Progress report from 40m team for the Advanced LIGO optical configuration

LSC meeting

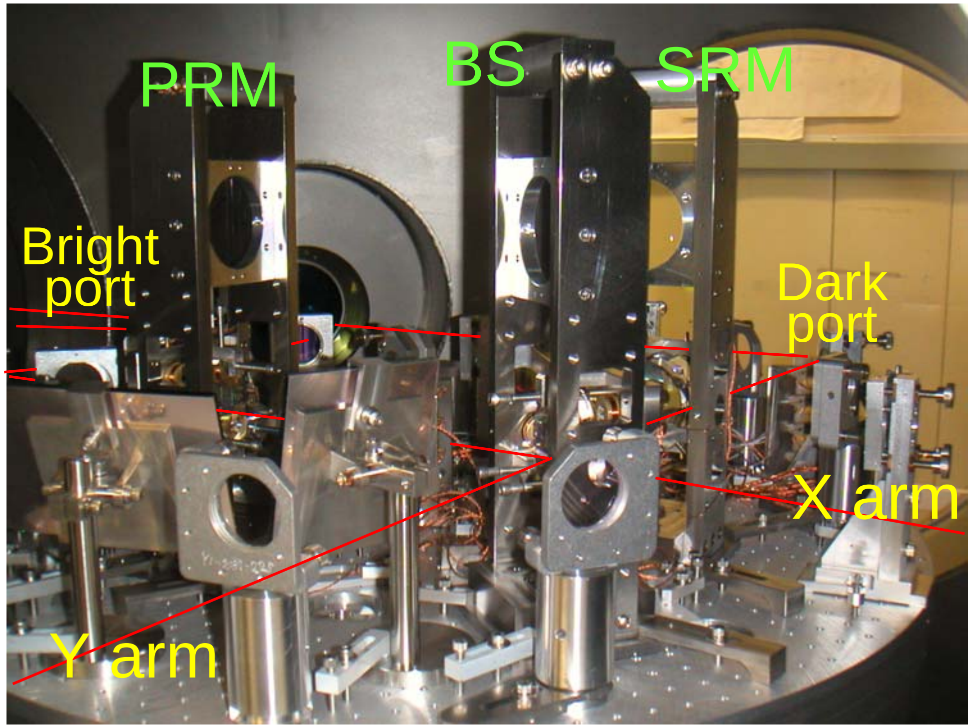
August 15, 2005

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 AdLIGO optical design
- Characterize noise mechanisms
- Verify optical spring and optical resonance
- Develop DC readout scheme
- Extrapolate to AdLIGO via simulation

