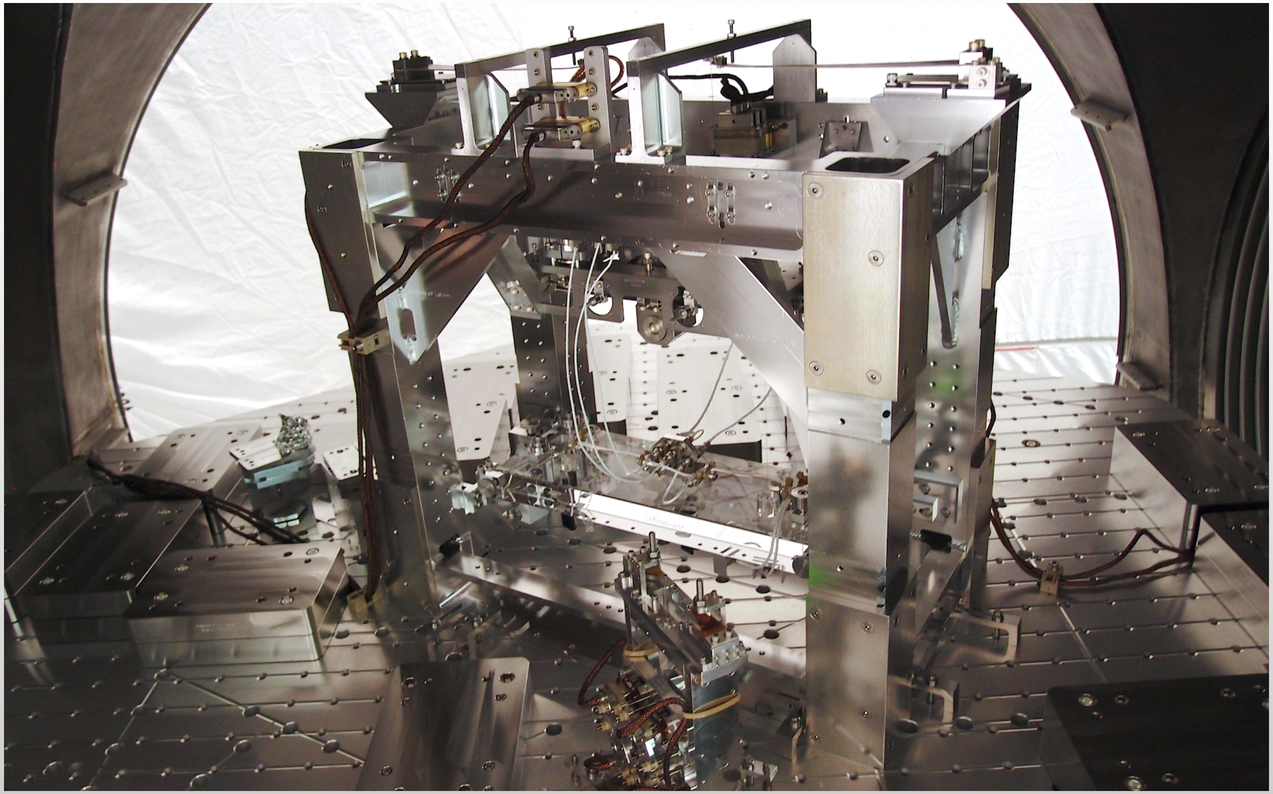
Advanced LIGO: Output Mode Cleaner



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Detchar call: aLIGO Subsystems Talks

Jul 20, 2015 LIGO-G1500940

What is the OMC?

Advanced LIGO Output Mode Cleaner (OMC)

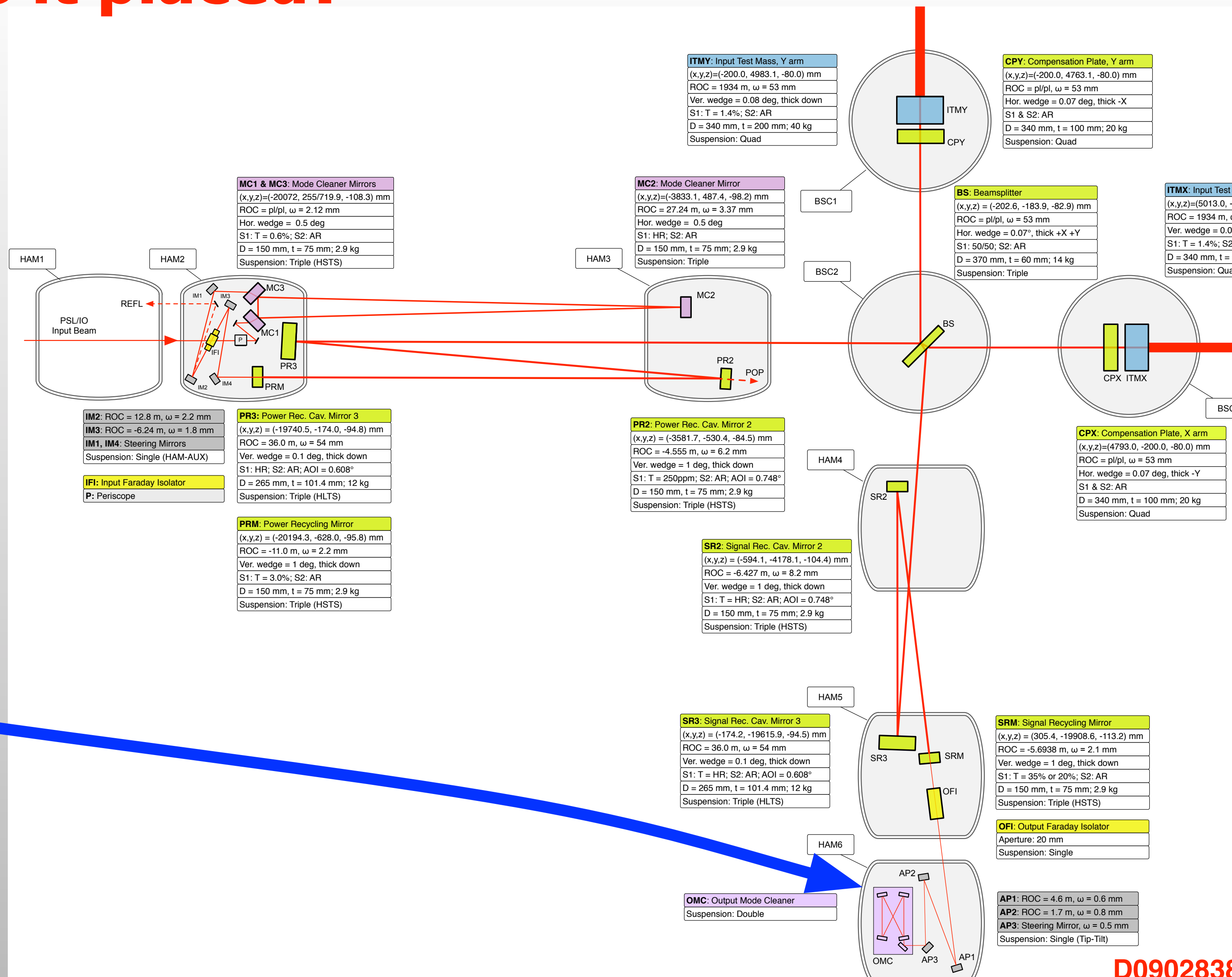
- ... is an optical cavity built on a fused silica plate.
  This optical breadboard is suspended by OMCS on HAM6 ISI

- ... is the last optical interface where the light
  from the interferometer light is converted to GW signals

- ... is designed and configured to transmit the signal field
  on the carrier light as much as possible, while removing
  any other field like carrier higher-order modes and any
  RF modulation sidebands

Where is the OMC?

Where is it placed?

