ADVANCED LIGO SUSPENSIONS
LSC-Virgo Meeting
September 2008

HAM Suspensions Update

Janeen Romie on behalf of Advanced LIGO US Suspension team

http://ilog.ligo-wa.caltech.edu:7285/advligo/Suspensions

Advanced LIGO SUS Team

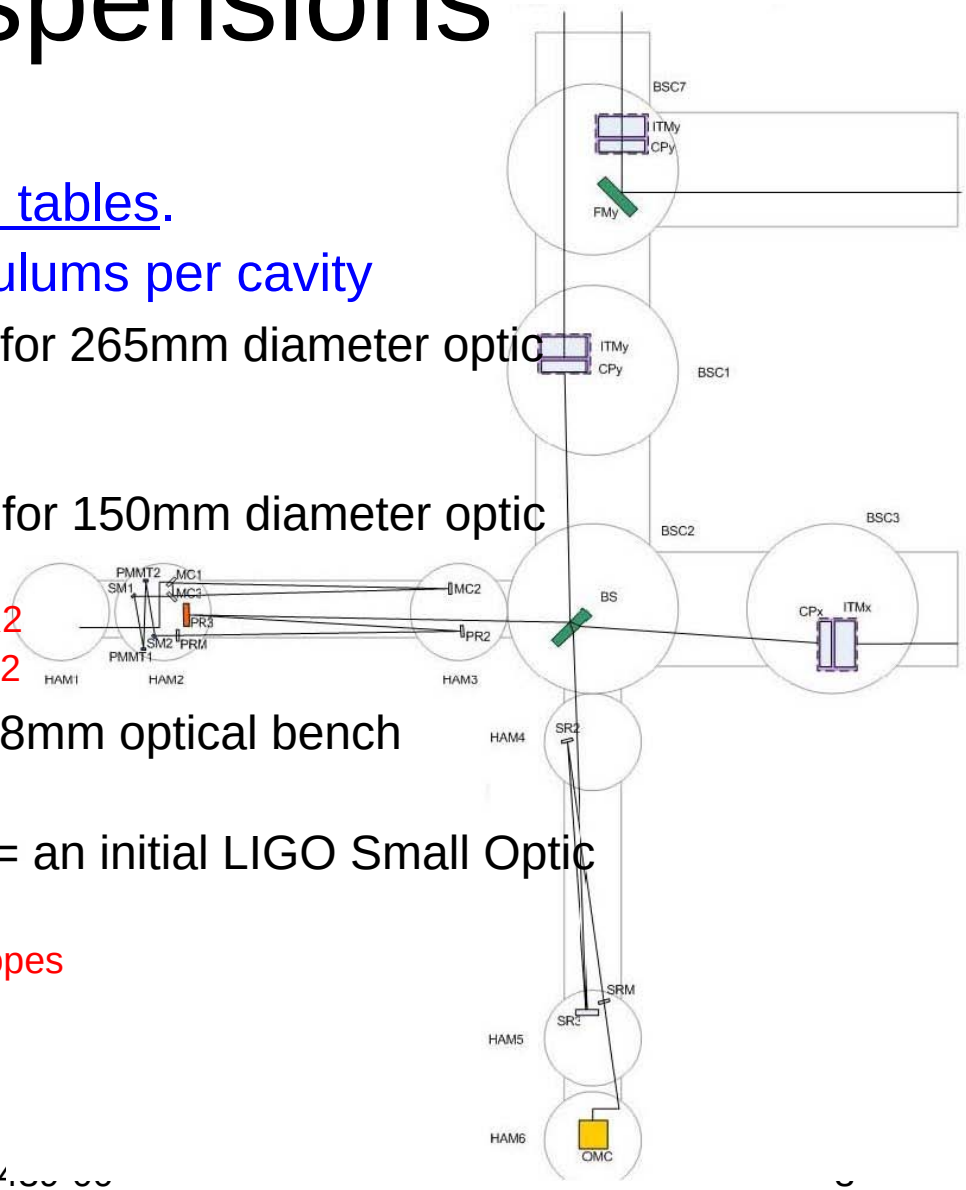
- **LIGO Caltech: R Abbott, H Armandula, M Barton, D Coyne, C Echols, J Heefner, A Heptonstall, K Mailand, N Robertson (also at Glasgow), C Torrie**
- **LIGO MIT: P Fritschel, R Mittleman, B Shapiro, N Smith, S Waldman**
- **LIGO LHO: B Bland, D. Cook, G Moreno**
- **LIGO LLO: D. Bridges, T Fricke, M Meyer, J Romie, D Sellers, G Traylor**
- **University of Glasgow: C Craig, L Cunningham, A Cumming, G Hammond, K Haughian, J Hough, R Jones , R Kumar, I Martin, S Rowan, K Strain, K Tokmakov, M Van Veggel**
- **Rutherford Appleton Laboratory (RAL): A Brummitt, J Greenhalgh, T Hayler, J O'Dell, I Wilmut**
- **University of Birmingham: S Aston, R Cutler, D Lodhia, A Vecchio**
- **University of Strathclyde: N Lockerbie**

