetime

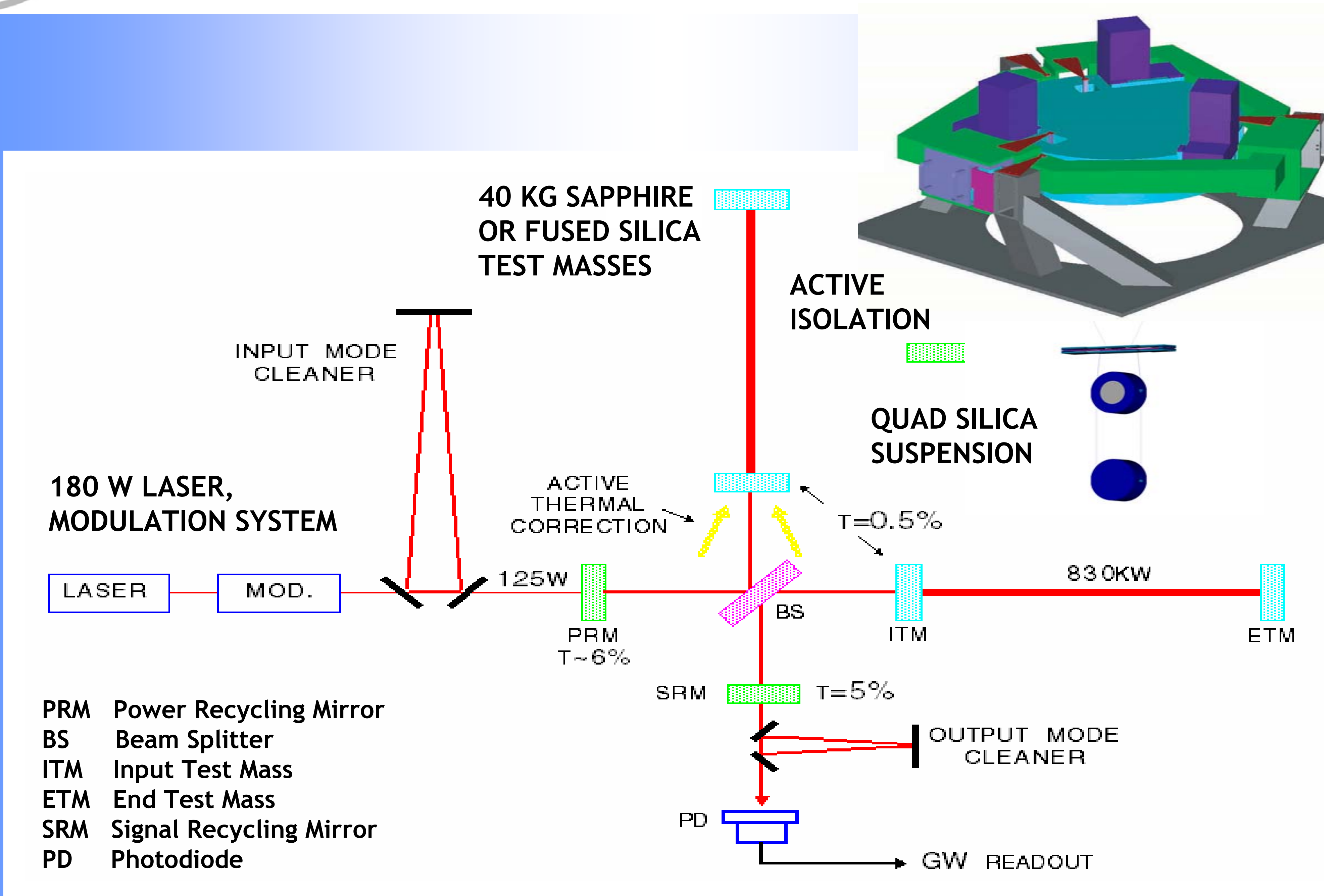
Initial LIGO planned (and required) to run at design sensitivity for 1 integrated year

- Will begin end of 2005



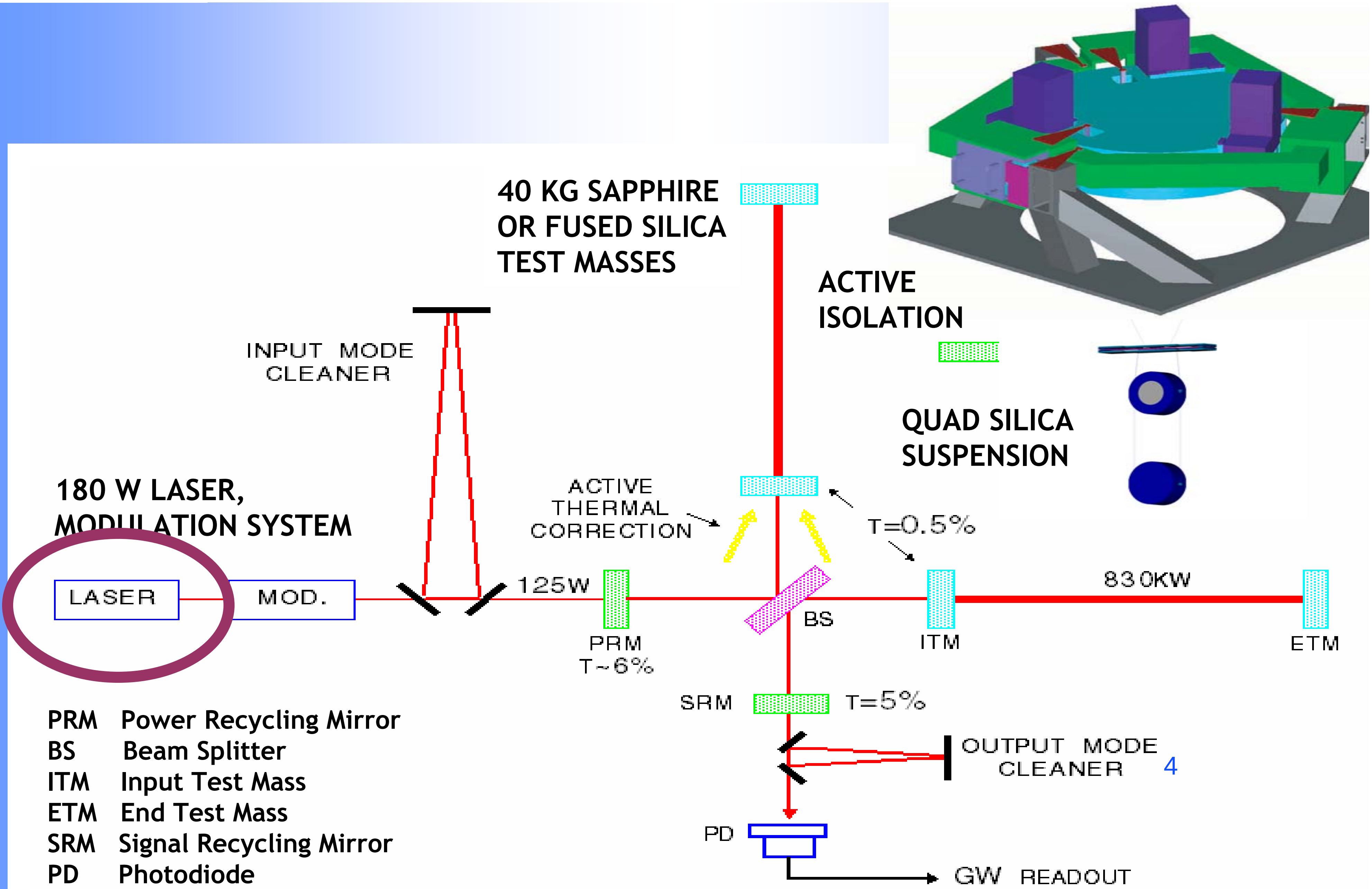
- **Second generation interferometer**
- **Quantum noise limited in much of band**
- **Signal recycling mirror for tuned response**
- **Thermal noise in most sensitive region**
- **About factor of 10 better sensitivity**
- **Sensitive band down to ~ 10 Hz**
- **Detect neutron star inspirals out to about 200 Mpc**