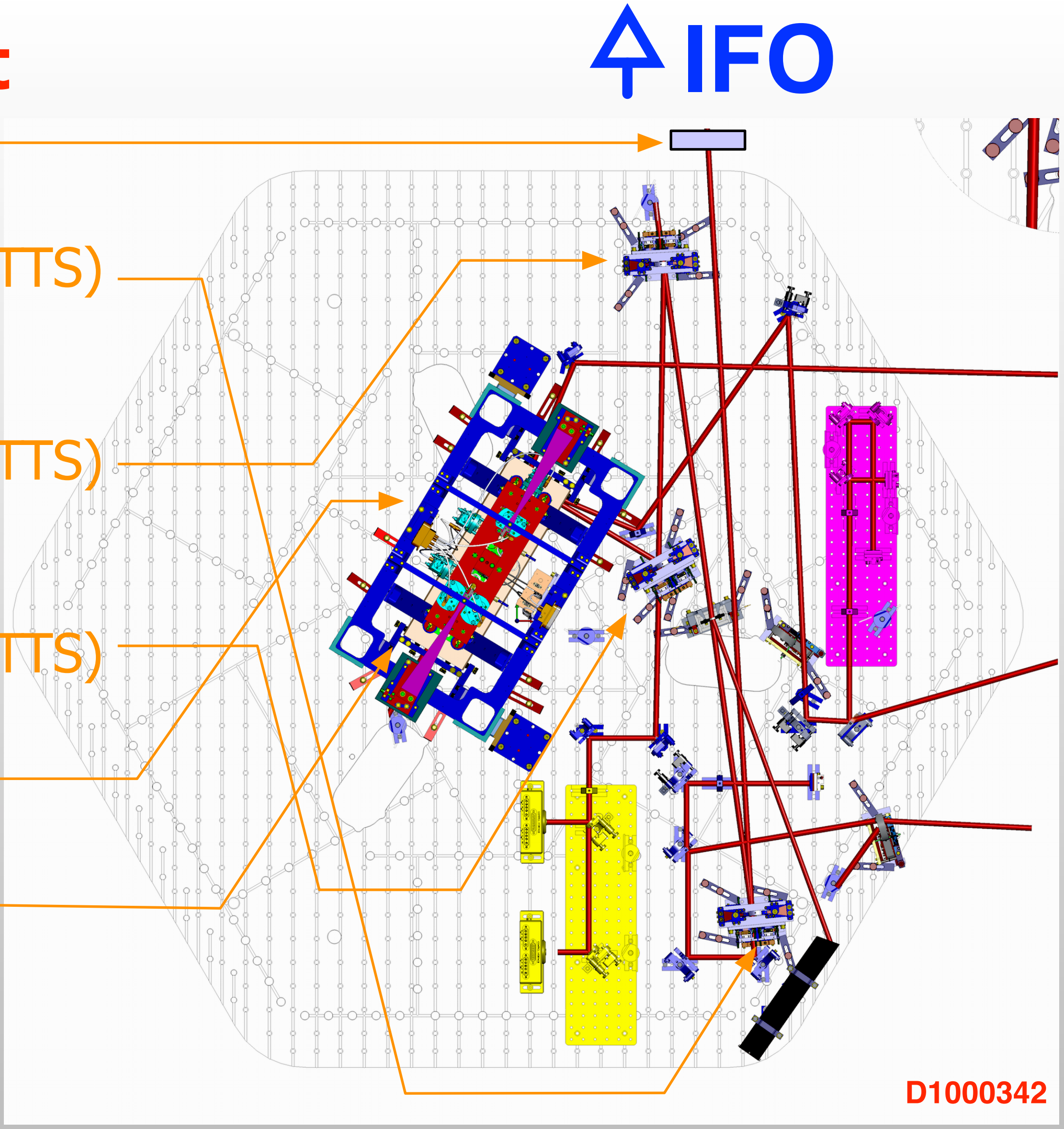


HAM6
&
OMC

Where is the OMC?

HAM6 Optical layout

- Septum window
- OM1 Tip-Tilt Suspension (HTTS) (Mode matching mirror)
- OM2 Tip-Tilt Suspension (HTTS) (Mode matching mirror)
- OM3 Tip-Tilt Suspension (HTTS)
- OMC Suspension (OMCS)
- OMC optical breadboard

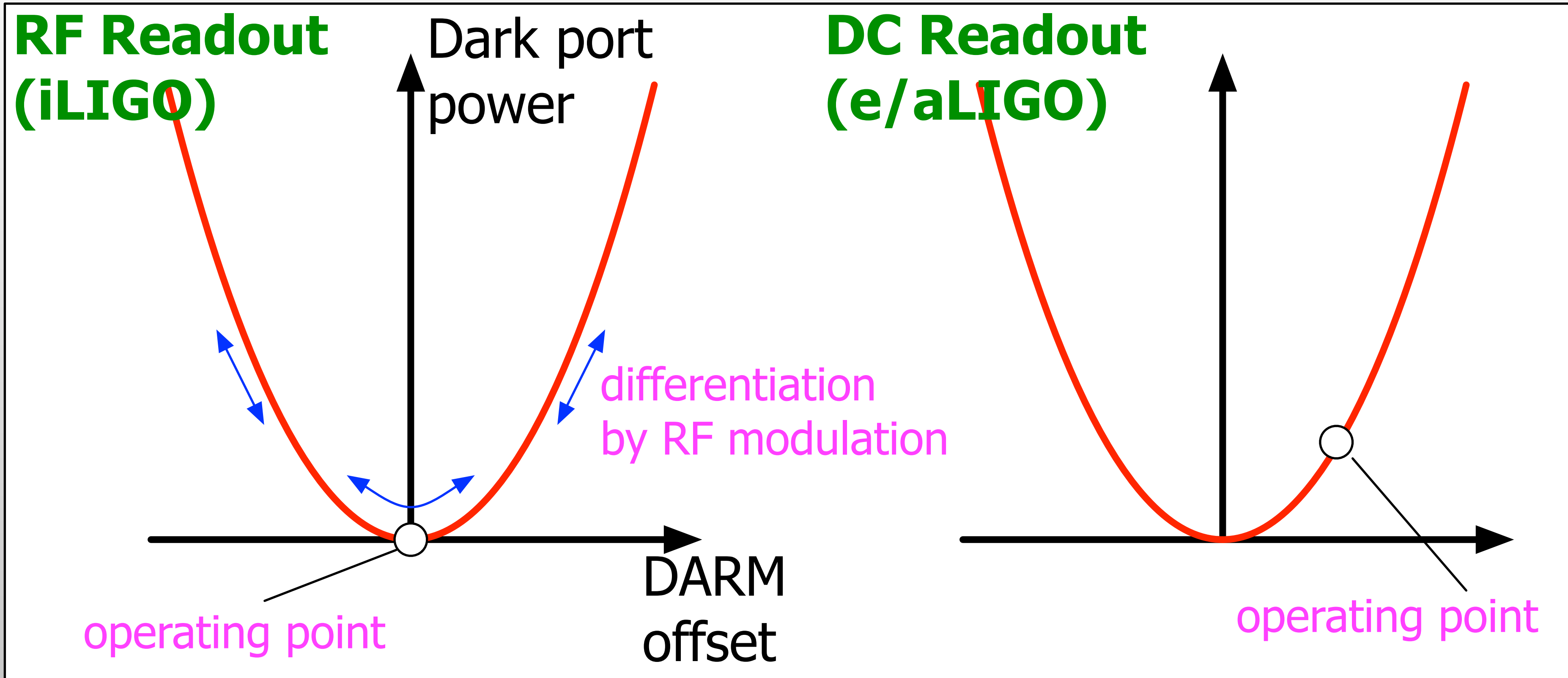


Why do we need the OMC?