HAM Suspensions

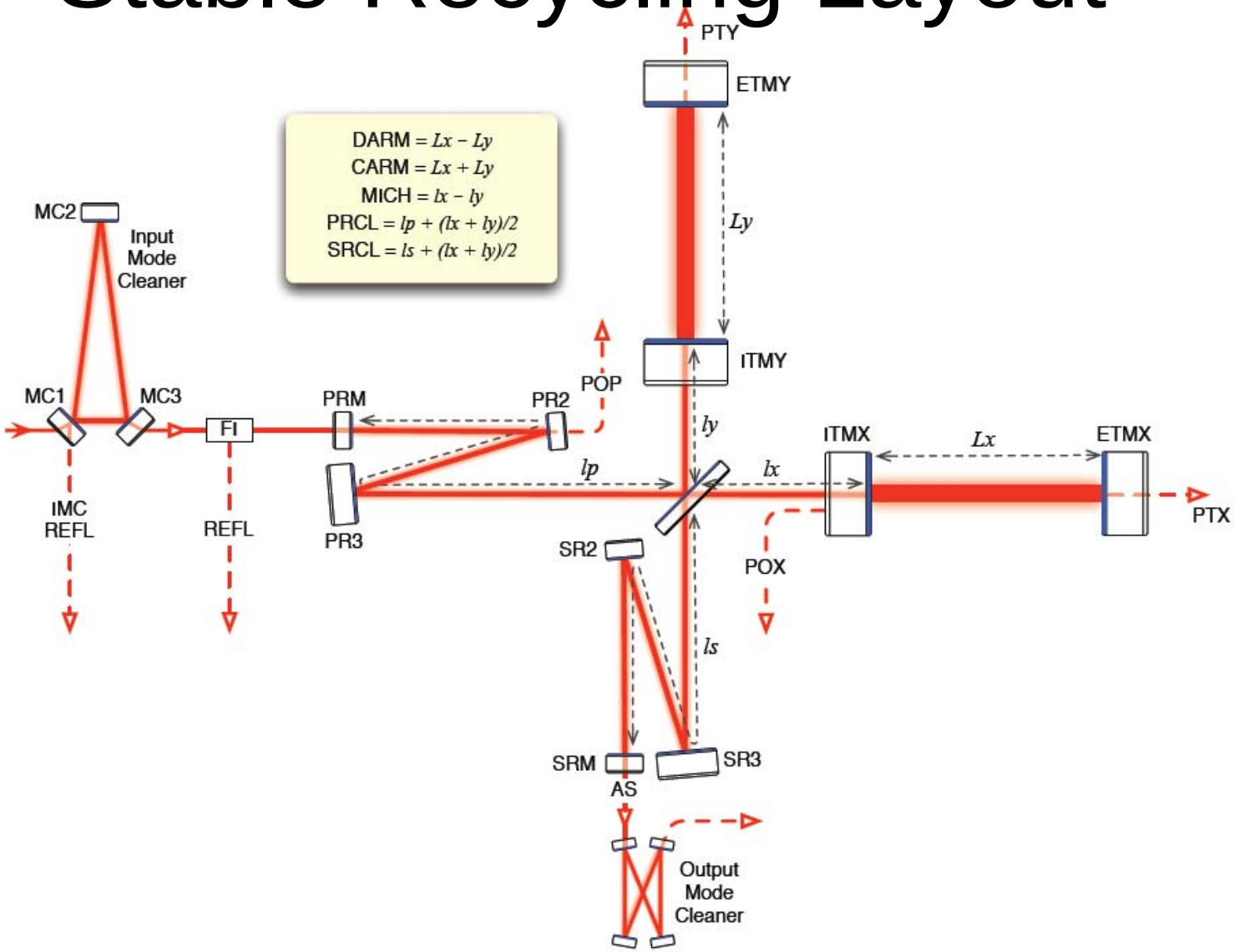
All suspensions sitting on HAM optical tables.

Stable recycling layout – 3 triple pendulums per cavity

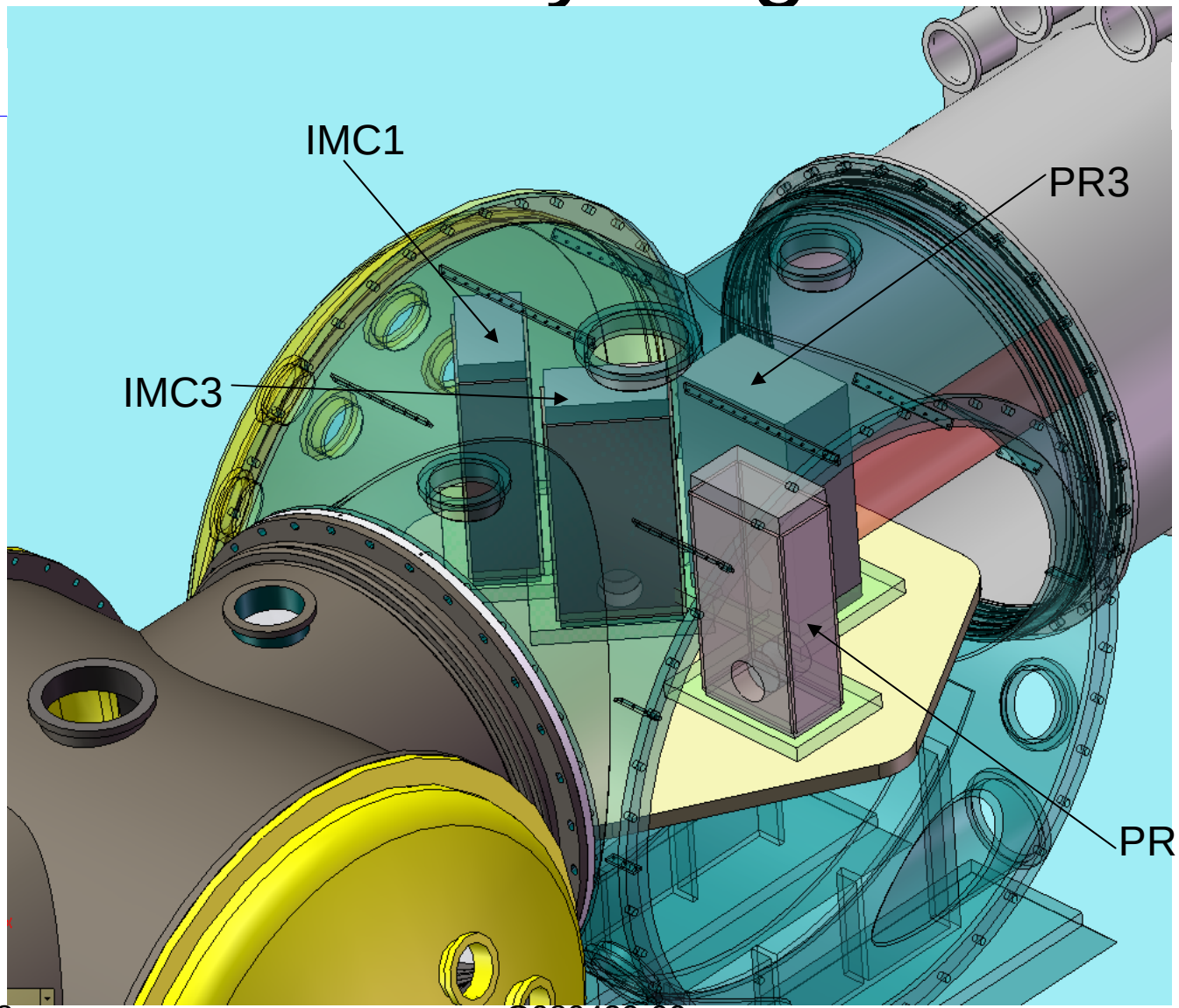
- **Large Triple** (HLTS) suspension for 265mm diameter optic
  - Power recycling cavity mirror PR3
  - Signal recycling cavity mirror SR3
- **Small Triple** (HSTS) suspension for 150mm diameter optic
  - Input mode cleaner
  - Power recycling cavity mirrors PRM, PR2
  - Signal recycling cavity mirrors SRM, SR2
- **Doubles** for 450mm x 150mm x 38mm optical bench
  - Output mode cleaner
- **Singles** for 76mm diameter optic = an initial LIGO Small Optic Suspension (SOS)
  - Input and output mode matching telescopes
  - Steering mirrors