LIGO Advanced LIGO Subsystems



LIGO

Prestabilized Laser



PRM Power Recycling Mirror
BS Beam Splitter
ITM Input Test Mass
ETM End Test Mass
SRM Signal Recycling Mirror
PD Photodiode

Prestabilized Laser

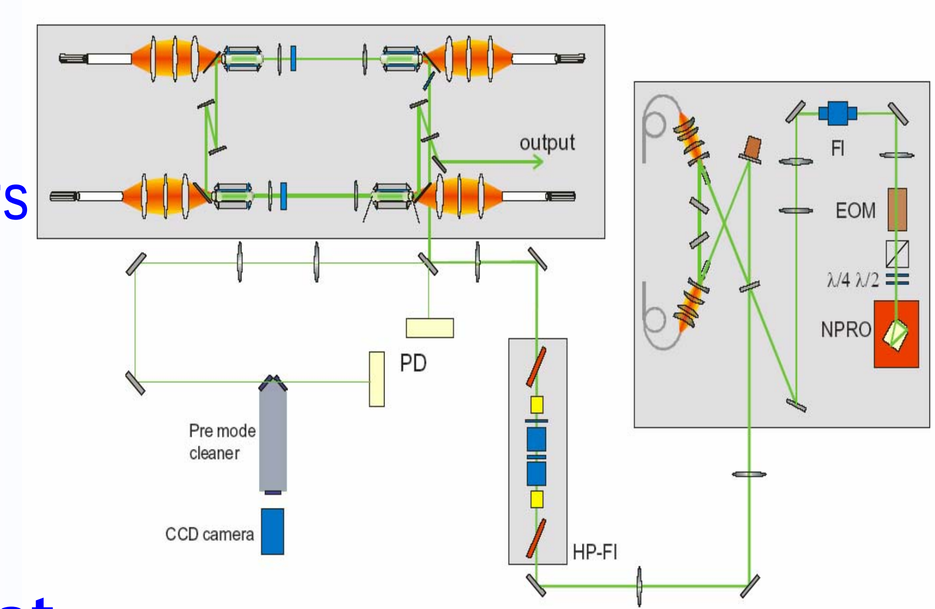
End-pumped Nd:YAG rod injection locked

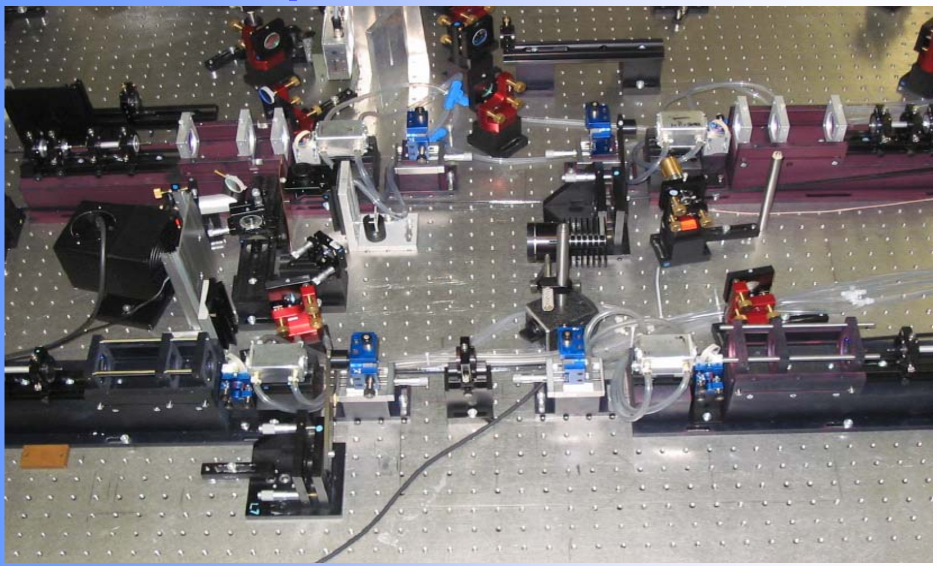
- Backup efforts in slabs & fiber lasers

Frequency stabilization

- 10 Hz/Hz$^{1/2}$ at 10 Hz required (10 Hz/Hz$^{1/2}$ at 12 Hz seen in initial LIGO)