DC Readout: G030460 T0900023 P1000009 G1101153

DC Readout

aLIGO employs "DC readout" scheme for sensing of GW signals



DC Readout is good:

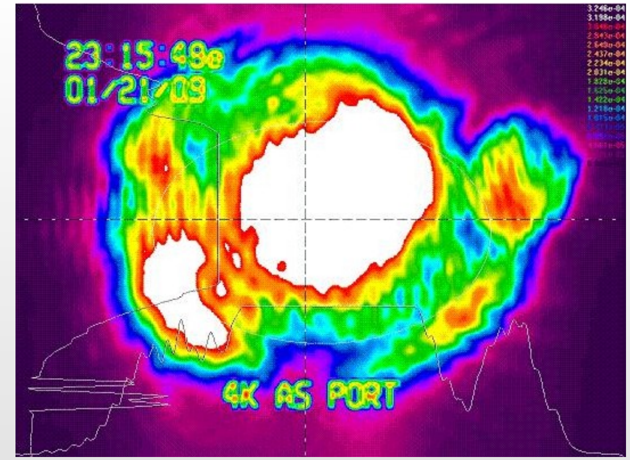
- removes nonstationary shot noise
- mitigates technical noises associated with the RF modulation

Why do we need the OMC?

Enemies of the DC Readout

- Carrier higher-order modes (HOMs)
- RF modulation sidebands (any spatial modes)

=> No contribution to the signal
and increase the shot noise



eLIGO AS port beam

Output mode cleaner

A short (~1m) optical cavity for the filtering of these optical fields

Filtering performance

higher finesse

Trade-off

lower finesse

Signal transmittance

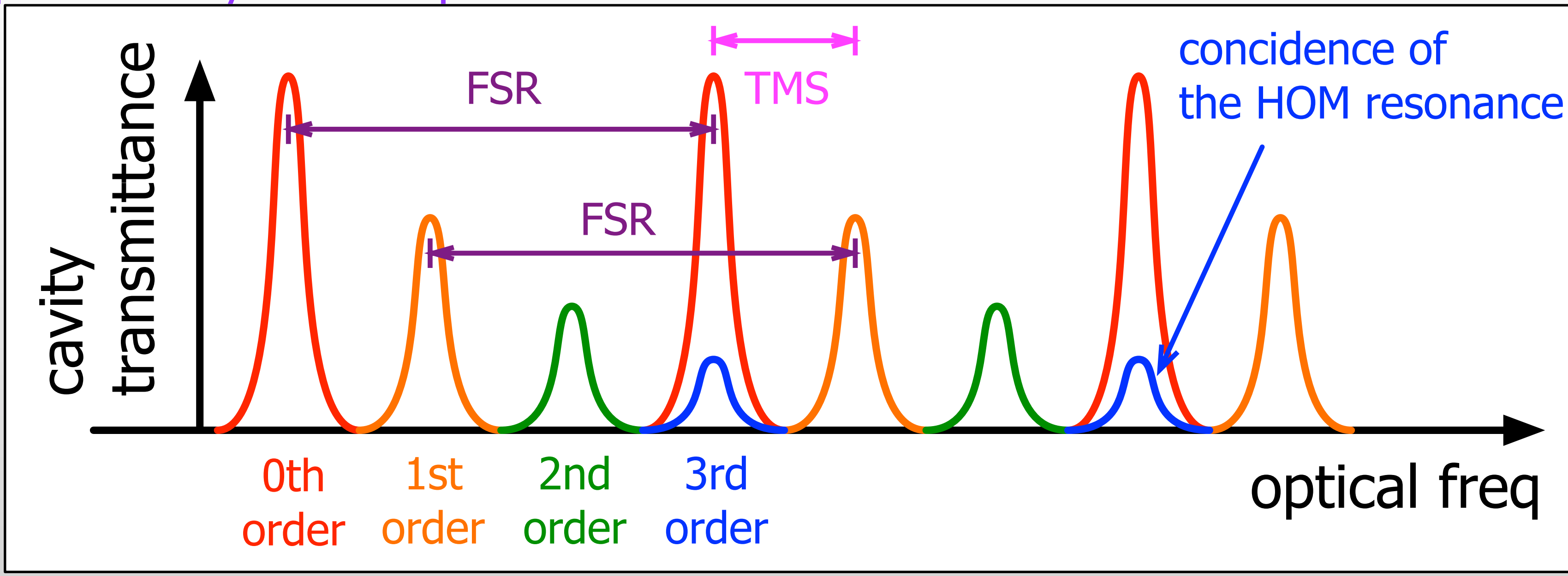
Finesse of our OMC:
~400, aiming for
~98% transmission
(in reality, 93~97%)

OMC Design: T1000276

How was it designed ~ Filtering Performance

Important parameter: Transverse Mode Spacing (TMS)

An optical cavity has a repetitive resonant structure



If TMS/FSR is a rational number (m/n) , n-th order HOMs get transmitted

TMS/FSR is dependent on the cavity geometry

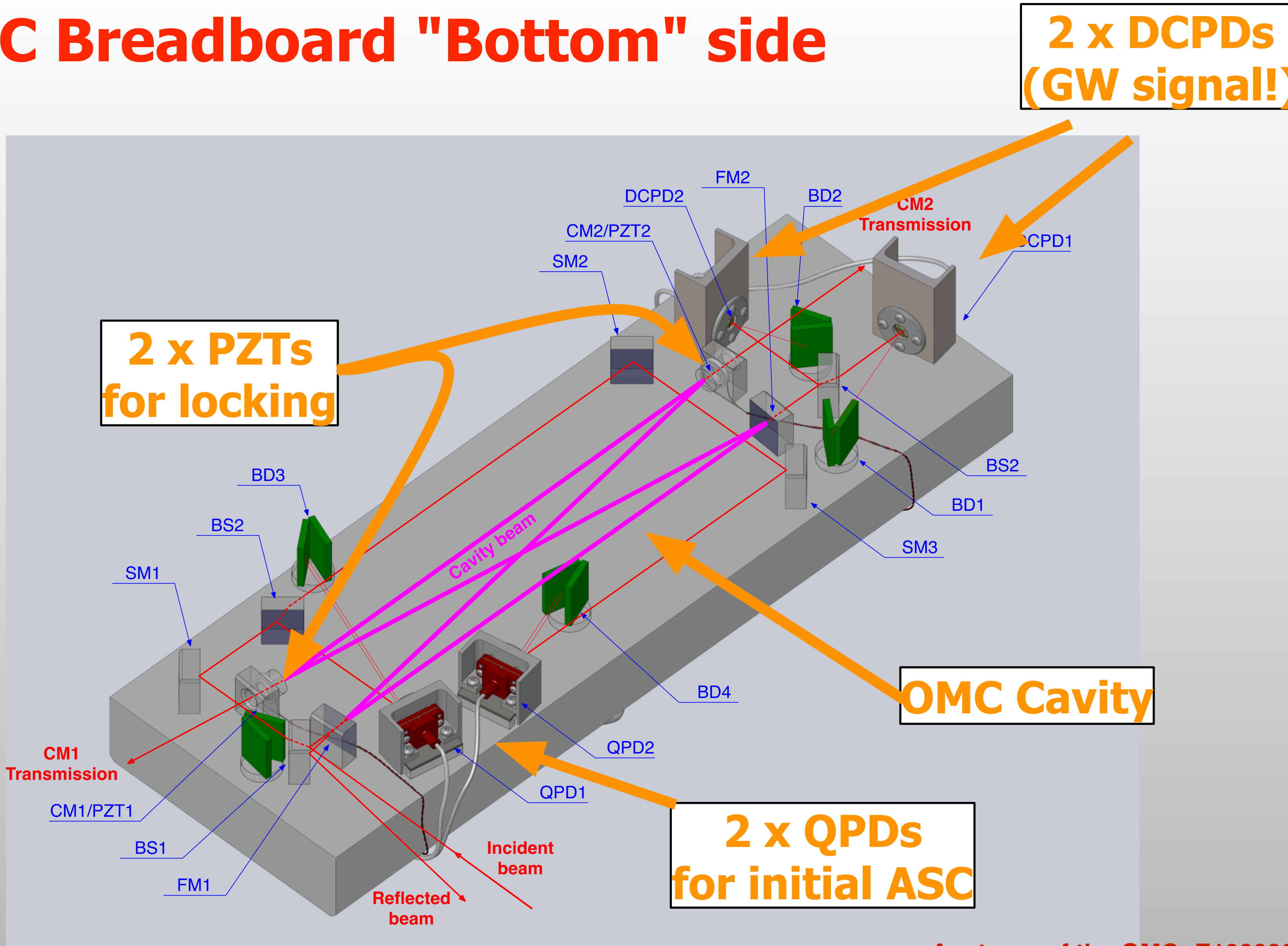
=>Careful adjustment of TMS/FSR is the key to avoid HOMs

The OMCs have been built so as to have the first coincident resonance of 32nd carrier higher order mode

OMC Design, Characterization: T1000276 G1300952 G1301001 T1500060

What's on the OMC?