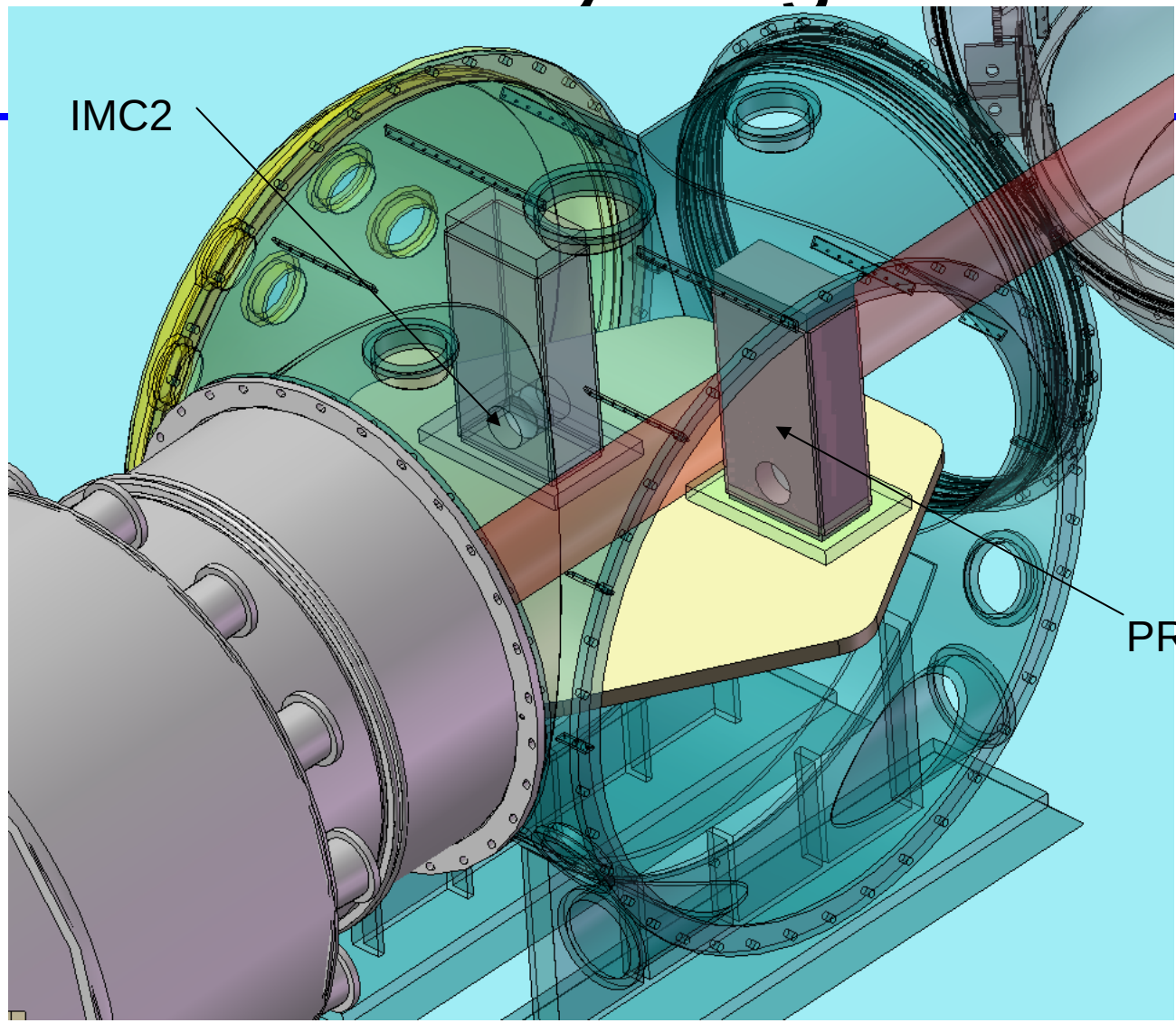
Stable Recycling Layout



Stable Recycling: HAM2



Stable Recycling:HAM3



HAM Suspensions Status

Large Triples

Prototype for Recycling Mirror R3 suspension is being fabricated now. Assembly at LLO.

- structure is stainless steel so less welding issues
- resonance testing at Caltech next month

Small Triples

Input Mode Cleaner (IMC) suspension prototypes fully tested at LASTI

- triple electronics requirements defined
- PDR soon

Double

LLO & LHO Output Mode Cleaners (OMC) installed and being tested.

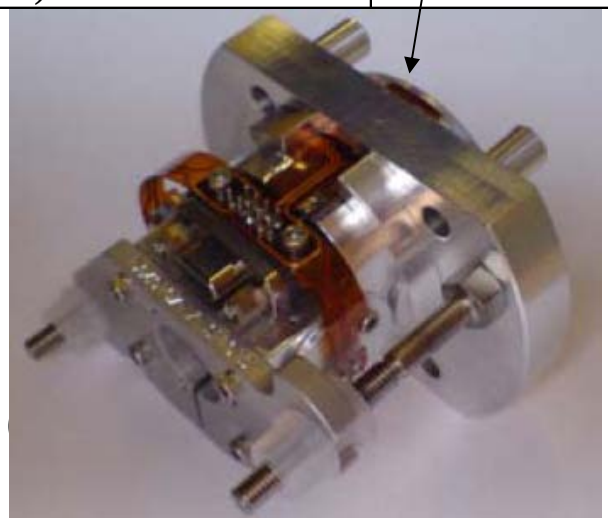
Singles

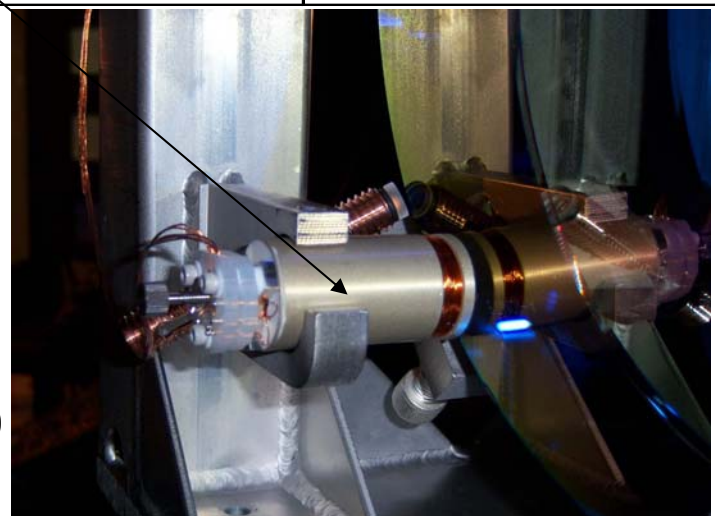
Assumed that only small updates of SOS required.