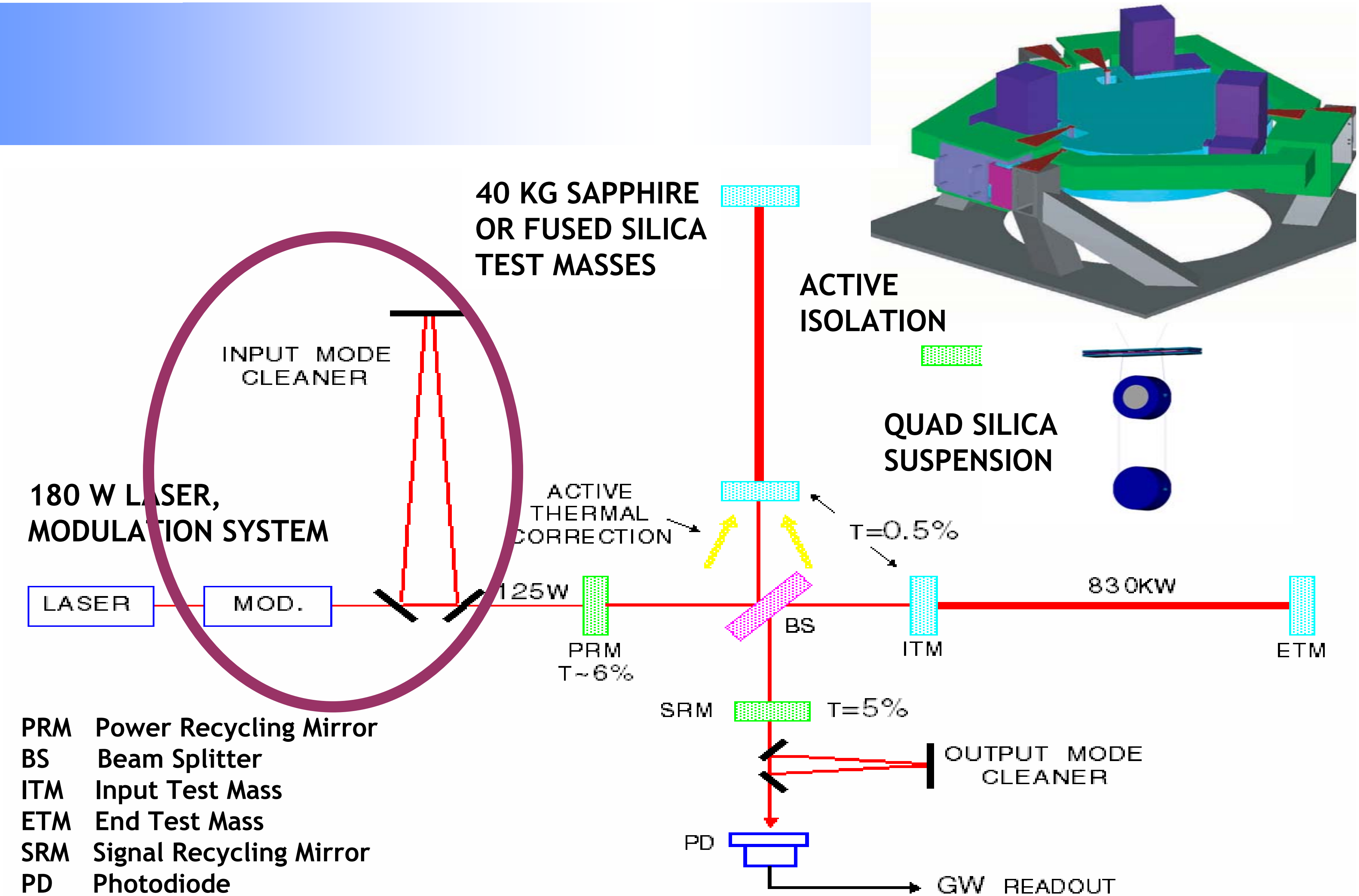
Intensity stabilization to 2x10^{-9} ΔP/P at 10 Hz required





- **Development at Max-Planck Hannover, Laser Zentrum Hannover**
- **Max Planck has granted funds for delivery of all PSLs**
- **Continued work on the mode shape of 200 W laser**

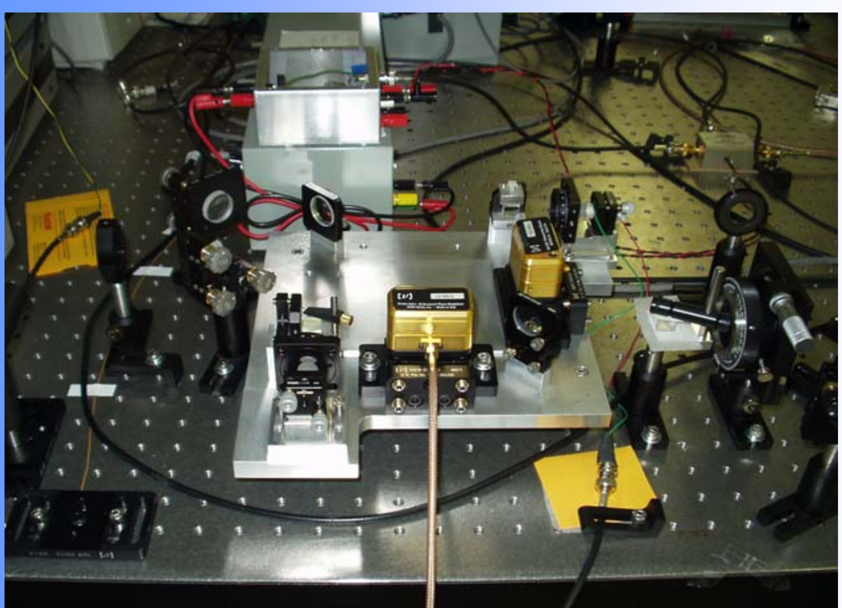
Input Optics



Input Optics

Design similar to initial LIGO
- 20X higher power
- Electo-optic modulators undamaged by 85 W for 400 hours

Mach-Zehnder modulation system
- Eliminates sidebands on sidebands
- Theoretical investigations of noise
- Prototype developed