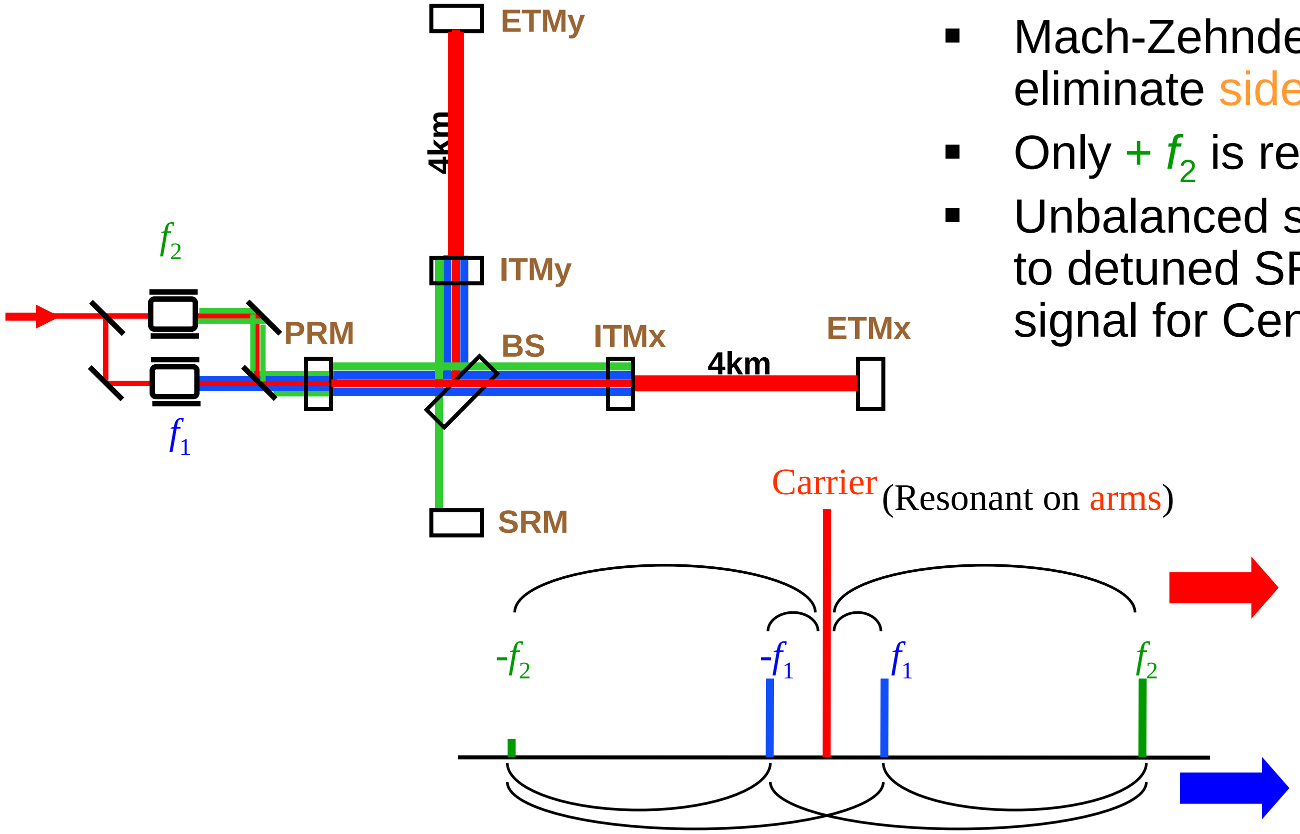


Differences between AdvLIGO and 40m prototype

- 100 times shorter cavity length
- Arm cavity finesse at 40m chosen to be = to AdvLIGO (= 1235)
  - » Storage time is x100 shorter.
- Control RF sidebands are 33/166 MHz instead of 9/180 MHz
  - » Due to shorter PRC length, less signal separation.
- LIGO-I 10-watt laser, negligible thermal effects
  - » 180W laser will be used in AdvLIGO.
- Noisier seismic environment in town, smaller stack
  - » ~1x10^{-6}m at 1Hz.
- LIGO-I single pendulum suspensions are used
  - » AdvLIGO will use triple (MC, BS, PRM, SRM) and quad (ITMs, ETMs) suspensions.

AdLIGO signal extraction scheme

- Mach-Zehnder will be installed to eliminate sidebands of sidebands.
- Only + f_2 is resonant on SRC.
- Unbalanced sidebands of +/-f_2 due to detuned SRC produce good error signal for 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, PRC, SRC) signals are extracted from beat between f_1 and f_2, not including arm cavity information.

