Experimental update from the 40m team

40m TAC meeting

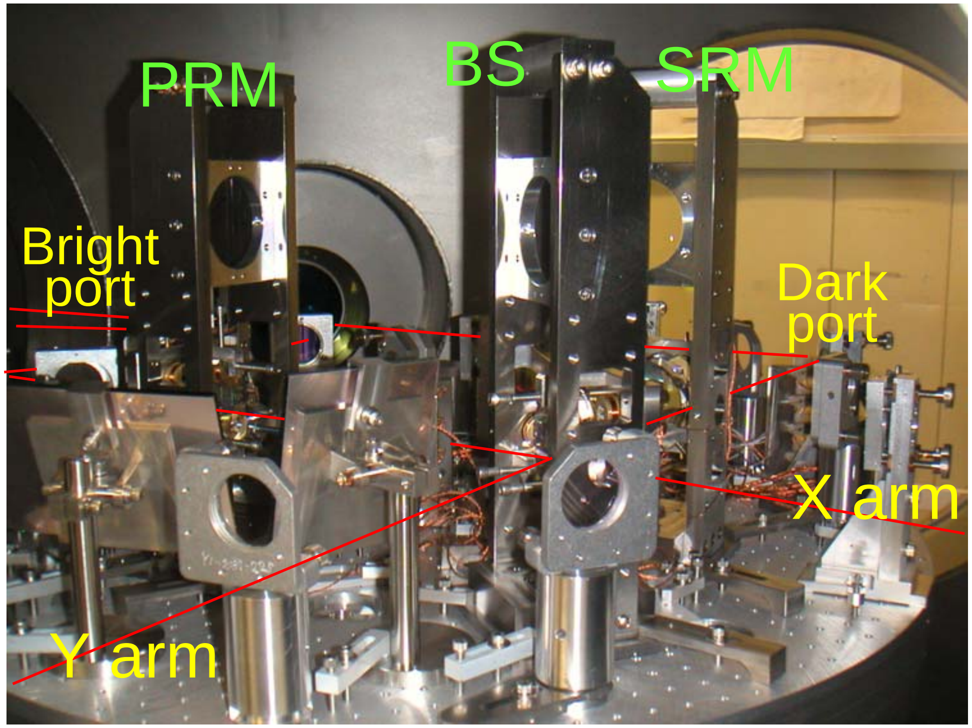
May 13, 2005

O. Miyakawa, Caltech
and the 40m collaboration

Caltech 40 meter prototype interferometer

Objectives

- Develop **lock acquisition procedure** of detuned Resonant Sideband Extraction (RSE) interferometer, as close as possible to Advanced LIGO optical design
- Characterize noise mechanisms
- Verify optical spring and optical resonance effects
- Develop DC readout scheme
- Extrapolate to AdLIGO via simulation
- etc.



Important Milestones

2003

Sept. Installation of Four TMs and BS***:done***

Oct. Lock of FP Michelson ***:done***

2004

Feb. Installation of Power Recycling Mirror (PRM) ,Signal Recycling Mirror (SRM) ***:done***

June. Installation Mach-Zehnder to eliminate sideband of sideband ***:done***

Oct. DRMI locked using Double Demodulation(DDM) ***:done***

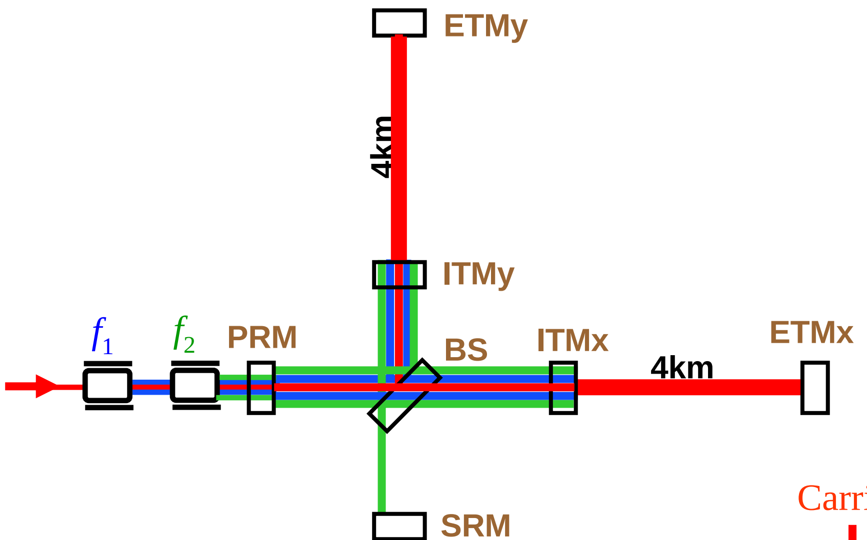
Nov. Both arms locked with off-resonance ***:done***

2005

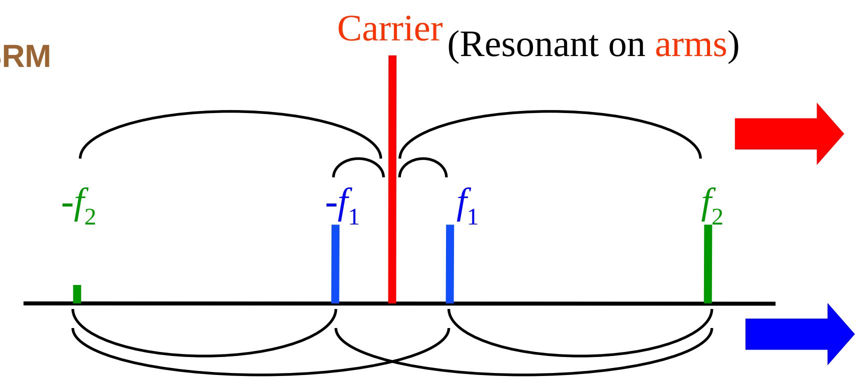
RSE ***:in progress***

Full lock is soon!