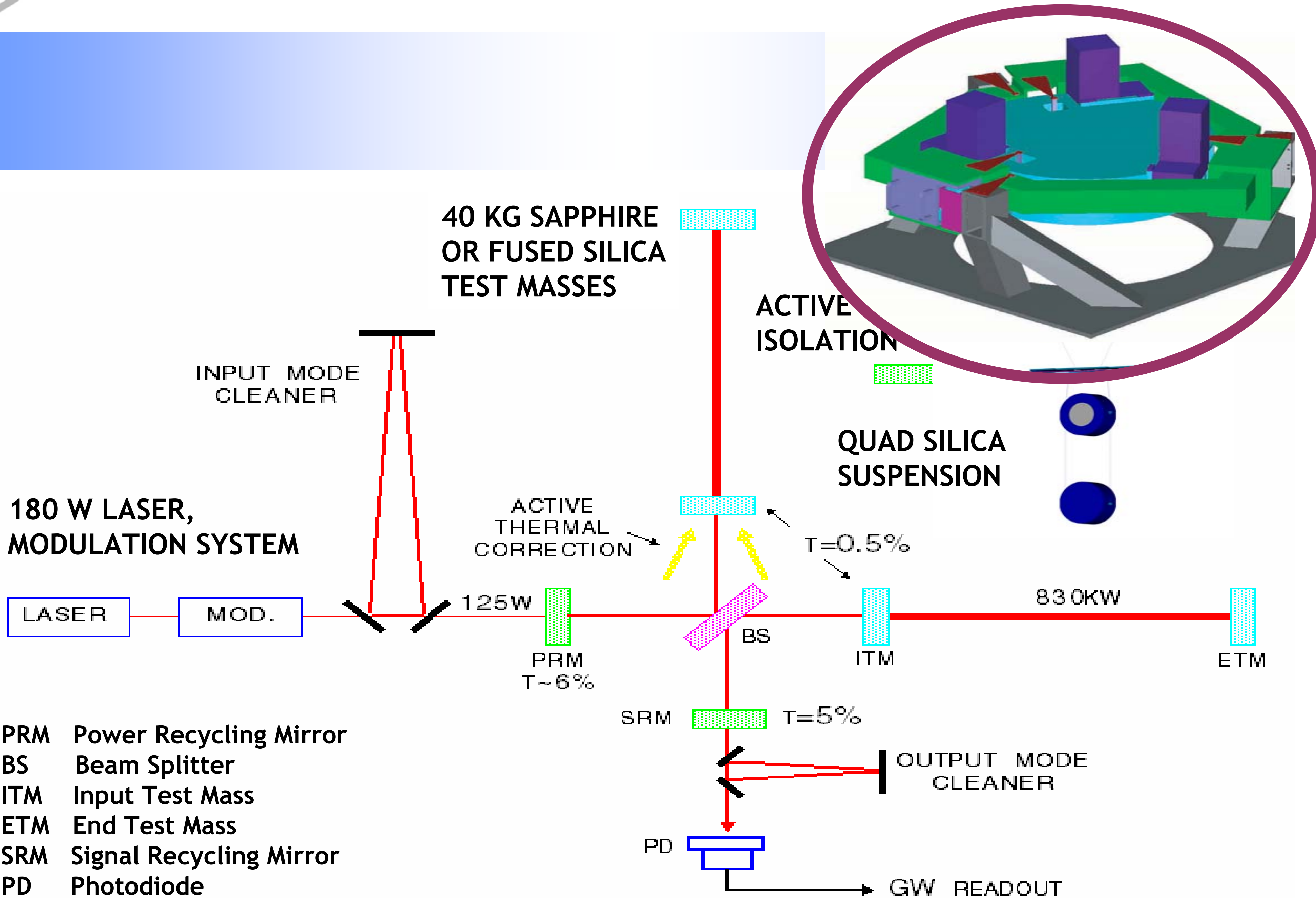


Faraday Isolator
- 20 mm aperture with thermal lensing & depolarization compensation

Adaptive Mode Matching Telescope
- Silica optics with CO_2 laser heating

Modeling indicates 1 ppm loss tolerable in mode cleaner

Seismic Isolation



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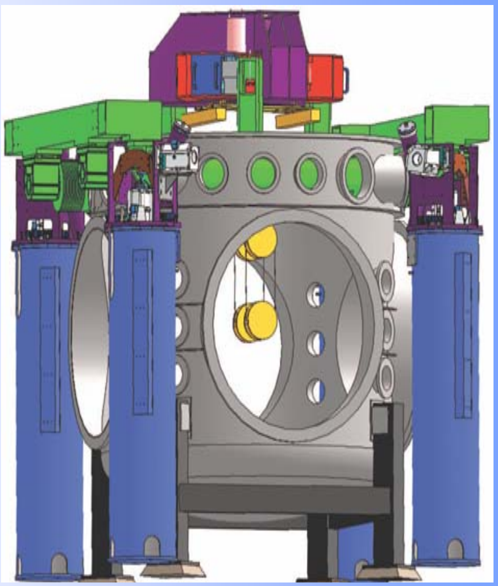
Seismic Isolation

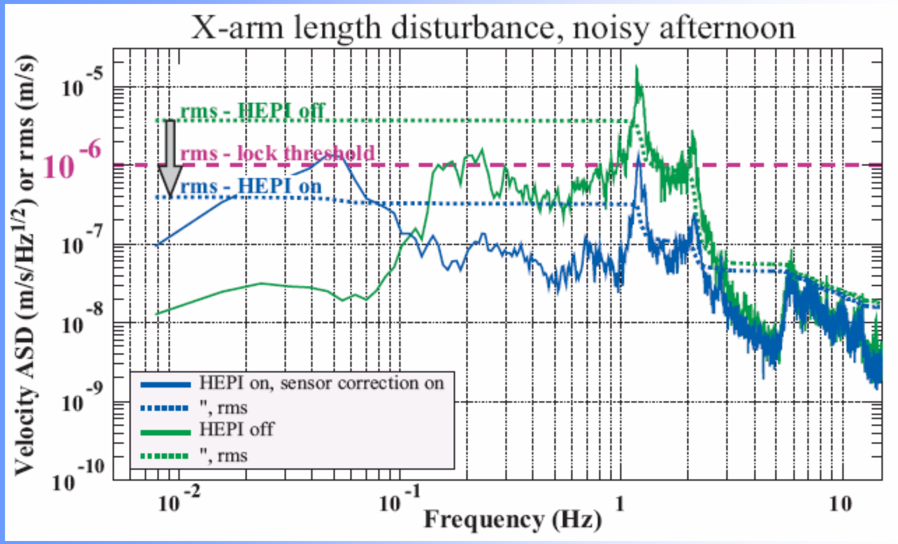
Choose an active approach for BSC

- High-gain servo systems, two stages of 6 degree-of-freedom each
- External hydraulic actuator pre-isolator
- Extensive tuning of system after installation