Triple SUS osems

Table 1: Magnet Sizes and Actuator Strengths

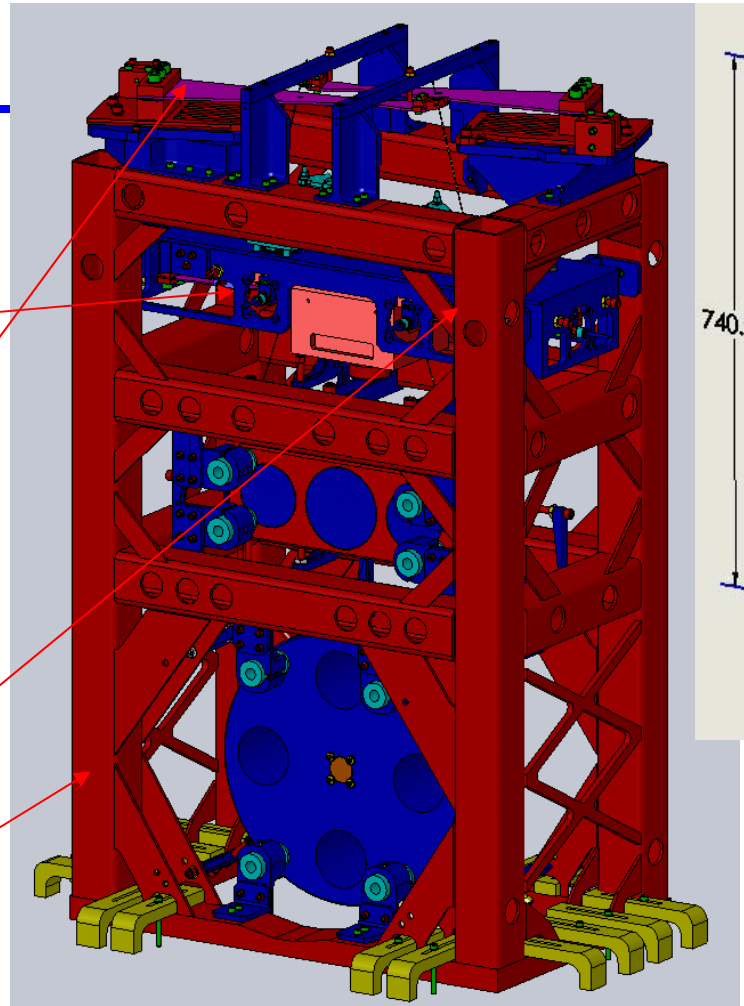
Suspension Type/Stage	OSEM Type	Magnet Size	Actuation Strength
BS TOP	BOSEM	10mm x 10mm	2 N/A
IMC TOP	BOSEM	10mm x 5mm	1 N/A
Small Cavity Triple TOP	BOSEM	10mm X 5mm	1 N/A
Large Cavity TOP	BOSEM	10mm x 10mm	2 N/A
BS Middle Stage (L1)	BOSEM	10mm x 5mm	1 N/A
IMC and Cavity Middle Stage (L1)	LIGO I	LIGO Magnets	0.016 N/A
IMC and Cavity Mirror Stage (L2)	LIGO I	New Magnets	0.002 N/A

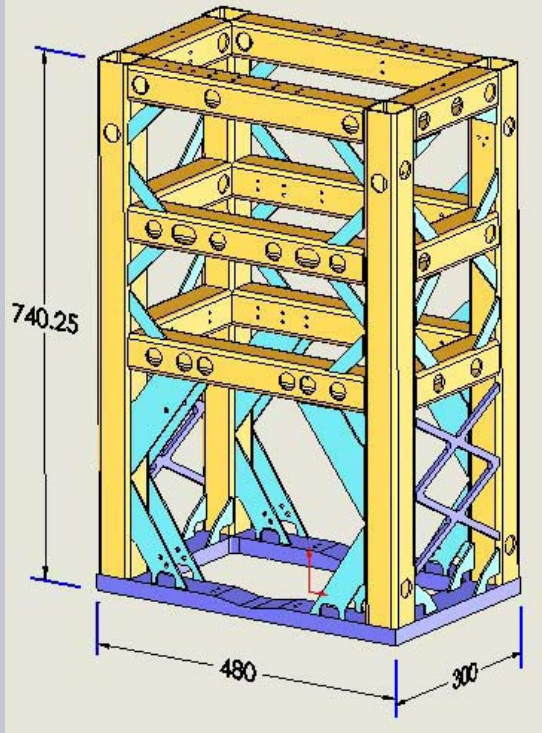




Large Triple Suspension, R3

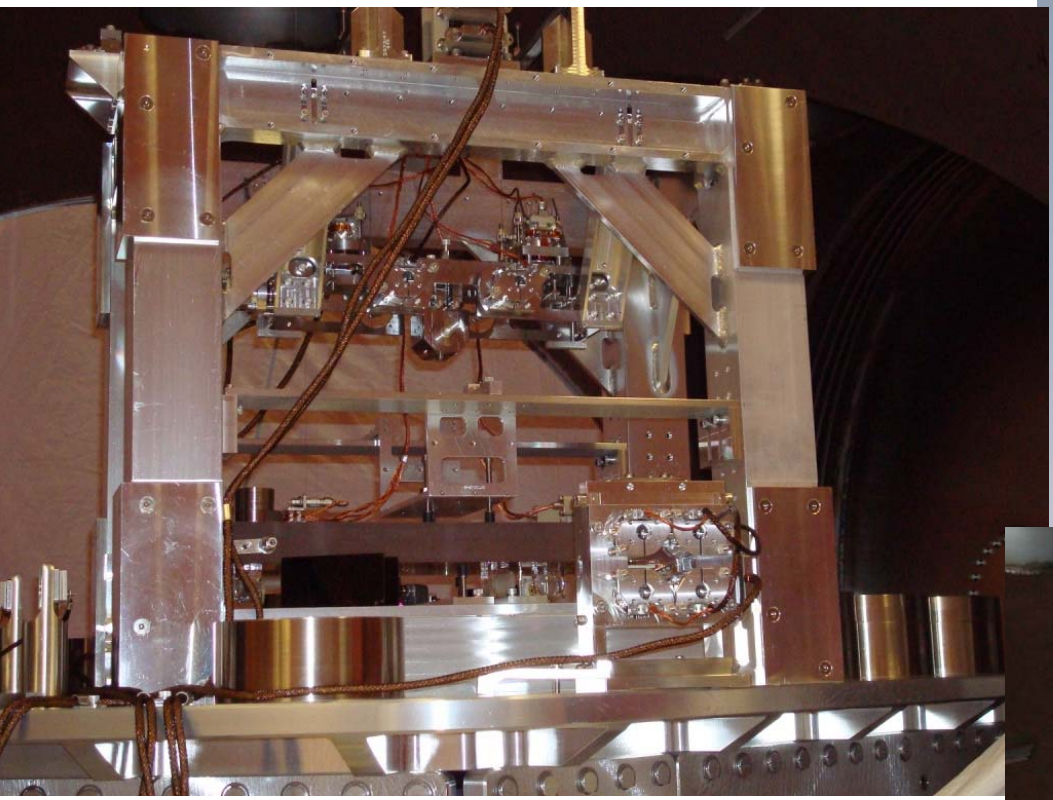
- triple pendulum
- OSEMs @ 3 masses
  - 6 @ top mass for damping of low frequency modes
  - 4 @ intermediate mass & mirror for global control
- blades at top of suspension & at top mass
- stainless steel welded structure