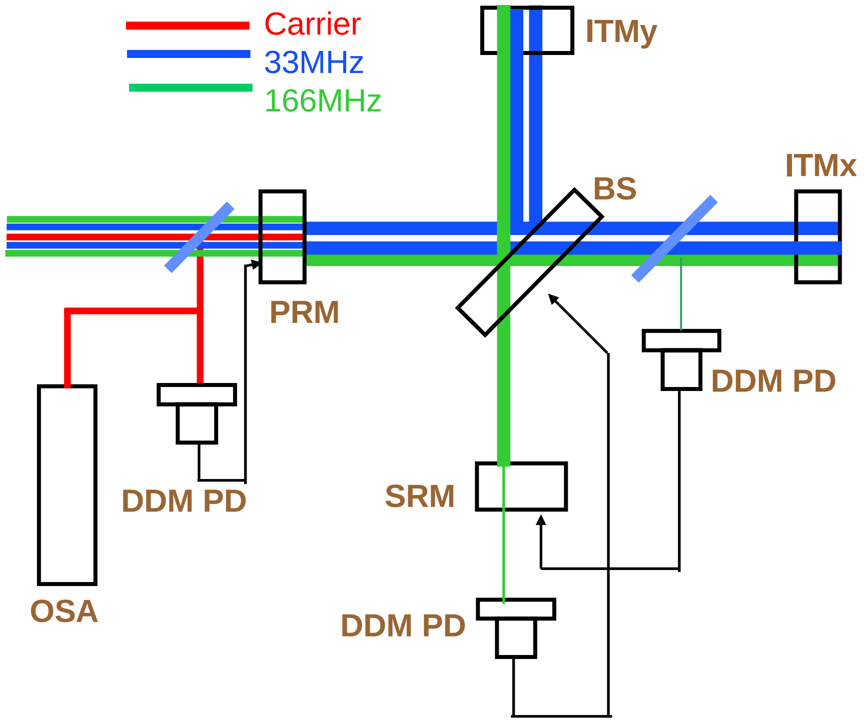
DRMI lock using double demodulation with unbalanced sideband by detuned cavity

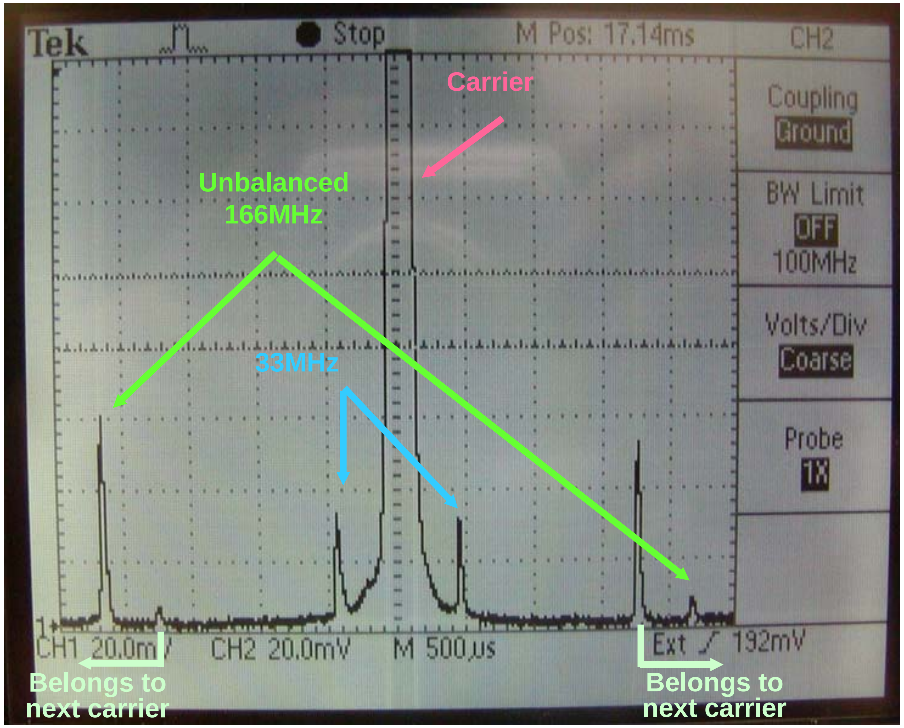
August 2004

- **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

All 5 degrees of freedom under controlled with DC offset on L_+ loop

Both arms locked with DRMI

- Lock acquisition time ~1 min
- Lasts ~ 20 min
- Can be switched to common/differential control