HAM design being reviewed

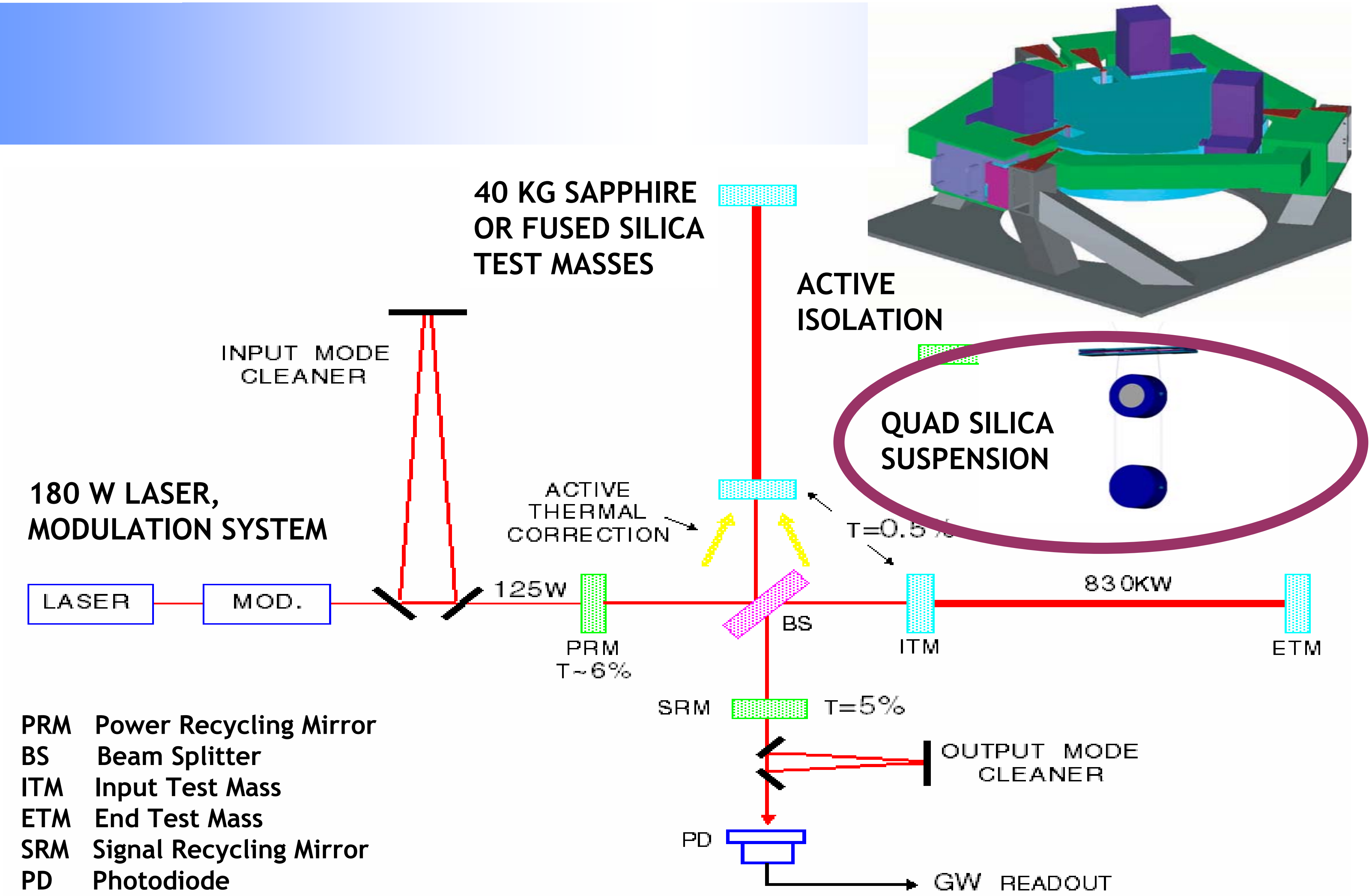
- Stanford prototype is baseline
- Studying single-stage system for lower cost & complexity



External hydraulic pre-isolator installed on initial LIGO (Livingston)

- Increases initial LIGO duty cycle
- Exceeds advanced LIGO requirements

Suspensions



Suspensions

Adopt GEO 600 silica suspension design
- Multi-stage suspension, final stage fused silica
- Ribbons baseline design, fibers as fallback

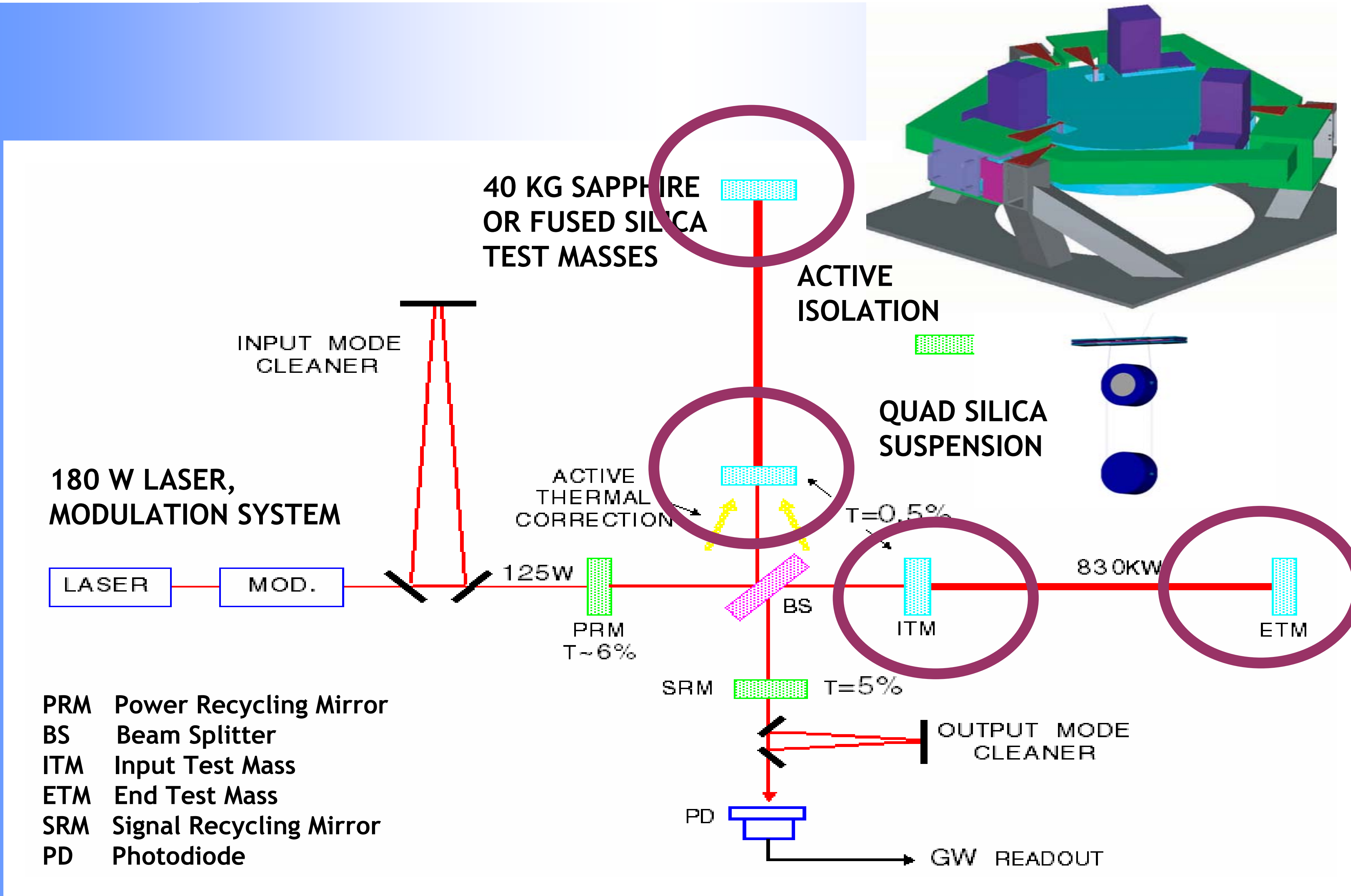
Quadruple pendulum design chosen
- Ribbons silicate bonded to test mass
- Leaf springs (VIRGO origin) for vertical compliance