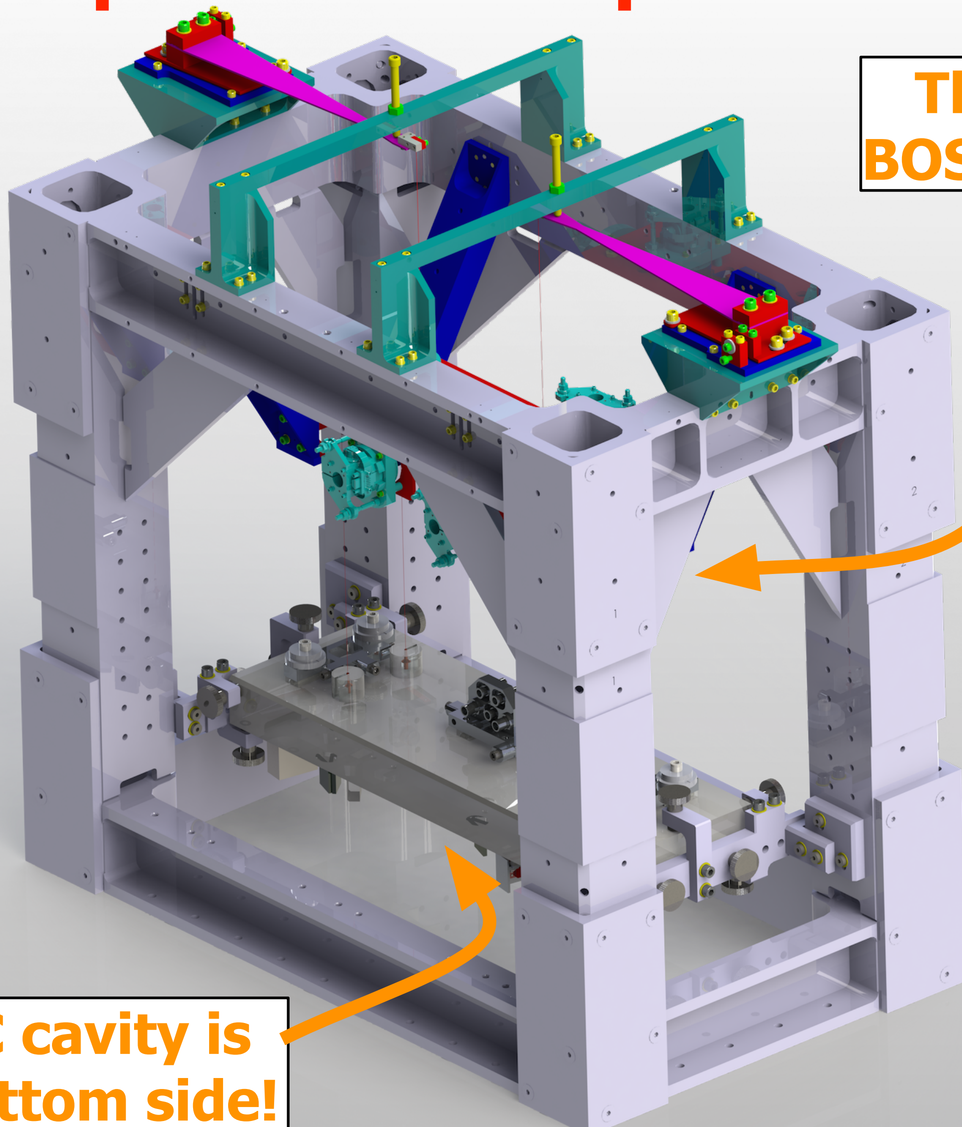
OMC Breadboard "Bottom" side



Anatomy of the OMC: E1300201

OMC Suspension (OMCS)

Double pendulum suspension



The middle stage has BOSEM sensor/actuators

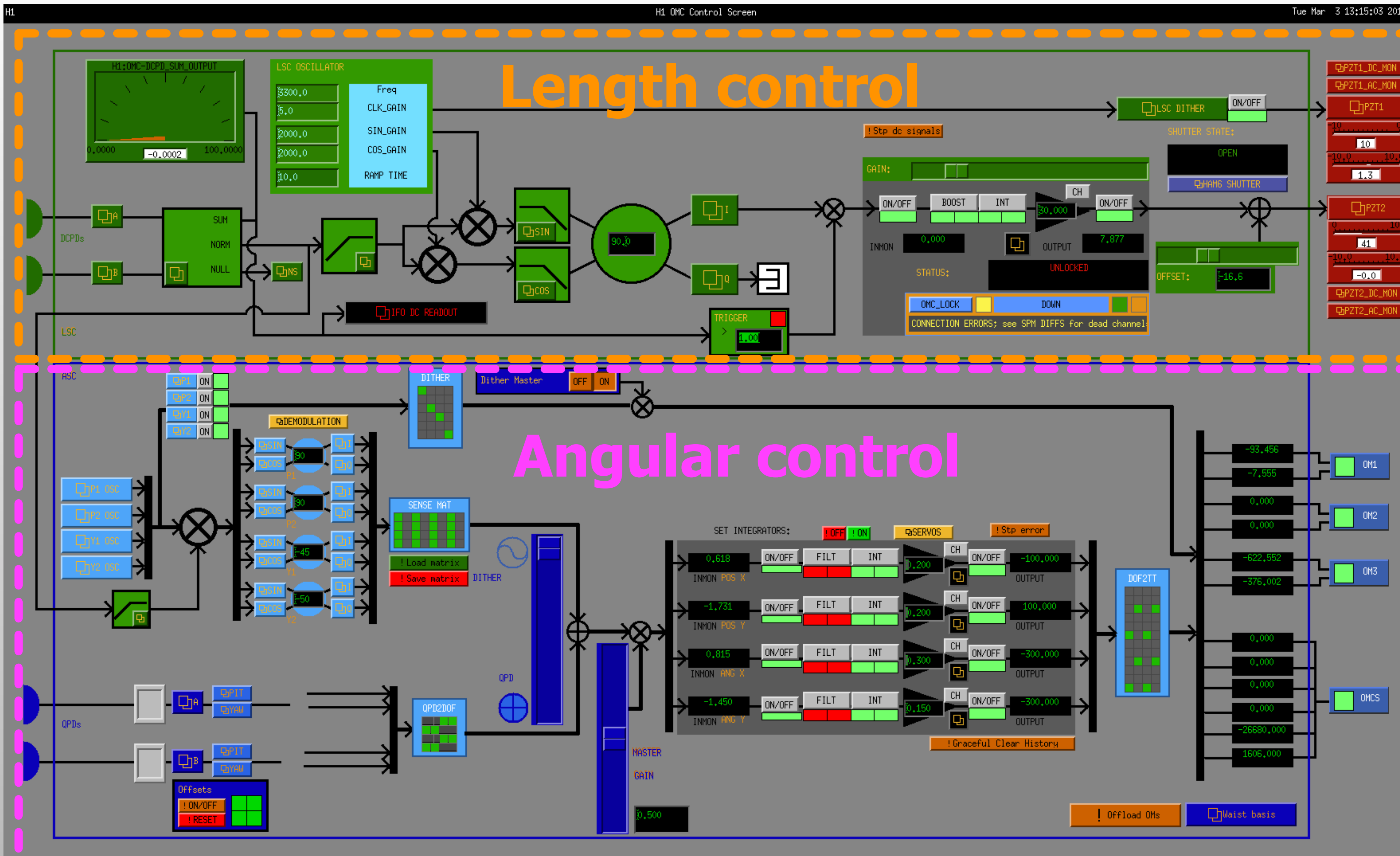
The OMC cavity is at the bottom side!