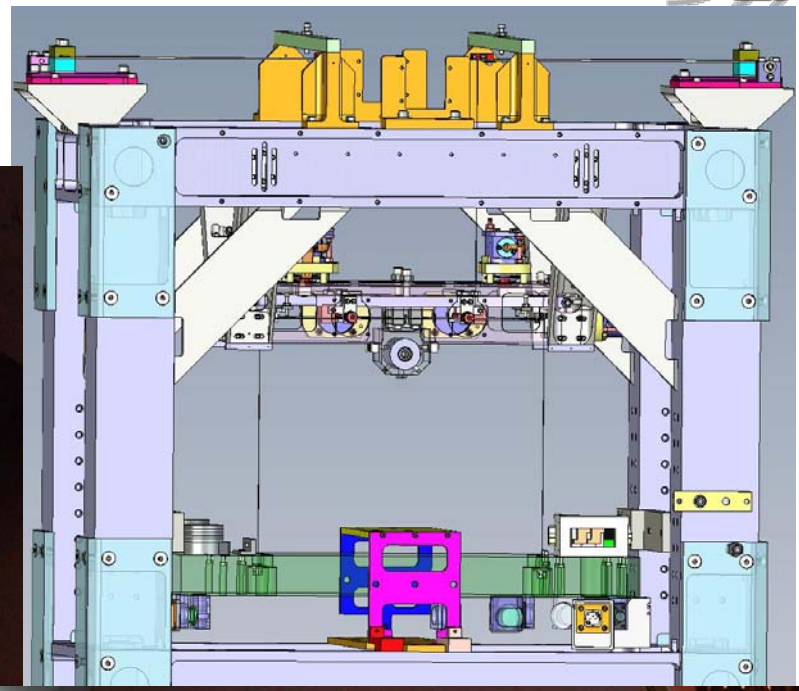


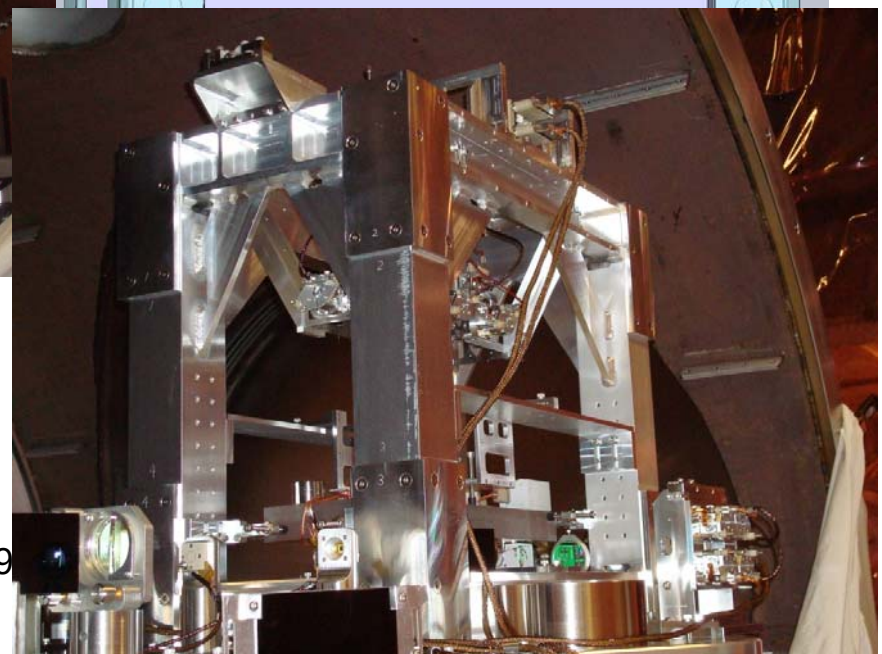


OMC SUS

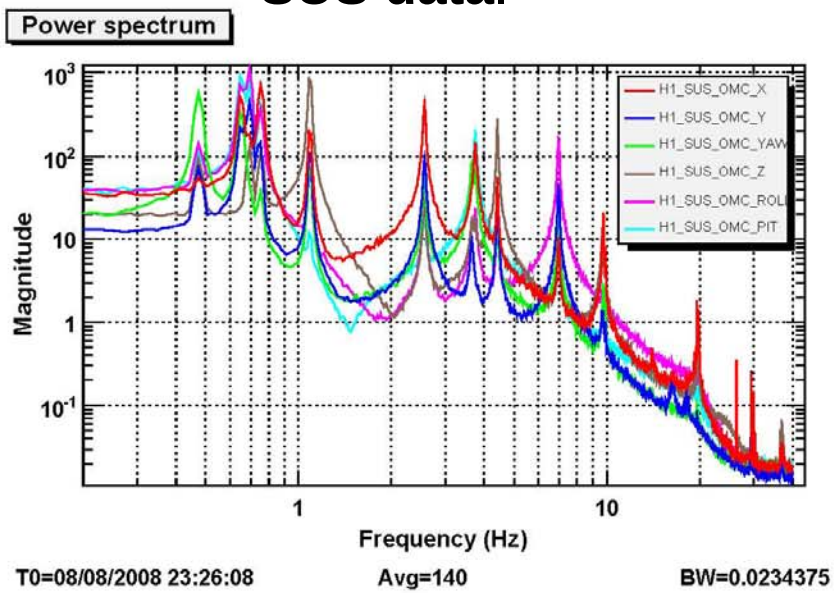
LHO OMC SUS