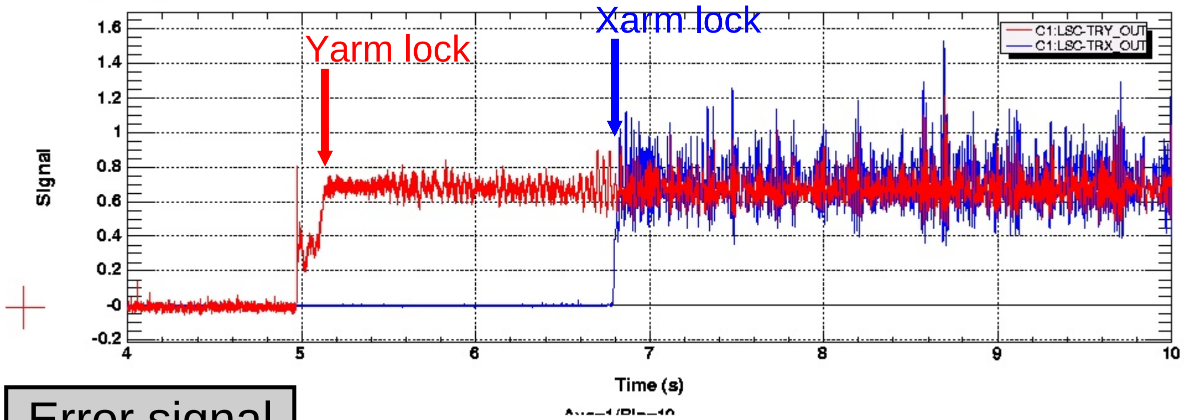
  L- : AP166 with no offset

  L+ : Trx+Try with DC offset

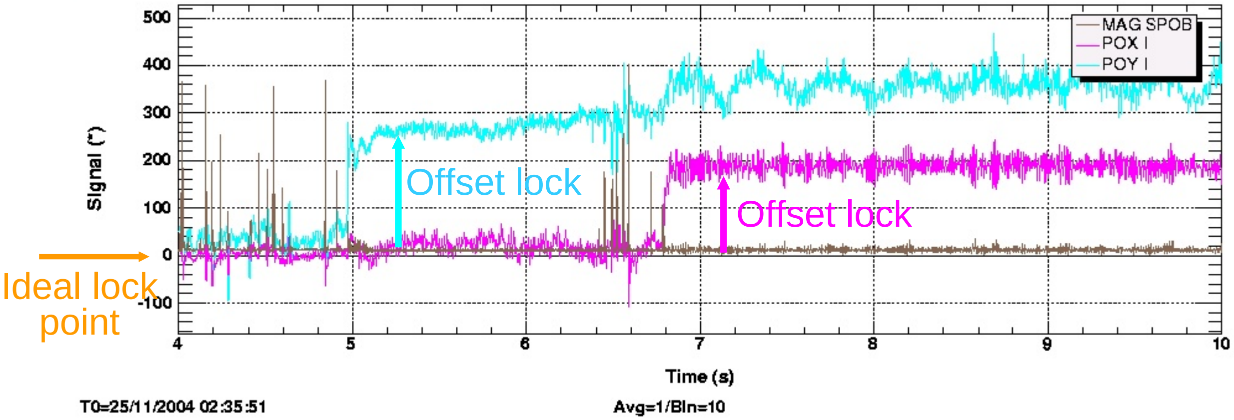
Have started trying to reduce offset from *L*+ loop