OMCS: D0900295 T080117

How is it controlled?

OMC control screen

Control / Noise: G1301007
RCG Codes & MEDM Screens: E1500161



How is it controlled?

OMC cavity length control

- Cavity length needs to be adjusted for the carrier TEM_{00} mode
  => Failing this induces **linear** coupling
  between the OMC length fluctuation to DARM
  => Otherwise it is **bilinear**

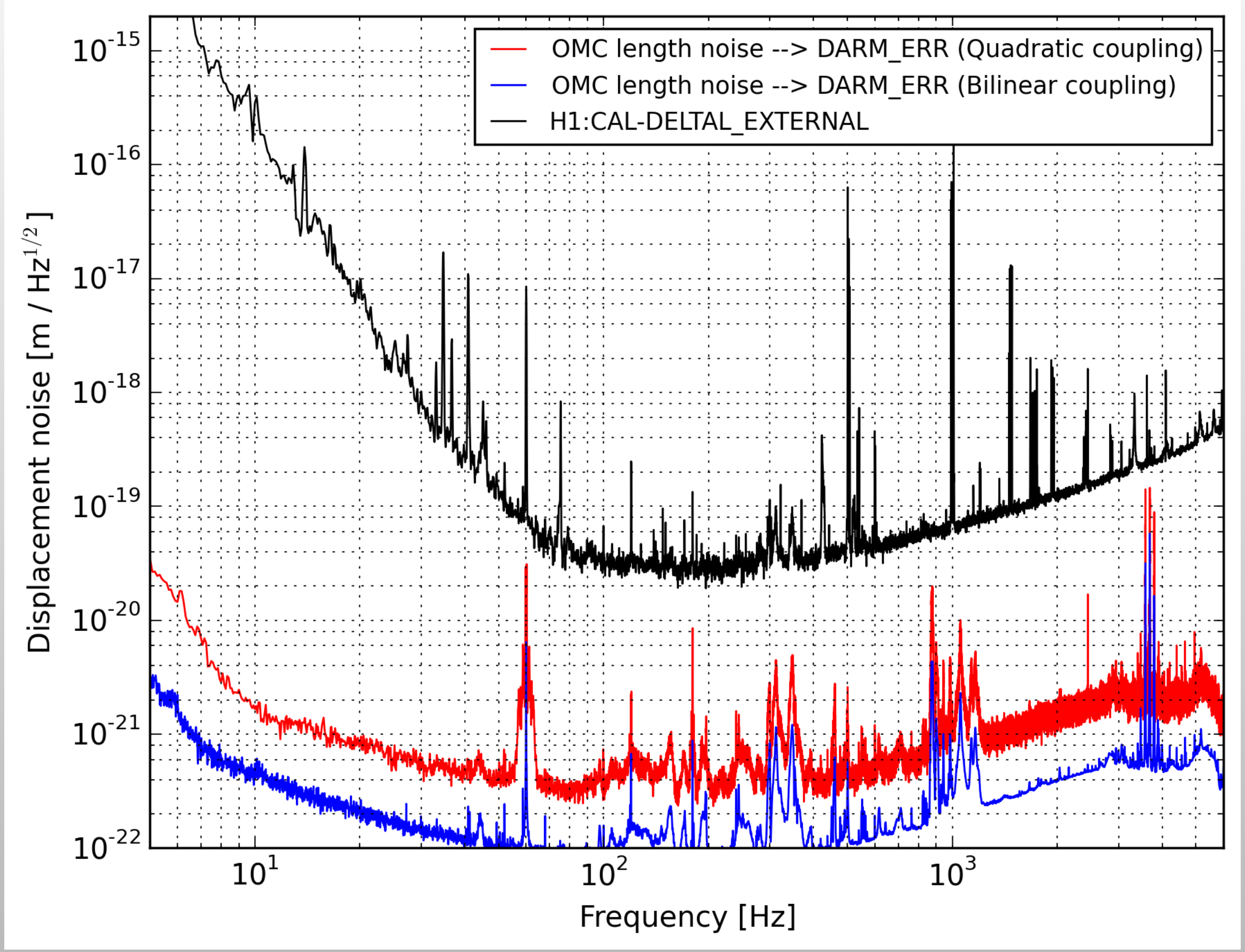
- Dither cavity length at f>1kHz
  => Demodulate the transmitted light at the modulation freq
  => Do not distinguish the modes: mode id necessary

Sensitive to the noise at the modulation frequency
(e.g. LHO ALOG 18034)

How is it controlled?

OMC cavity length noise coupling to DARM

(e.g. LHO ALOG 19212 by Dan Hoak)



How is it controlled?

OMC angular control

- Input beam alignment (4 dofs)
  - => Failing this induces **linear** coupling between the OMC beam alignment fluctuation to DARM

- Option1: Control with onboard OMC QPDs
  - => Robust, better S/N
  - => Difficult to determine the operating point? (How to do it if mode shape is constantly changing?)

- Input beam dither (above 1kHz) / transmission demodulation
  - => Maximize the transmission
  - => Low S/N & Slow

How is it controlled?

OMC angular control

- The beam on the OM1 is pinned by an ASC servo
  (AS_C QPD -> SR2 & SRM)

- Error signals in HAM6 (AS WFS A/B pointing 4dof, OMC ASC 4dof)
- Actuator in HAM6 (OM1-3 Pitch&Yaw = 6dof)
    => 2 actuator dofs missing!

LLO can operate without one of the WFS
    => ignore this pointing

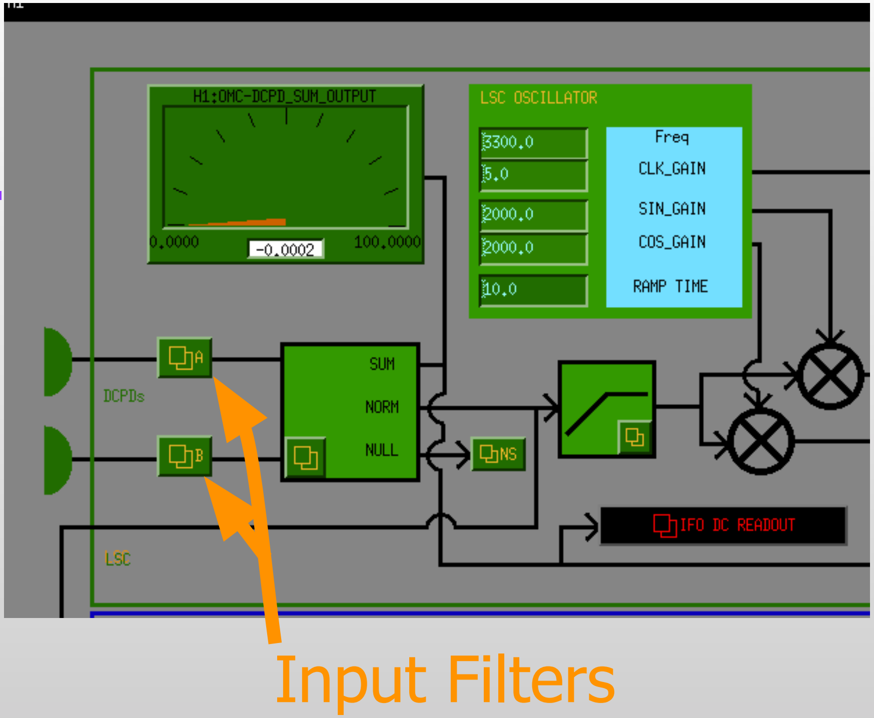
LHO needs both WFS for operation
    => Use OMCS as an actuator
    => Causes scattered light noise depending on the OMCS motion
        (OMs also cause this noise)

How is the DARM signal obtained

DC Readout

Normalization: T0900023
RCG Codes & MEDM Screens: E1500161
RCG Code: modification: LHO ALOG 18437

- The DARM signal: obtained from the sum of the two DCPD outputs.