AdLIGO signal extraction scheme



- Two modulations are used to separate high finesse, 4km long arm cavity signals from Central part (Michelson, PR, SR) signals.
- Only + f_2 is resonant on SRC
- Unbalanced sidebands of +/-f_2 make error signal of Central part



- Single demodulation
- Arm information

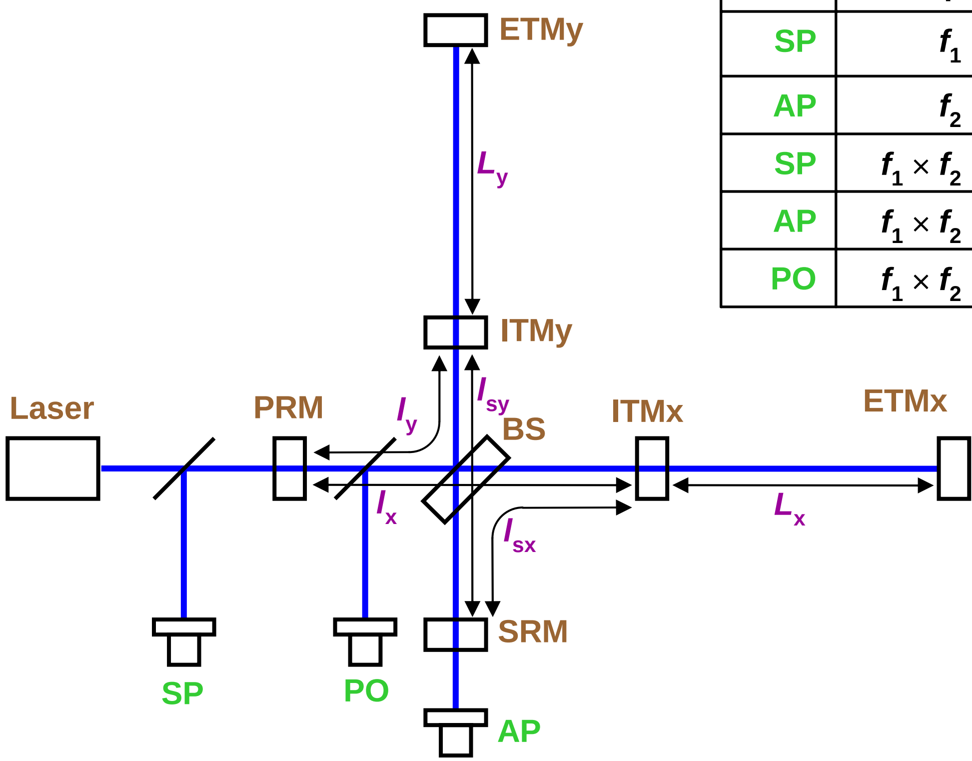
- Double demodulation
- Central part information

- Arm cavity signals are extracted from beat between carrier and f_1 or f_2.
- Central part (Michelson, PR, SR) signals are extracted from beat between f_1 and f_2, not including arm cavity information.

5 DOF for length control

Signal Extraction Matrix (in-lock)

Port	Dem. Freq.	L_+	L_-	l_+	l_-	l_s
SP	f_1	1	-3.8E-9	-1.2E-3	-1.3E-6	-2.3E-6
AP	f_2	-4.8E-9	1	1.2E-8	1.3E-3	-1.7E-8
SP	$f_1 \times f_2$	-1.7E-3	-3.0E-4	1	-3.2E-2	-1.0E-1
AP	$f_1 \times f_2$	-6.2E-4	1.5E-3	7.5E-1	1	7.1E-2
PO	$f_1 \times f_2$	3.6E-3	2.7E-3	4.6E-1	-2.3E-2	1