PPARC funding approved for Adv LIGO (2003)
- Significant financial, technical contribution; quad suspensions, electronics & some substrates
- Quad lead in UK→ U Glasgow, Birmingham, Rutherford

Mode Cleaner (triple) control prototype in LASTI
- Performance as expected, some model improvements
- Quad control prototype delivered this Fall

Laser fiber/ribbon drawing apparatus developed
- Welds being characterized for strength/Q etc.
- No problems seen

Core Optics



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Core Optics

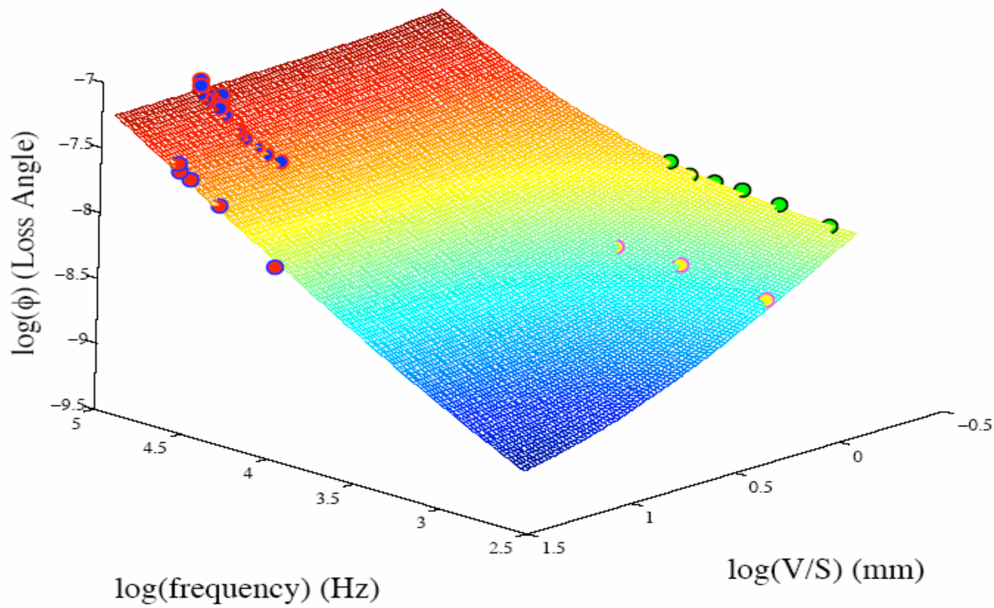
Silica chosen as substrate material

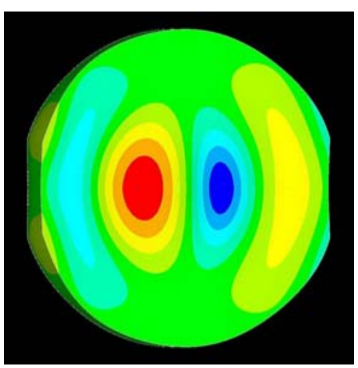
- Improved thermal noise performance from original anticipation
- Some concerns about unknowns with sapphire

Coatings dominate thermal noise & optical absorption

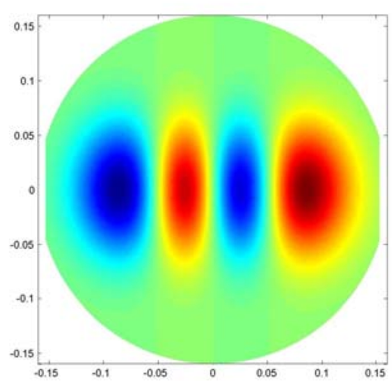
- Progress reducing ϕ with doping
- See talk by Sheila Rowan