- The DCPDs have in-vacuum preamplifiers and whitening (Characterization T1300552)

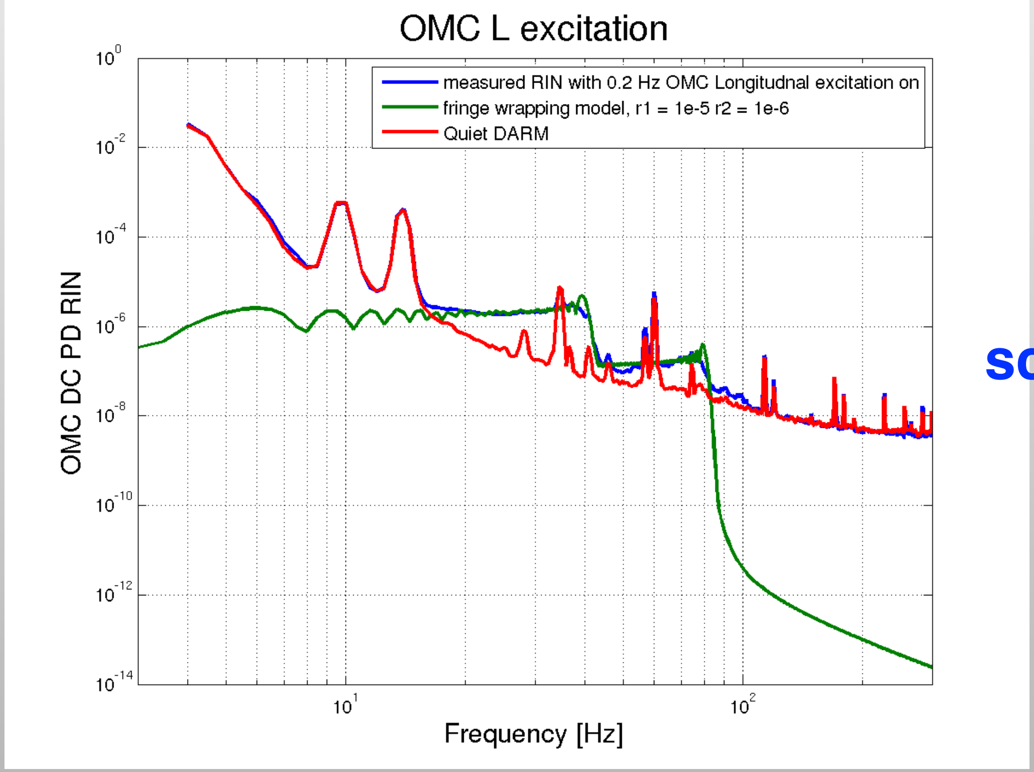
- The transfer functions of the in-vacuum amps have to be compensated by the input filters.
(This is a calibration matter, LHO ALOG 17647, LLO ALOG 18223)

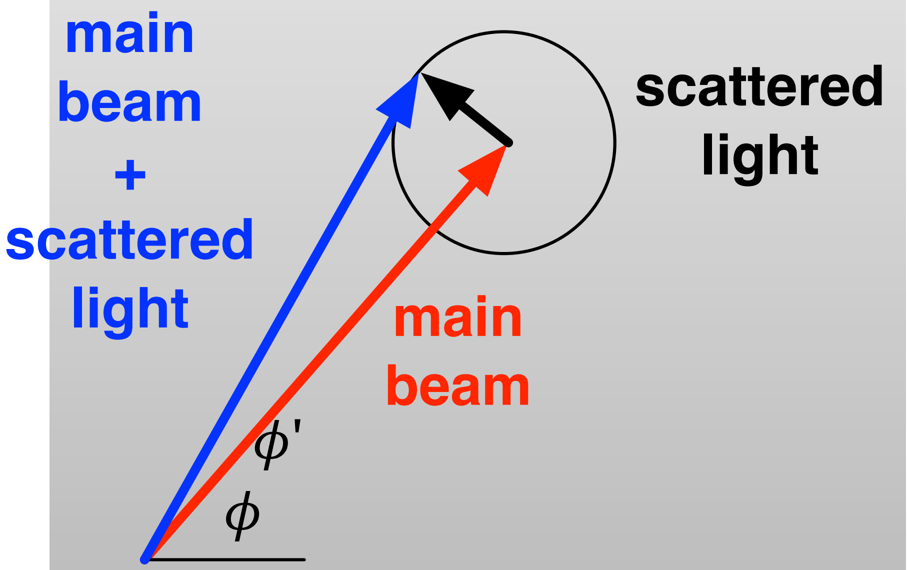
Scattered light noise

LIGO-G1500940
P16

Back scatter from/via the OMC

- Back propagates the optical path and couple to the arm field
- Scattering from or at the OMC: The first fringe wrapping shelf
- Scattering from the OMC reflection path: The second fringe wrapping shelf which has the twice fringe velocity.