Common of arms : $L_+ = (L_x + L_y) / 2$

Differential of arms : $L_- = L_x - L_y$

Power recycling cavity : $l_+ = (l_x + l_y) / 2$

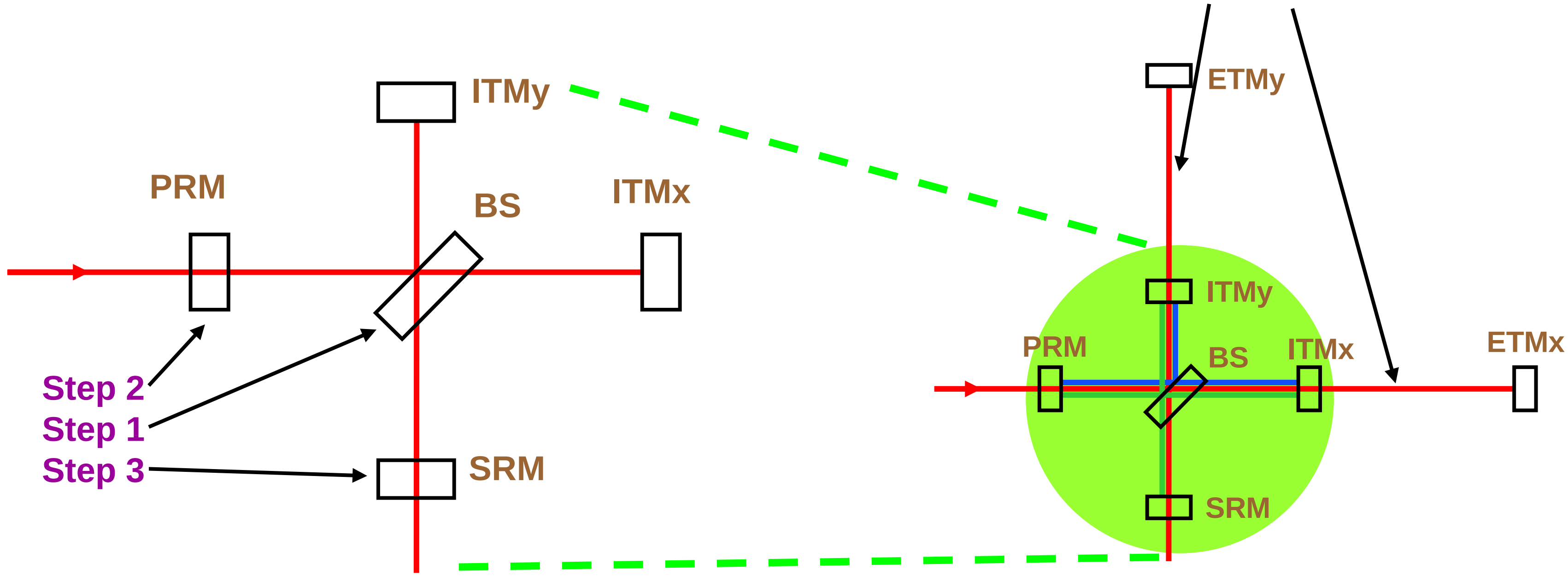
Michelson : $l_- = l_x - l_y$

Signal recycling cavity : $l_s = (l_{sx} + l_{sy}) / 2$

Lock Acquisition of Detuned RSE

1. lock central part

2. lock arm cavities



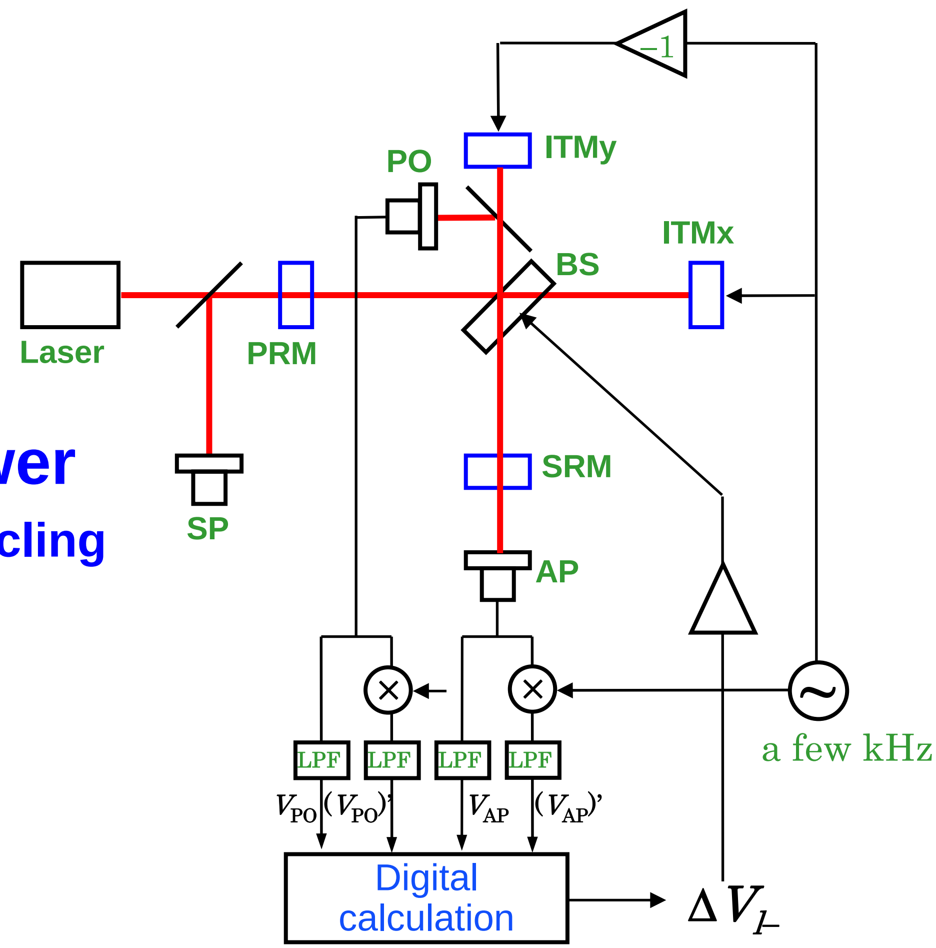
- Central part: not disturbed by carrier resonance on arm cavity (but disturbed by sidebands resonance)
- Arm cavities: not disturbed by locked central part
- Lock acquisition — After lock:
  - I_- : dither @ 1200 Hz → DDM@AP
  - I_+ : 33MHz@SP → DDM@SP
  - I_s : DDM@PO → DDM@PO

Looking for good signal for lock acquisition

- **Dither locking for l_- signal**
- **Divide signal by inside power**
  - » **Good cancellation of power recycling**

$$\Delta V_{l_-} = \frac{d}{d\,l_-}\left(\frac{V_{\mathrm{AP}}}{V_{\mathrm{PO}}}\right)$$

$$= \frac{V'_{\mathrm{AP}}\,V_{\mathrm{PO}} - V_{\mathrm{AP}}\,V'_{\mathrm{PO}}}{V_{\mathrm{PO}}^{\ 2}}$$



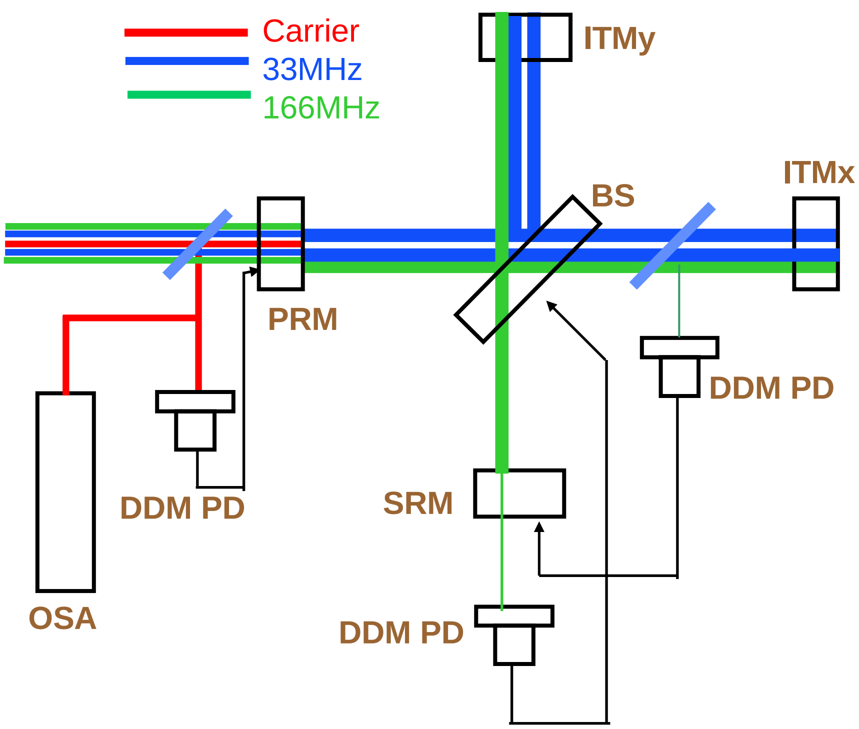
DRMI lock using double demodulation with Unbalanced sideband by detuned cavity