But…

Arm power



Error signal

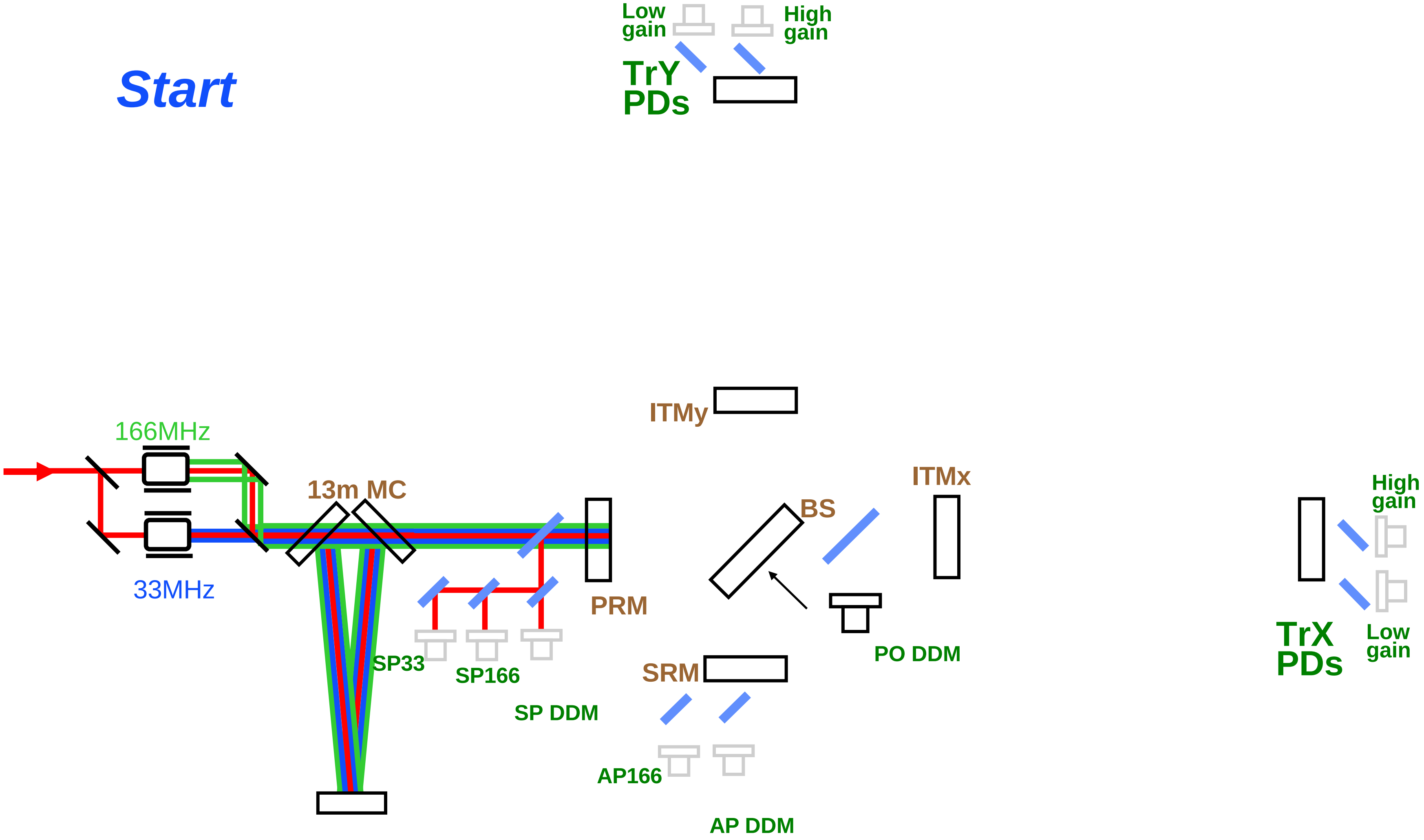


Progress in last 6 months

- For the last 6 months , we have been able to control all 5DOF, but with CARM offset.
- Reducing the CARM offset has been made difficult by technical noise sources. We have spent last 6months reducing them;
  - »suspension noise, vented to reduce couplings in ITMX
  - »improved diagonalization of all suspensions
  - »improved frequency noise with common mode servo
  - »automation of alignment and lock acquisition procedures
  - »improved DC signals and improved RF signals for lock acquisition.
- We can now routinely lock all 5 DOFs in a few minutes at night.