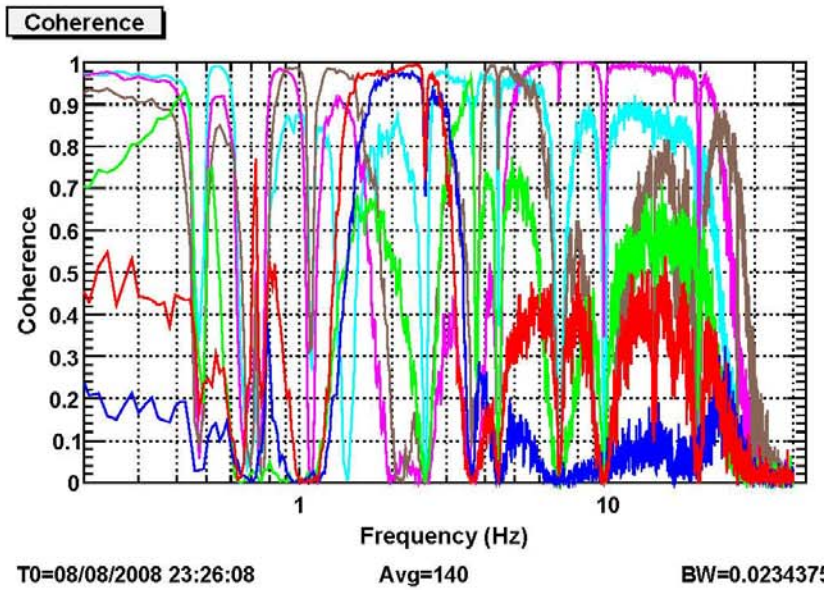


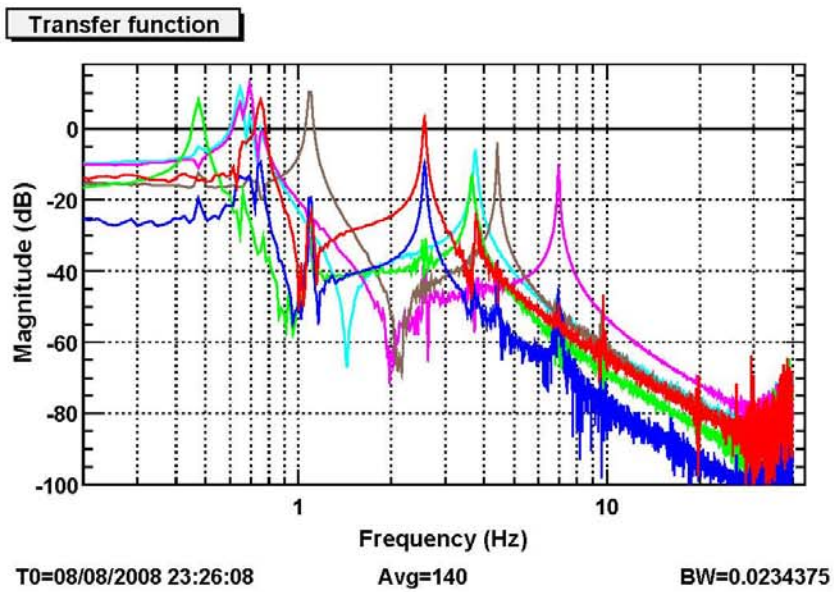


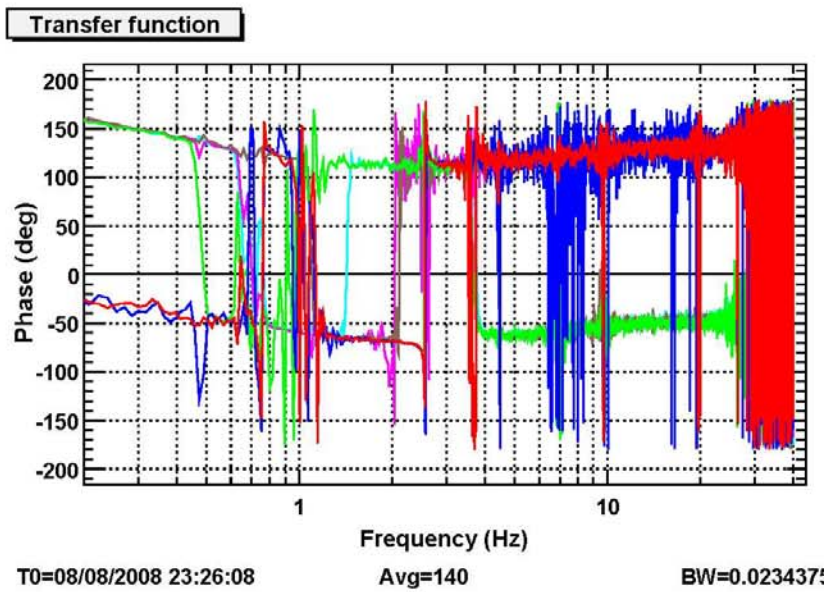


Preliminary LHO OMC SUS data.