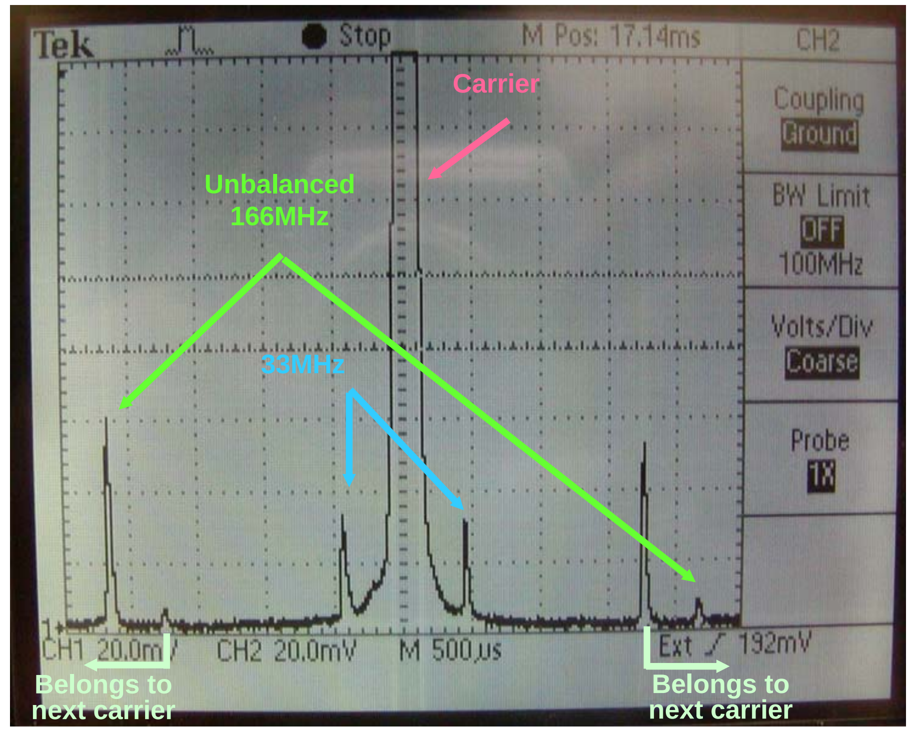
August 2004

- **DRMI locked with carrier resonance (like GEO configuration)**

November 2004

- **DRMI locked with sideband resonance (Carrier is anti resonant preparing for RSE.)**





Typical lock acquisition time : ~10sec
Longest lock : 2.5hour

Struggling lock acquisition for Arms

Problems

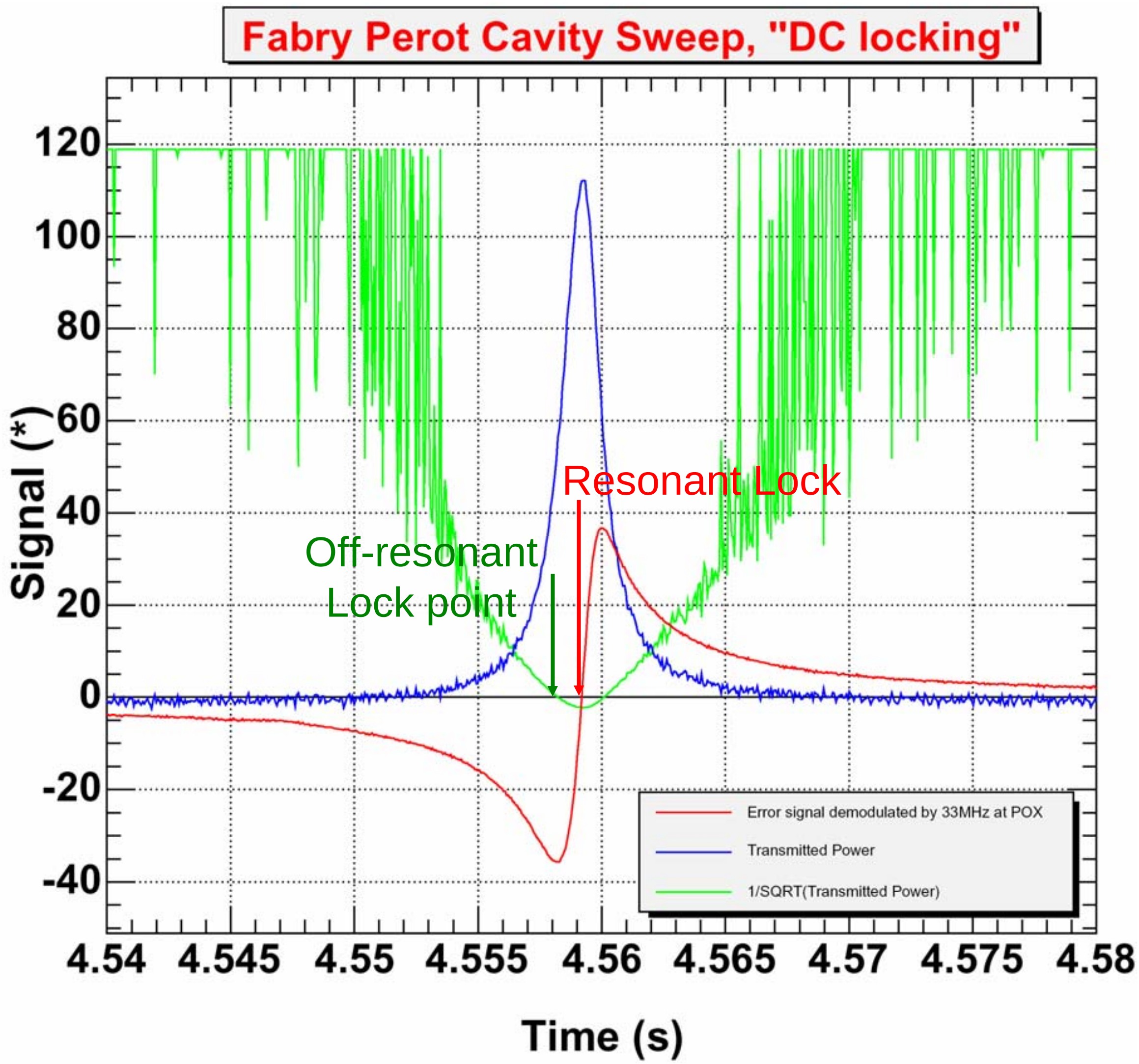
1. Too fast mirror motion on Xarm due to poor ITMX damping(?)
2. High recycling gain of ~15 produces large coupling between two arms
3. Very High combined finesse of ~18000
4. Slow sampling rate of 16kHz for direct lock acquisition