Mechanical Loss in Fused Silica





Mechanical mode
47.27 kHz



Optical mode
Overlap 0.8

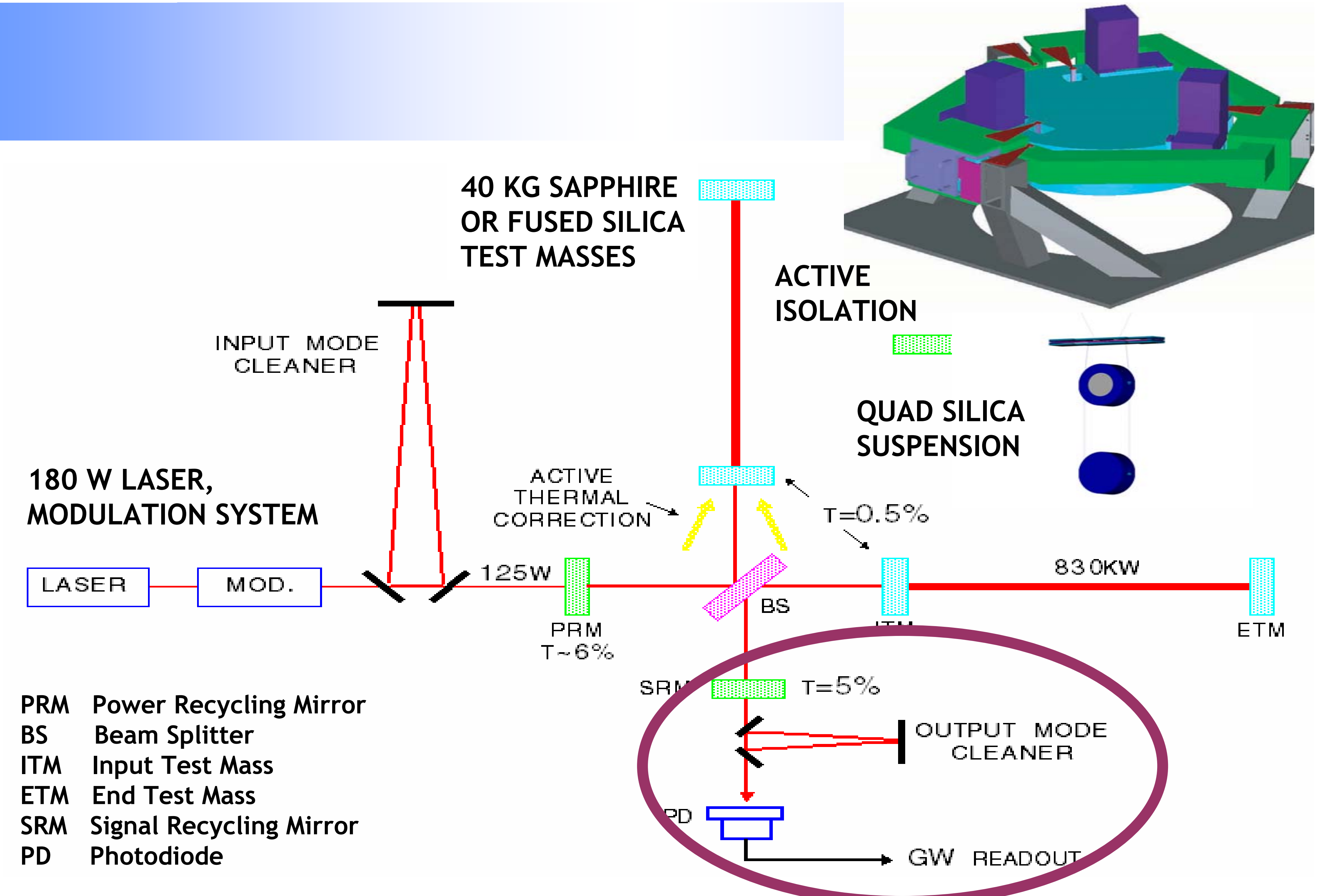
Parametric instability being studied

- May have to spoil modal Q's of optics

Other issues

- Thermal compensation works on initial LIGO (see previous talk)
- Noise effects of charging under investigation

Readout



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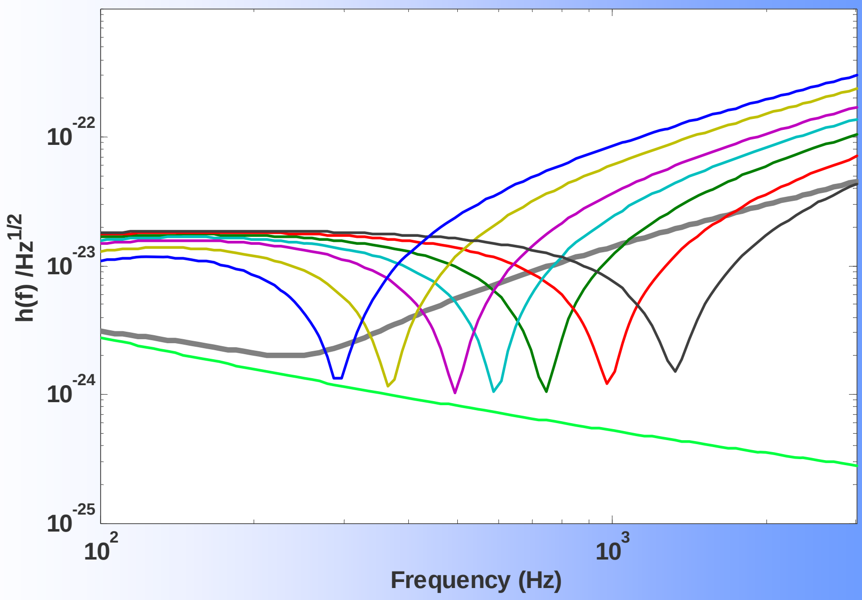
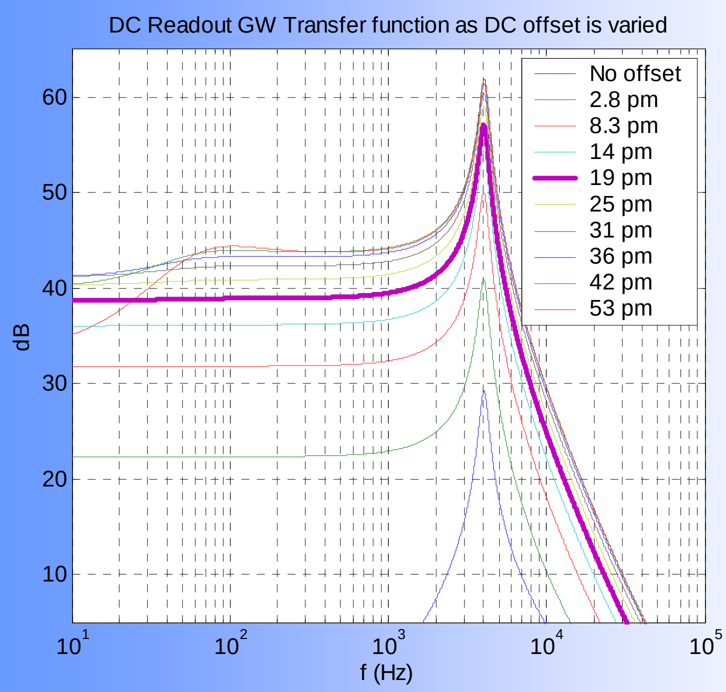
Readout

Dual recycled (signal & power) Michelson with Fabry-Perot arms

- Offers flexibility in instrument response
- Can provide narrowband sensitivity
- Critical advantage: can distribute optical power in interferometer as desired
- Output mode cleaner





DC rather than RF sensing

- Offset ~ 1 pm at interferometer dark fringe
- Best signal-to-noise ratio
  - Simplifies laser, photodetection requirements
  - Perfect overlap between signal & local oscillator
  - Easier to upgrade to quantum non-demolition in future

Prototypes - I

LASTI (LIGO Advanced System Test Interferometer) - MIT

- Test full scale components
- Verify installation
- Explore seismic/low frequency noise
- Already used for initial LIGO – HEPI
- Triple control suspension prototype installed
- Quad control suspension prototype this Fall