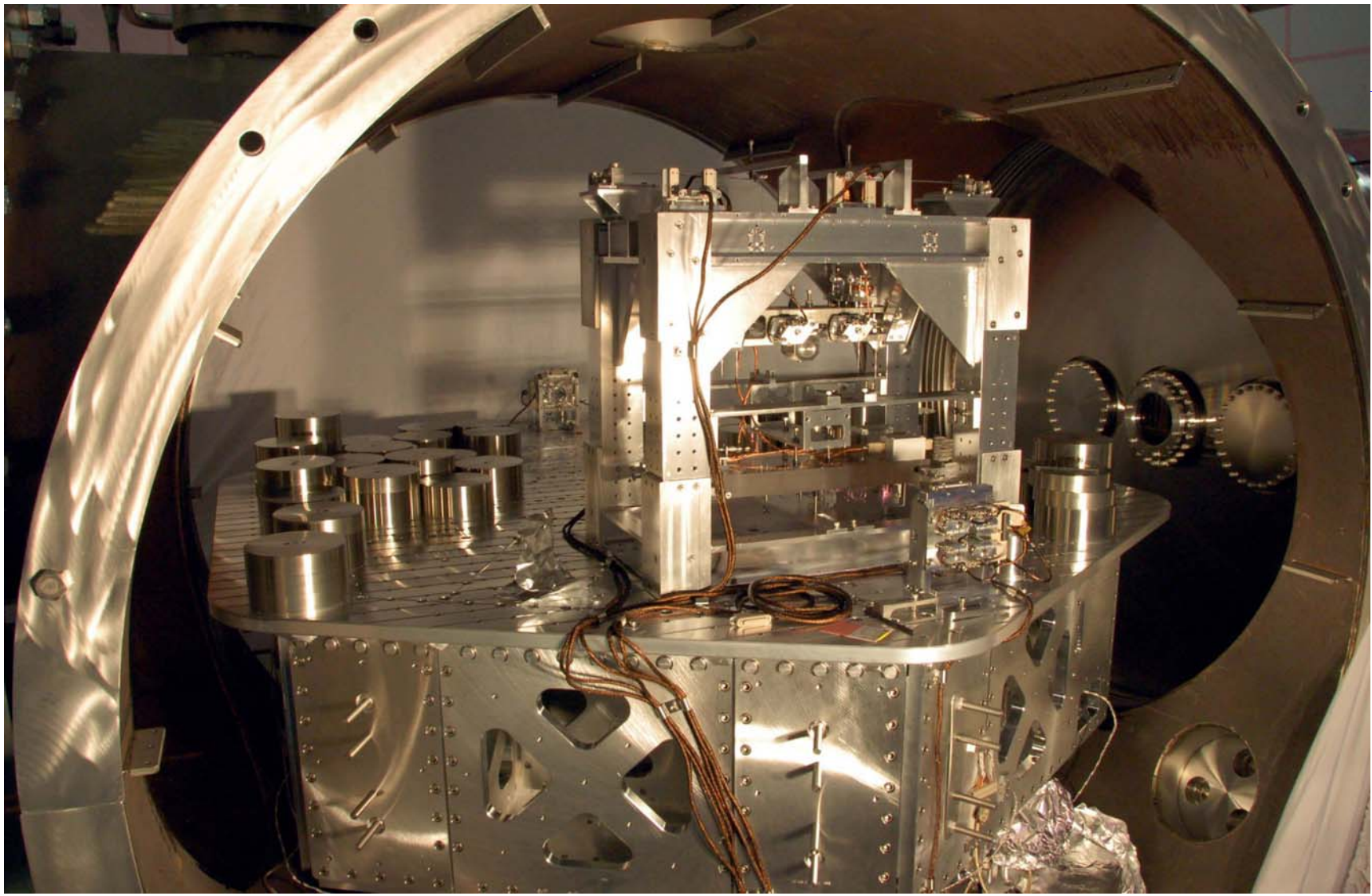








LLO OMC SUS



Maraging steel blade springs

- Large triple prototype blades and 2nd OMC blades fabricated earlier this year.
  - All out-of-spec.
  - Vendor reworked by shot peening.
  - Added plastic region at shot peened sites.
    - Shot peening only seems to work with thin blades
  - Accepted for eLIGO, will be retrofitted for aLIGO
  - Lessons learned:
    - need jigs during aging treatment
    - need tightened fabrication procedure
    - need clamps for inspection at the vendor facility
  - Another round of prototypes is needed to widen potential machine shop pool

Blade process

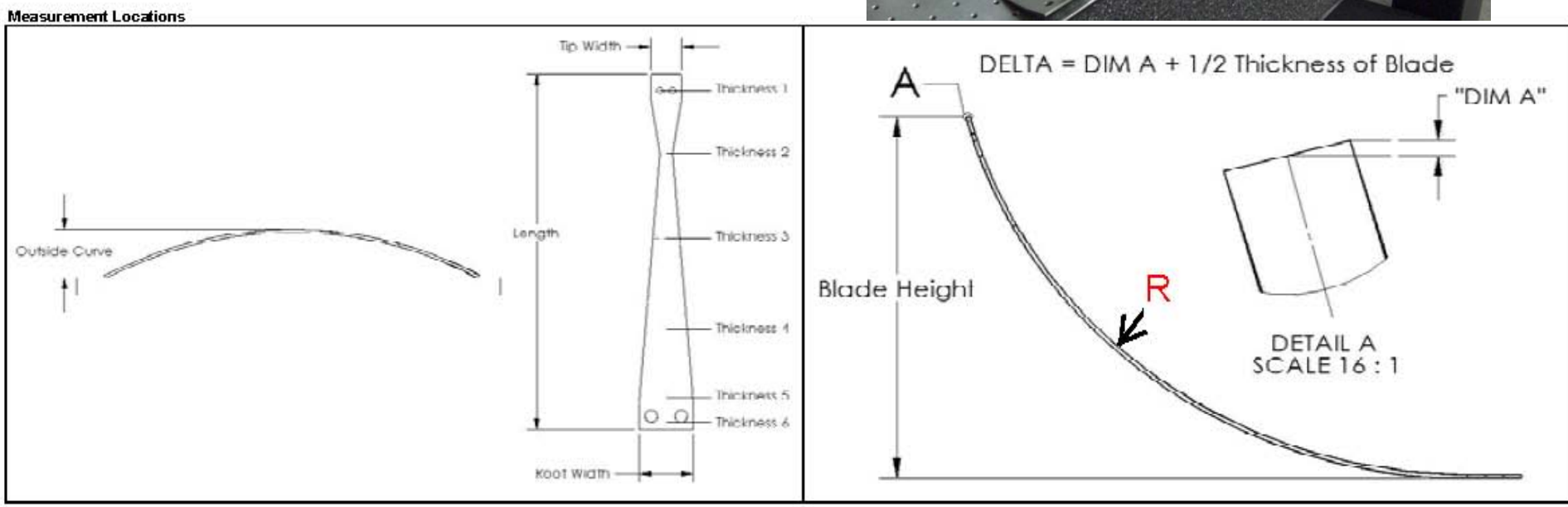
- http://ilog.ligo-wa.caltech.edu:7285/advligo/Suspensions/CantileverBlades
- Input gathered from many sources including GEO600, VIRGO, RAL, LIGO SEI
- Proposed maraging steel blade process:
  - Procure C-250 Maraging steel (annealed)
  - Machine & roll blades
  - Initial inspection of dimensions
  - Age harden at 435 deg C for 100 hours in a "comb" jig
  - Initial creep bake - 150 deg C for 100 hours, under load
  - Characterization - can be done now or after plating, also hardness testing

Blade process -continued

- Electroless Nickel Plating:
  - Specialized Pre-clean
  - Electroless Nickel Plate (low 5% phosphor bath) to a thickness of 0.5 um (microns)
  - Specialized Re-clean
  - Within 4 hours of the nickel plating, bake blades at 150 deg C for 12 hours
- Characterization - if not done before nickel plating
- Clean and RGA bake,150 deg C for 48 hours - not under load
- Final Creep bake under load,150 deg C for a week

Electroless Nickel plating bath

Blade characterization data



Large triple prototype blade data

Blade Type:	RM Upper
Drawing Number:	D020617-C
Delta (see Descriptions Sheet):	0.074 inches
Test Mass Used:	17.565 kg

Dimensions from Drawing	
Root Width	2.560 inches
Tip Width	1.000 inches
Thickness	0.091 inches
Length	10.84 inches
Blade Height	4.141 inches