For Arm lock

We have two steps.

1. Middle resonance of carrier using "Off-resonant DC lock" scheme ***…done***
2. Remove offset to have full resonance of carrier ***…in progress***

Off-resonant DC lock scheme for arm cavity



Error signal is produced by transmitted light as

$$\frac{1}{\sqrt{\text{Transmitted power}}} + \text{offset}$$

Off resonant DC transmission
Arm lock with DRMI

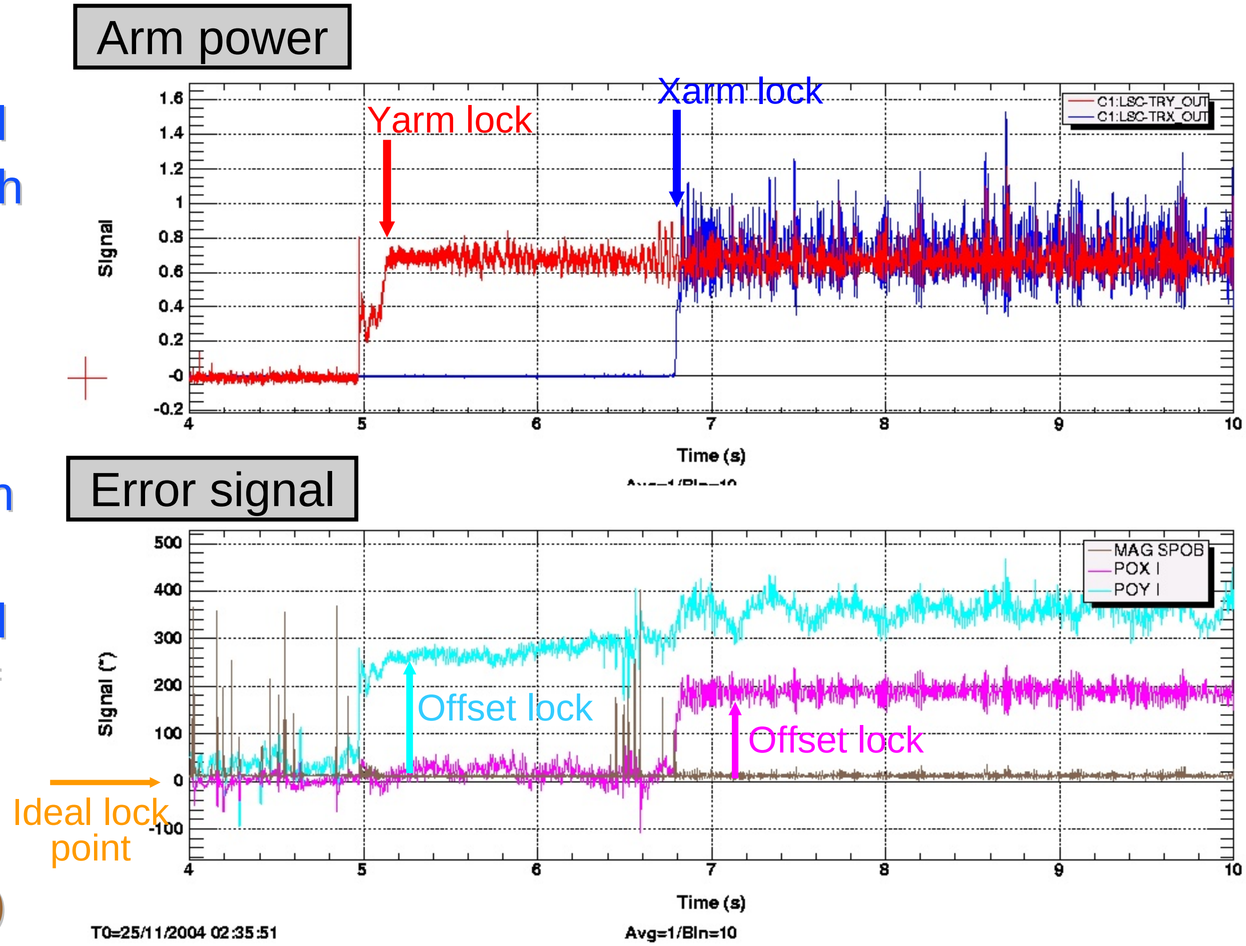
DRMI with single arm lock

- Lock acquisition time ~1 min
- Can be switched to RF signal
- Full carrier was stored in each arm cavity separately