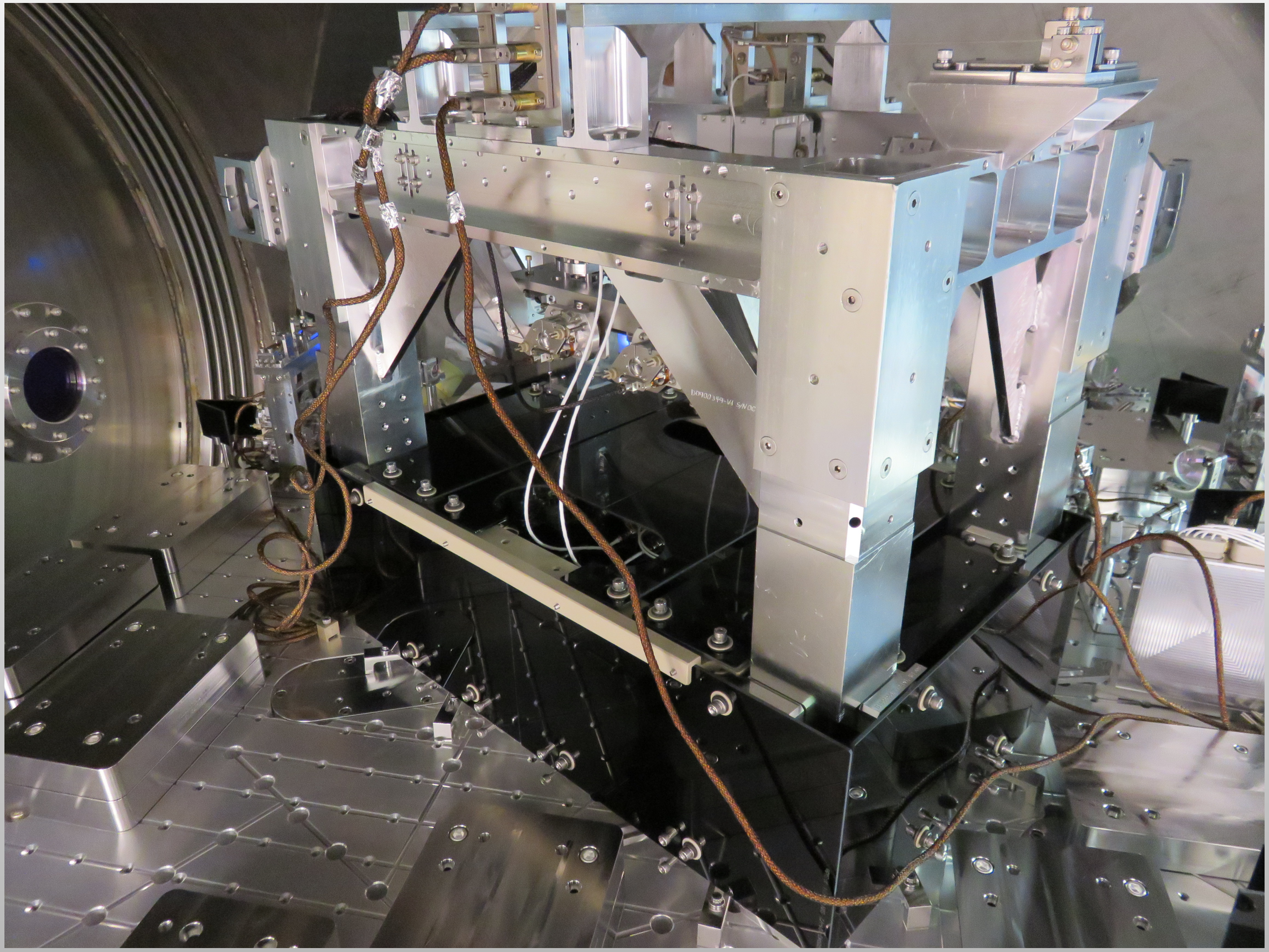




Scattered light noise

OMC Shroud

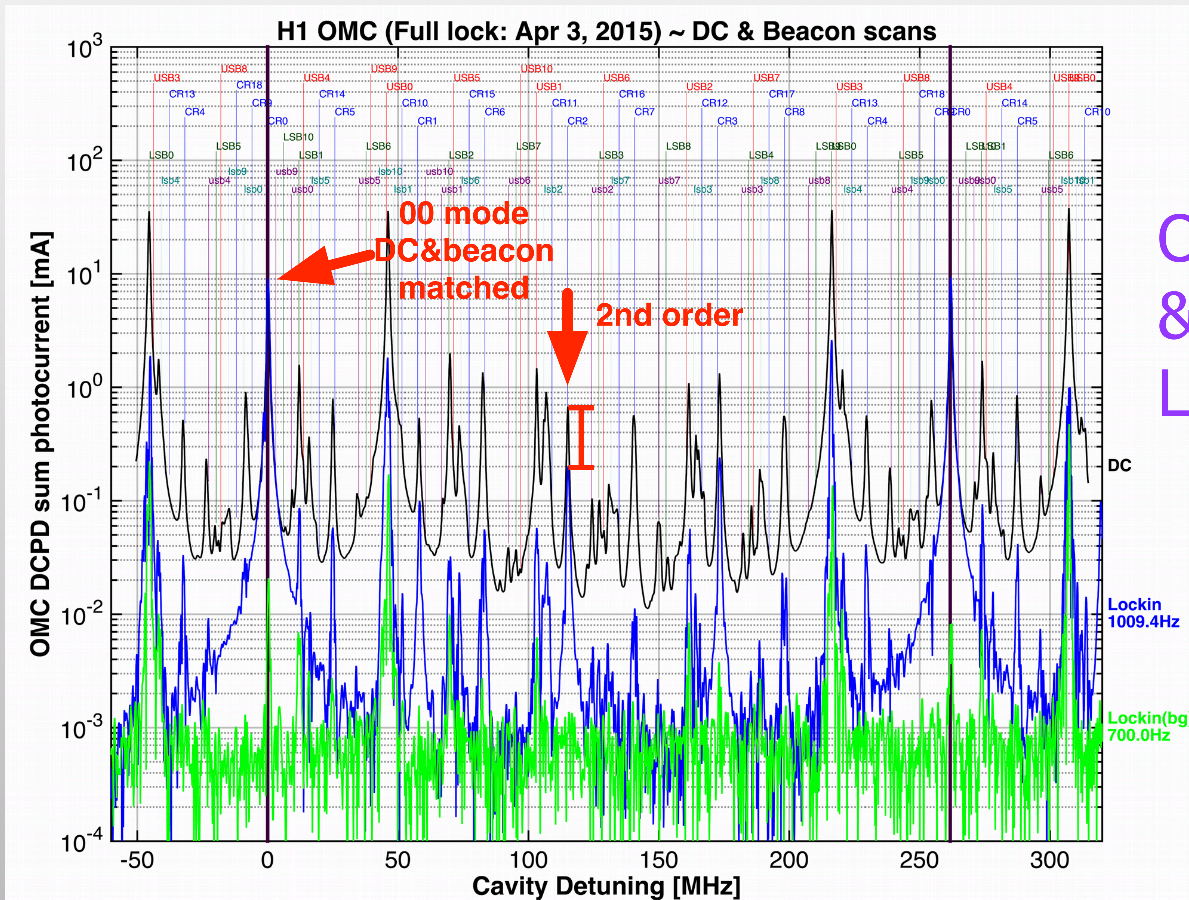
- Black glass beam baffles: The scattering that happens around the OMC breadboard will be attenuated.



Mode matching

OMC Mode mismatch

- Loss of the signal degrades the shot noise level: This would particularly become a problem when an input squeezing is used



OMC mode scan
& OMC beacon scan
LHO ALOG 17782

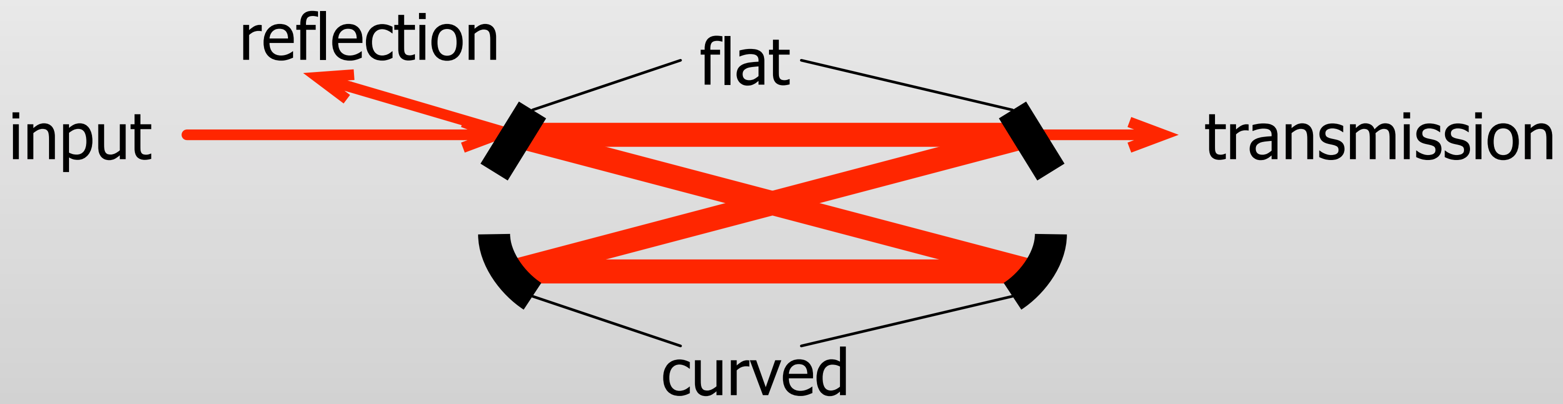
Low loss squeezing T1400715

Spare slides

OMC cavity design

Basically eLIGO OMC design was followed

- Bowtie 4-mirror ring cavity
  even mirrors => simpler HOM structure
  ring cavity => less back scattering



- Finesse: ~400 (for ~98% transmission)
  Roundtrip length ~1m (the breadboard size)
  Curved mirror radius ~2.5m