Initial Blade Characterization Test	values in inches								values in millimeters							
Blade S/N	001	002	003	004	005	006	007	008	001	002	003	004	005	006	007	008
Root Width	2.559	2.558	2.558	2.561	2.559	2.559	2.560	2.559	65.00	64.97	64.97	65.05	65.00	65.00	65.02	65.00
Tip Width	1.002	1.000	1.000	1.000	1.000	1.000	1.000	1.000	25.45	25.40	25.40	25.40	25.40	25.40	25.40	25.40
Thickness 1	0.09295	0.09240	0.09305	0.09275	0.09410	0.09285	0.09360	0.09320	2.36	2.35	2.36	2.36	2.39	2.36	2.38	2.37
Thickness 2	0.09225	0.09255	0.09310	0.09230	0.09255	0.09260	0.09265	0.09230	2.34	2.35	2.36	2.34	2.35	2.35	2.35	2.34
Thickness 3	0.09235	0.09225	0.09215	0.09190	0.09185	0.09210	0.09175	0.09250	2.35	2.34	2.34	2.33	2.33	2.34	2.33	2.35
Thickness 4	0.09155	0.09220	0.09200	0.09185	0.09180	0.09255	0.09160	0.09200	2.33	2.34	2.34	2.33	2.33	2.35	2.33	2.34
Thickness 5	0.09115	0.09165	0.09150	0.09095	0.09115	0.09140	0.09135	0.09175	2.32	2.33	2.32	2.31	2.32	2.32	2.32	2.33
Thickness 6	0.09100	0.09140	0.09145	0.09105	0.09110	0.09130	0.09135	0.09170	2.31	2.32	2.32	2.31	2.31	2.32	2.32	2.33
Outside Curve	1.329	1.328	1.372	1.356	1.382	1.372	1.374	1.344	33.76	33.73	34.85	34.44	35.10	34.85	34.90	34.14
Length	10.841	10.840	10.842	10.841	10.842	10.842	10.840	10.842	275.36	275.34	275.39	275.36	275.39	275.39	275.34	275.39
Unloaded Height (Initial)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Loaded Height (Initial)	-4.365	-4.277	-4.323	-4.340	-4.369	-4.293	-4.325	-4.345	-110.87	-108.64	-109.80	-110.24	-110.97	-109.04	-109.86	-110.36
Unloaded Height (after 1 cycle)	-0.001	-0.003	-0.004	-0.001	-0.007	-0.003	-0.002	-0.015	-0.03	-0.08	-0.10	-0.03	-0.18	-0.08	-0.05	-0.38
Loaded Height (after 1 cycle)	-4.362	-4.284	-4.324	-4.342	-4.379	-4.296	-4.316	-4.349	-110.79	-108.81	-109.83	-110.29	-111.23	-109.12	-109.63	-110.46
Unloaded Height (after 2 cycles)	-0.001	-0.003	-0.005	-0.001	-0.008	-0.002	-0.003	-0.011	-0.03	-0.08	-0.13	-0.03	-0.20	-0.05	-0.08	-0.28
Vertical Bounce Frequency (Hertz)	1.36	1.36	1.38	1.36	1.35	1.36	1.35	1.39	1.36	1.36	1.38	1.36	1.35	1.36	1.35	1.39
Blade Height	3.936	4.043	4.002	3.989	4.012	4.016	3.971	3.965	99.97	102.69	101.65	101.32	101.90	102.01	100.86	100.71
Average Deflection	4.364	4.281	4.324	4.341	4.374	4.295	4.321	4.347	110.833	108.725	109.817	110.261	111.100	109.080	109.741	110.414
Change in Deflection after 1 cycle	0.001	0.003	0.004	0.001	0.007	0.003	0.002	0.015	0.025	0.076	0.102	0.025	0.178	0.076	0.051	0.381
Change in Deflection after 2 cycles	0.000	0.000	0.001	0.000	0.001	-0.001	0.001	-0.004	0.000	0.000	0.025	0.000	0.025	-0.025	0.025	-0.102
Offset from Vertical	-0.428	-0.238	-0.322	-0.352	-0.362	-0.279	-0.350	-0.382	-10.859	-6.033	-8.166	-8.941	-9.195	-7.074	-8.877	-9.703
Corrected Offset from Vertical	-0.502	-0.312	-0.396	-0.426	-0.436	-0.353	-0.424	-0.456	-12.738	-7.912	-10.046	-10.820	-11.074	-8.954	-10.757	-11.582

Linearity Test

Linearity Test Mass 1	15.665 kg
Linearity Test Mass 2	17.565 kg
Linearity Test Mass 3	18.205 kg

	values in inches								values in millimeters							
Blade S/N	001	002	003	004	005	006	007	008	001	002	003	004	005	006	007	008
Linearity Unloaded Height	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Linearity Loaded Height 1	3.873	3.790	3.818	3.856	3.905	3.831	3.809	3.844	98.37	96.27	96.98	97.94	99.19	97.31	96.75	97.64
Linearity Loaded Height 2	4.363	4.281	4.323	4.341	4.374	4.295	4.320	4.347	110.82	108.74	109.80	110.26	111.10	109.08	109.73	110.41
Linearity Loaded Height 3	4.604	4.453	4.552	4.558	4.551	4.392	4.411	4.502	116.94	113.11	115.62	115.77	115.60	111.56	112.04	114.35

Overload Test

Overload Test Mass	kg

	values in inches								values in millimeters							
Blade S/N									0	0	0	0	0	0	0	0
Overload Test Unloaded Height									0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Test Mass Loaded Height									0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Overload Test Mass Loaded Height (0 minutes)									0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Overload Test Mass Loaded Height (15 minutes)									0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

NOTES:

1) Thickness measurements were difficult due to the curve of the blade. The most accurate measurements are those near the root (numbers 5 and 6)
2) The bounce frequency of the upper blades was found by timing 20 cycles. 40 cycles was used for the lower blades.
3) Deflection was measured to top of wire clamp. 0.315" (thickness of clamp) was added to this measurement to get the deflection to the top of the blade.
4) Measurements were taken using 17.58 kg due to the 15 degree angle of the upper wire when installed in the suspension. This is the mass of the suspension (18.20 kg) times the cosine of 15 degrees

Results

Blade Characterization Results

	values in inches								values in millimeters							
Blade S/N	001	002	003	004	005	006	007	008	001	002	003	004	005	006	007	008
Average Deflection	4.364	4.281	4.324	4.341	4.374	4.295	4.321	4.347	110.833	108.725	109.817	110.261	111.100	109.080	109.741	110.414
Change in Deflection (1 cycle)	0.001	0.003	0.004	0.001	0.007	0.003	0.002	0.015	0.025	0.076	0.102	0.025	0.178	0.076	0.051	0.381
Change in Deflection (2 cycles)	0.000	0.000	0.001	0.000	0.001	-0.001	0.001	-0.004	0.000	0.000	0.025	0.000	0.025	-0.025	0.025	-0.102
Corrected Offset from Vertical	-0.502	-0.312	-0.396	-0.426	-0.436	-0.353	-0.424	-0.456	-12.738	-7.912	-10.046	-10.820	-11.074	-8.954	-10.757	-11.582

Linearity Test

Conclusions

- SUS team benefits from sharing ideas, designs & lessons learned on a weekly basis.
- Development work through the end of FY2009, in parallel with Project work
- Drawings, drawings, reviews, reviews….