Both arms lock with DRMI

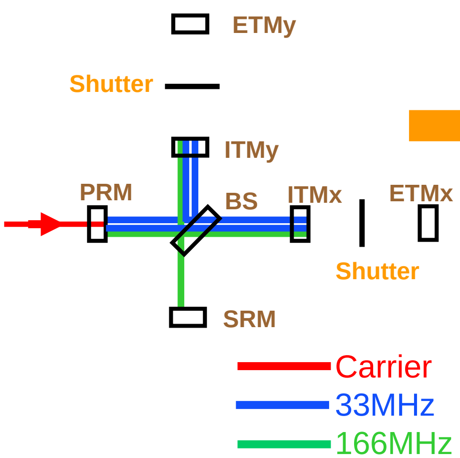
- Lock acquisition time ~10 min
- Lasts ~ 10 min
- Can be switched to RF signal
- ~200 times dynamic range of carrier resonance

  >>Needs second transmitted PD (low noise/high dynamic range)



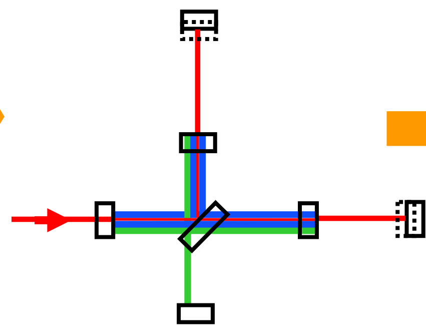
The way to full RSE

DRMI using DDM



Done

Off-resonant arms using DC lock



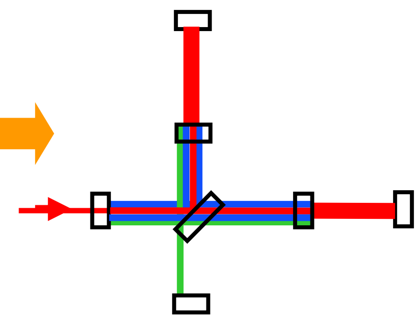
Done

Ideas for arm control signal

- (POX/TrX), (POY/TrY)
- (POX/TrX) + (POY/TrY), (POX/TrX) – (POY/TrY)
- SP166/PRC, AP166/PRC
- (TrX + TrY), (TrX – TrY) / (TrX + TrY)