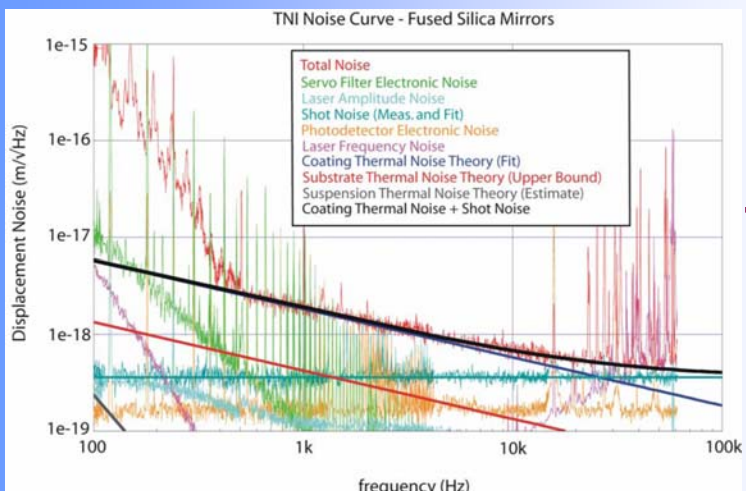
40 m Interferometer - Caltech

- Sensing/controls tests of readout
  - Locking of dual recycled interferometer
- Engineering model for data acquisition, software, electronics
- Exploring modulation techniques
  - Mach-Zehnder design

Prototypes - II

Engineering Test Facility - Stanford

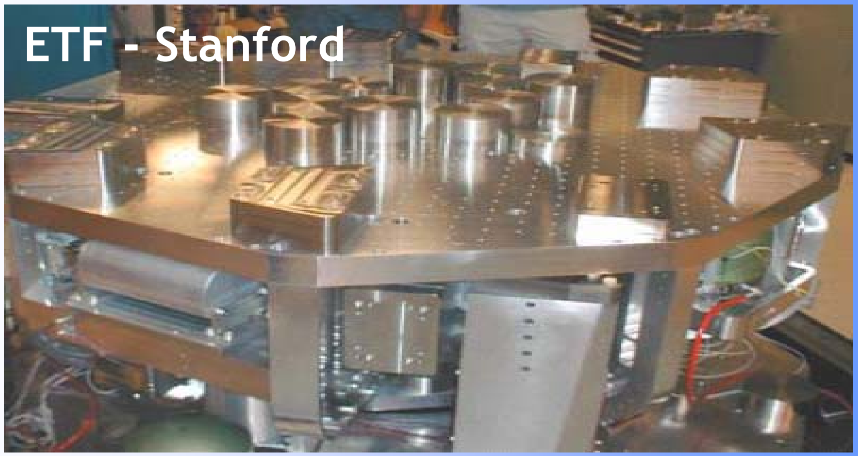
- Seismic isolation prototype
- 1000x Isolation demonstrated
- 1-10 Hz performance in progress



TNI Results

Thermal Noise Interferometer - CIT

- Silica/tantala Brownian noise
- Sapphire thermoelastic noise
- Silica/titania-doped tantala Brownian noise -- in progress



Gingin - Western Australia

- High power tests
- Thermal lens compensation
- Hartmann wavefront sensor
- Parametric instability tests

Mexican Hat Mirrors - CIT

- Reduce thermal noise
- Seeing higher order modes in agreement with theory

Advanced LIGO Project Status

National Science Board (NSB) endorsed Advanced LIGO proposal in October 2004

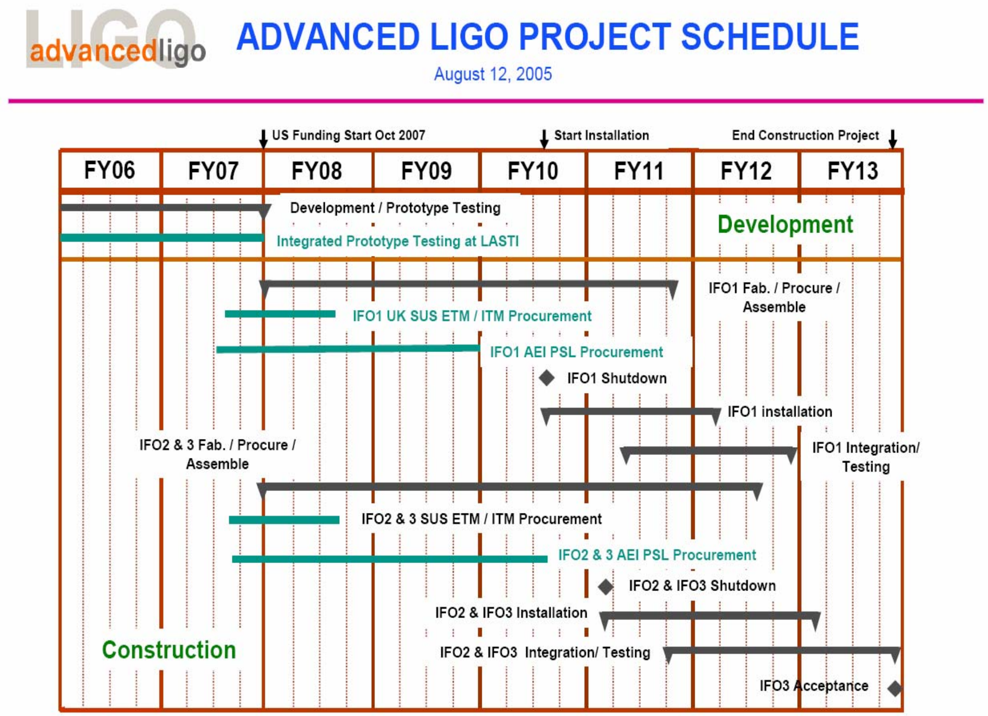
- Contingent upon integrated year of observation with Initial LIGO

National Science Foundation & Presidential Budget includes LIGO

- One of 3 new projects to start in next 3 years
- October 2007 start date

Shut down first initial LIGO interferometer mid 2010

- Finish installing 3rd interferometer end 2013



Review of costs, manpower & schedule complete in 2005

- Fresh analysis→updates of technology
- Current best estimates comparable with NSB-approved costs

Conclusions

- **Advanced LIGO will have ~ 10 X sensitivity of initial LIGO**
  - 1000 X rate for homogeneously distributed sources
- **Seismic isolation down to near 10 Hz**
- **Laser will have ~ 200 W of power**
- **Fused silica ribbon suspensions**
- **Fused silica substrates for core optics**
  - Coating crucial and still under development
- **DC readout of dual-recycled configuration**
- **Prototypes in place or under development for most noise sources and/or areas of concern**
- **Budget situation hopeful for 2007 start**
  - No check in hand yet

Contact Information

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