Filtering Performance

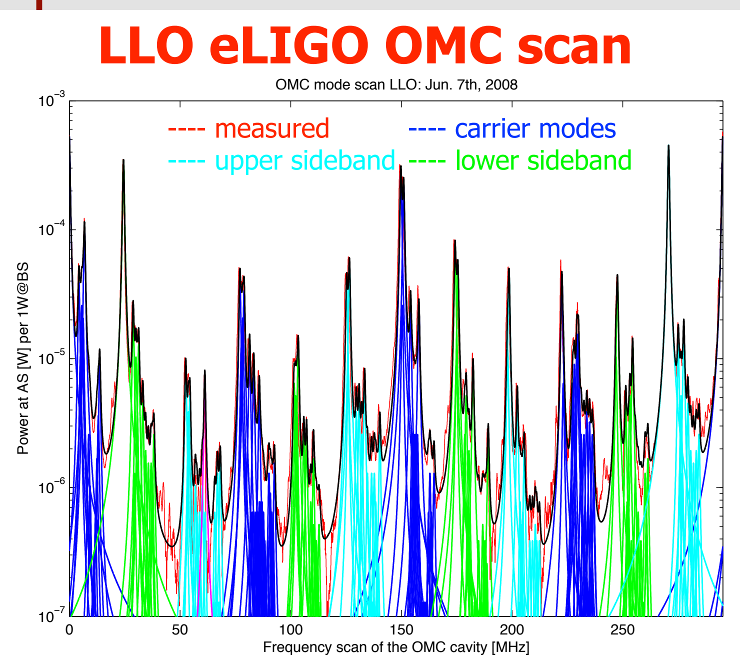
Estimation of the filtering performance

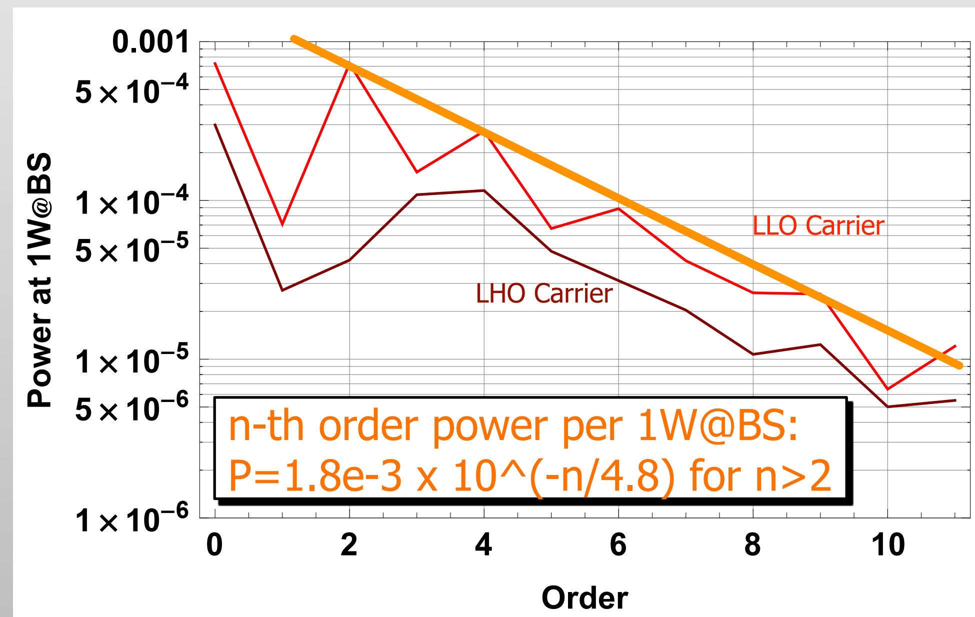
Total transmitted power

= $\sum$(power in each mode) x (transmission of each mode)

- Modeling of the interferometer output beam (details in G1201111)

power laws based on the eLIGO performance of the IFO optics



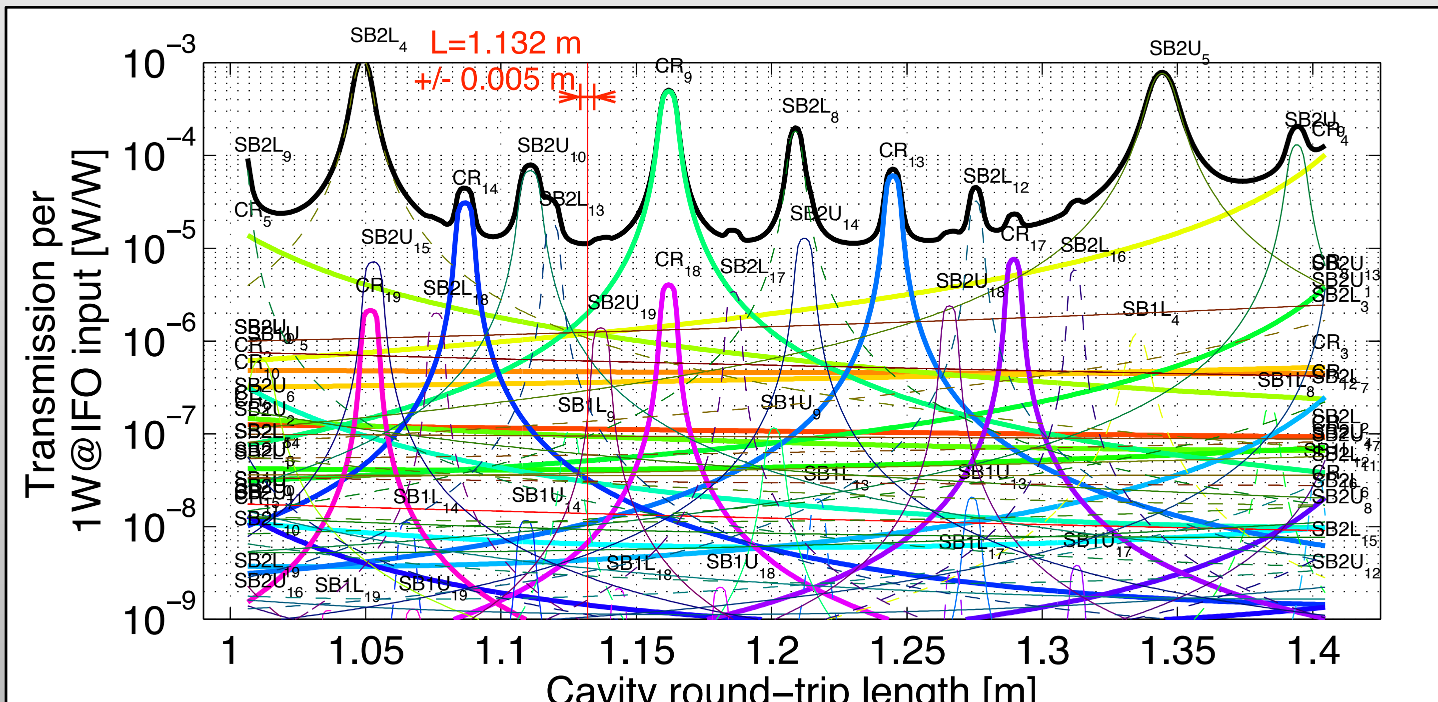


This wouldn't be a prediction, but have some usefulness, anyway

Filtering Performance

Estimated filtering performance

- Expected junk light power at the dark port (100W input = 4kW @BS)
  ~12W leakage => filtered down to 1mW. <u>Well within the PD capability.</u>
  This could become better thanks to mode healing and better optics in aLIGO
- Cavity length tolerance: L=1.132 +/– 0.005 [m]
- Mirror RoC tolerance: R=2.575 +/– 0.015 [m]



CRn - carrier n-th mode, SB(1,2)(U,L)n - sideband n-th mode,
SB1 - 9MHzSB, SB2 - 45MHz SB, U - upper SB, L - lower SB

Optical testing

Power Budget

Estimated from the input power, transmitted power, visibility, and cavity finesse

		Specfication
Cavity transmission for TEM_{00}:	97.8 %	98.4 %
Curved mirror transmission:	42 ppm	50 ppm
Loss per bounce:	22.3 ppm	10 ppm
Loss per roundtrip:	173 ppm	140 ppm
PD Q.E.	92%	
Total thruput of TEM_{00}	90%	(PD Q.E. = 92%)

About 20% total loss allowed for 6dB squeezing.

A half of the budget already eaten up by the OMC. **(not nice)**
These PDs were previously (eLIGO) reported to have Q.E.>95%
Need further investigation (or replacement)