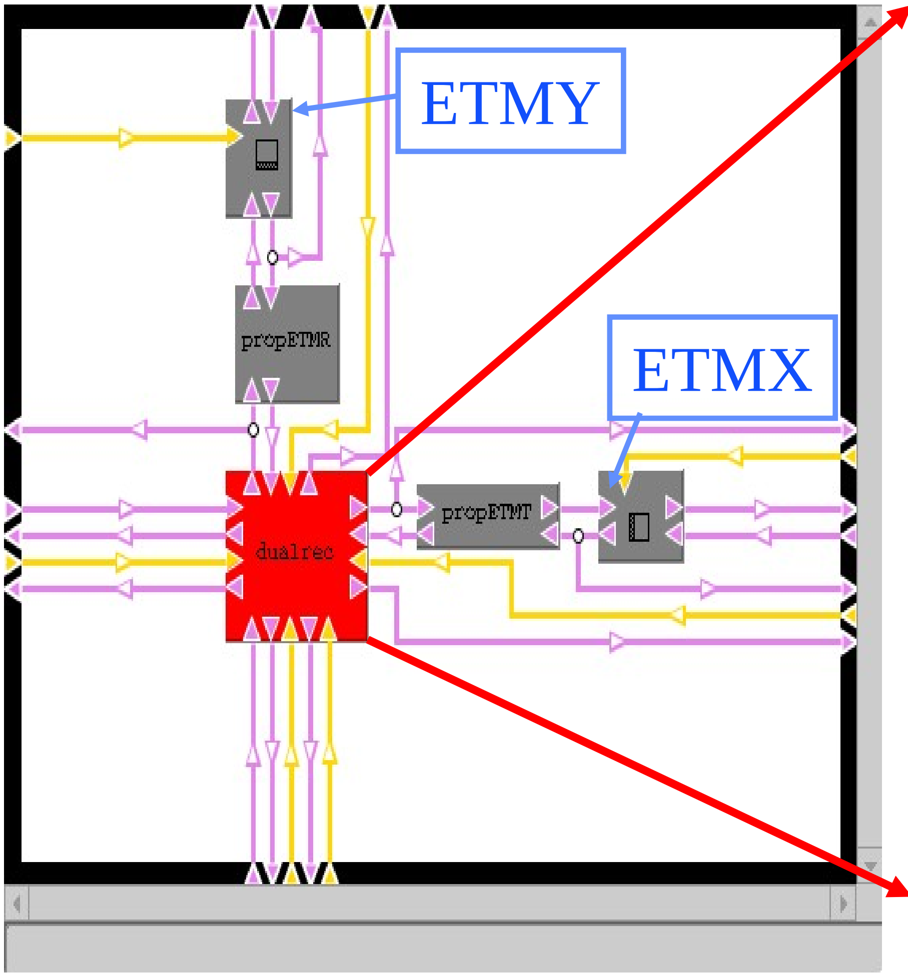
In progress

RSE

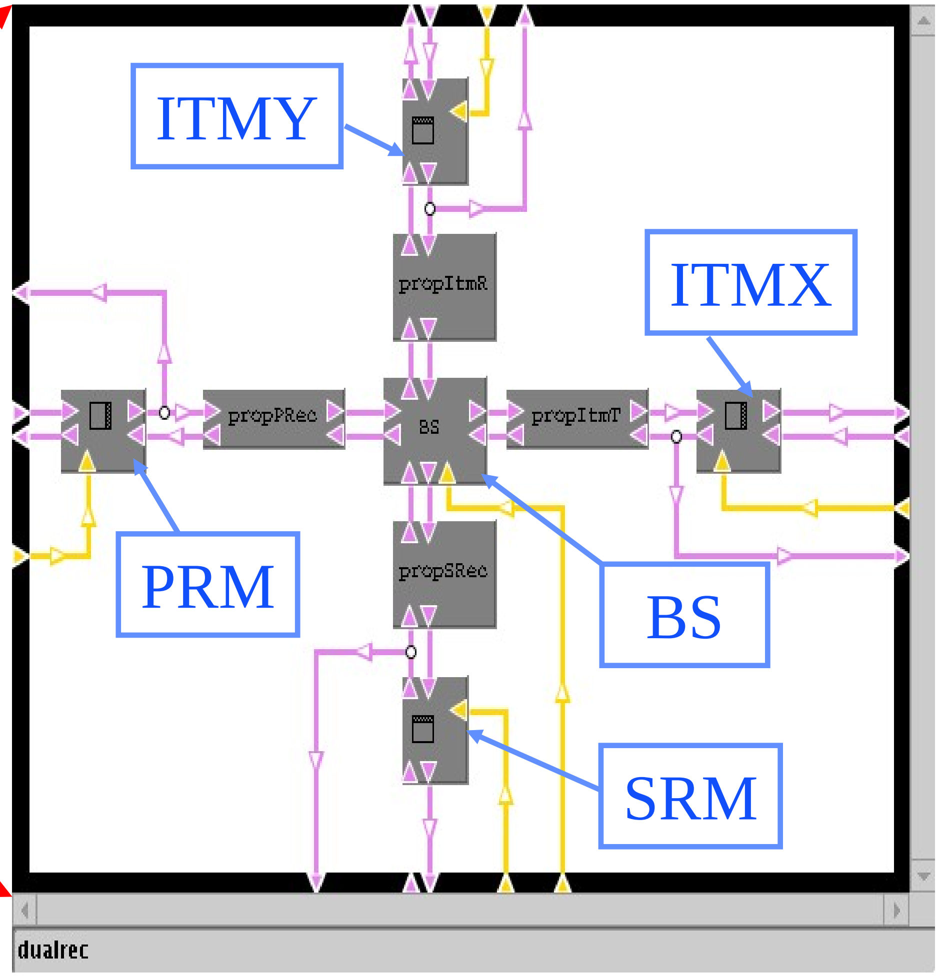


e2e SIMULATION: 40m/AdvLIGO package optical configuration

IFO with Arms



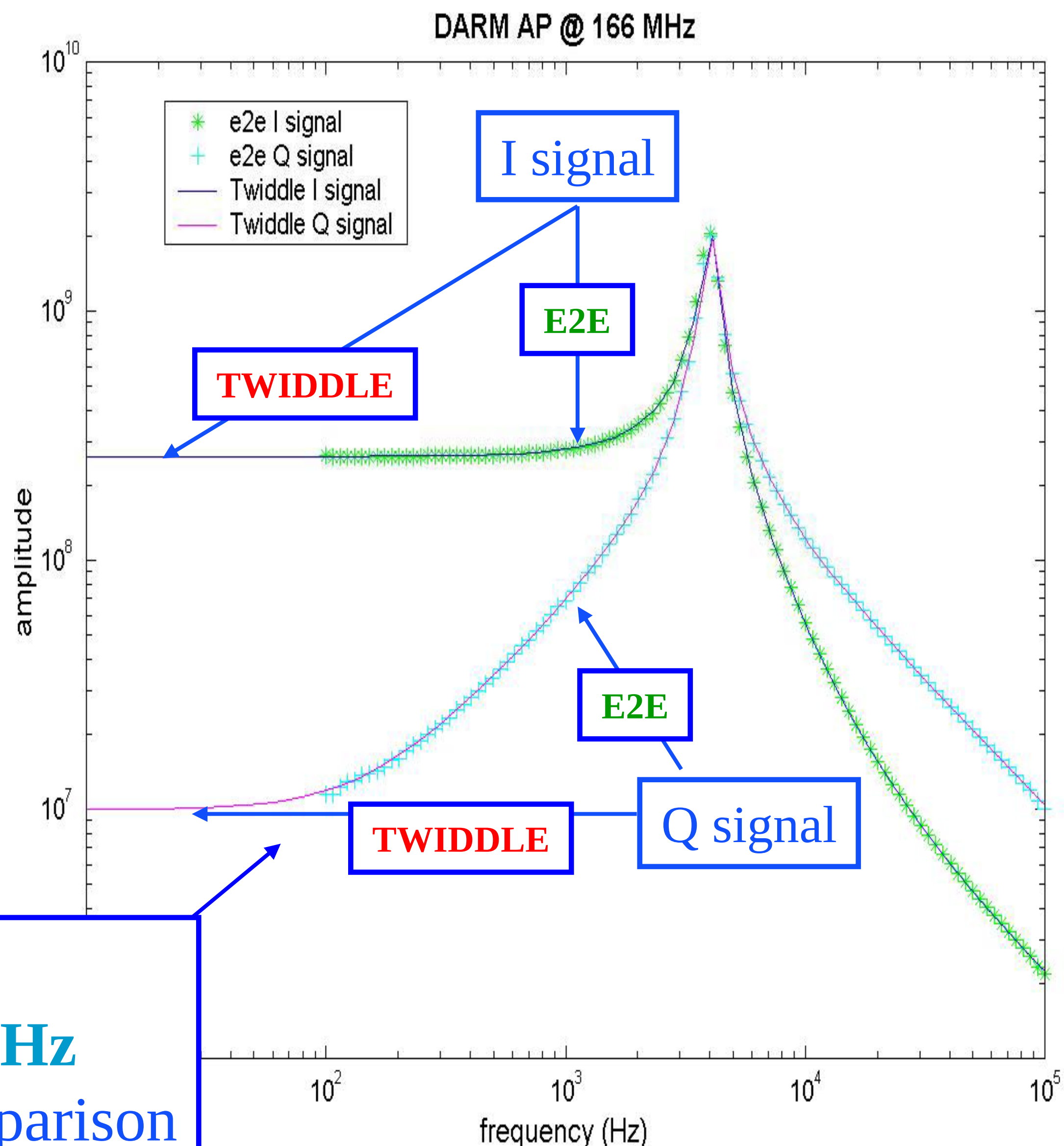
IFO Central part



e2e SIMULATION: 40m/AdvLIGO package

- E2E validation of DC fields comparing with TWIDDLE results: good agreement !

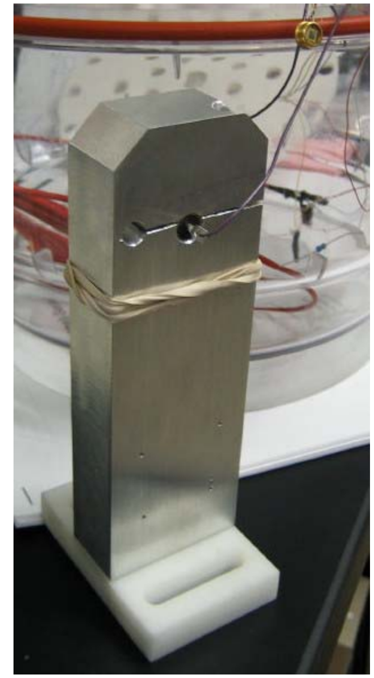
- E2E transfer functions simulations (and comparison with TWIDDLE ones) of DOF at SP, AP and PO shaking the end mirrors with *white noise* at different demodulation frequencies : (33,133,166,199) MHz

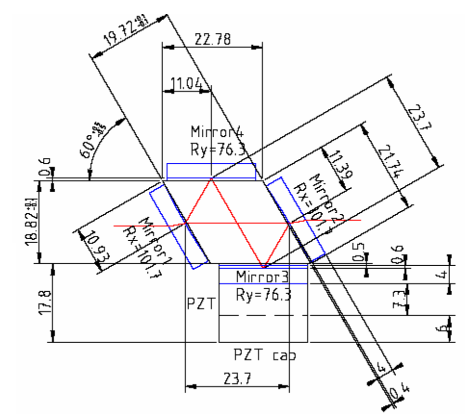


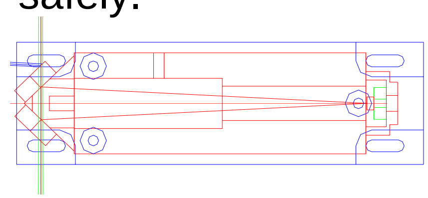
Example:
DARM @ **AP 166 MHz**
TWIDDLE and E2E comparison

DC Readout at the 40m

- Homodyne detection (via a DC readout scheme) has been chosen as the readout scheme for AdLIGO.
  - » DC Readout eliminates several sources of technical noise (mainly due to the RF sidebands):
    - – Oscillator phase noise
    - – Effects of unstable recycling cavity.
    - – The arm-filtered carrier light will serve as a heavily stabilized local oscillator.
    - – Perfect spatial overlap of LO and GW signal at PD.
  - » DC Readout has the potential for QND measurements, without major modifications to the IFO.
- We can use a 3 or 4-mirror OMC to reject RF sidebands.
  - » Finesse ~ 500
  - » In-vacuum, on a seismic stack.
- The DC Detection diode
  - » an aluminum stand to hold a bare photodiode, and verified that the block can radiate 100 mW safely.

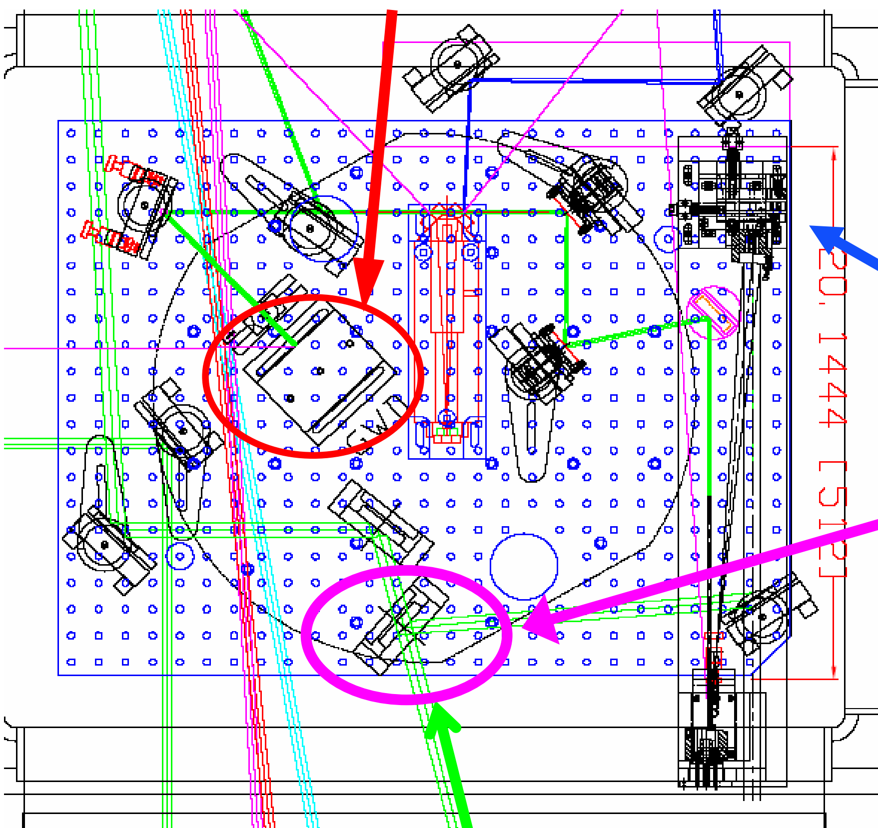






OMC Beam Steering :
A preliminary layout is ready to go

The Diode



From SRM

Existing in-vac seismically isolated optical table

Mike Smith has designed a compact, monolithic MMT, similar to our input MMT. We'll be using spherical mirrors.

This will actually be the second PZT steering mirror. The first mirror after the SRM will also be a PZT steering mirror.

- Ready for a review in late this month