Lock acquisition procedure towards detuned RSE

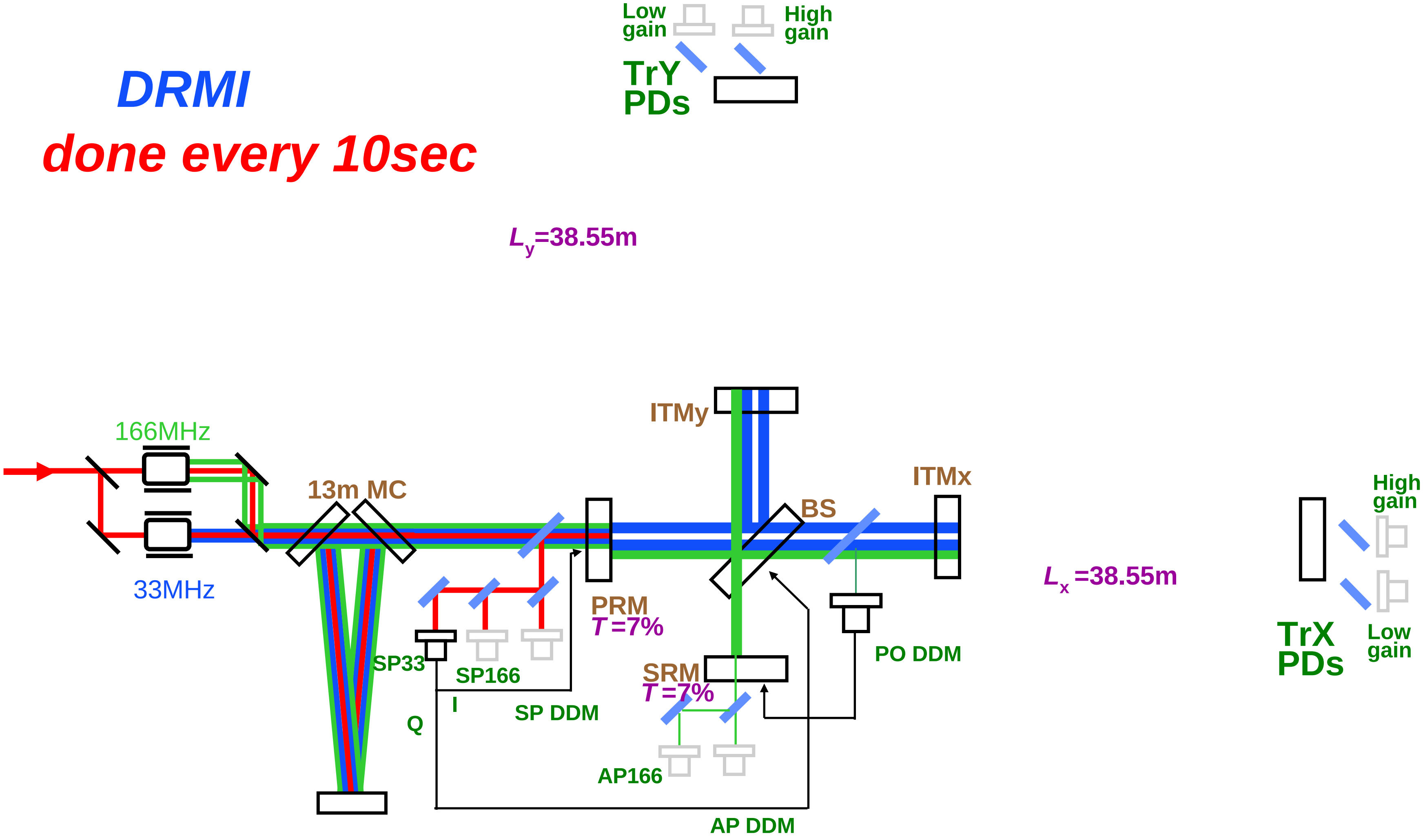
Start



Lock acquisition procedure towards detuned RSE

DRMI

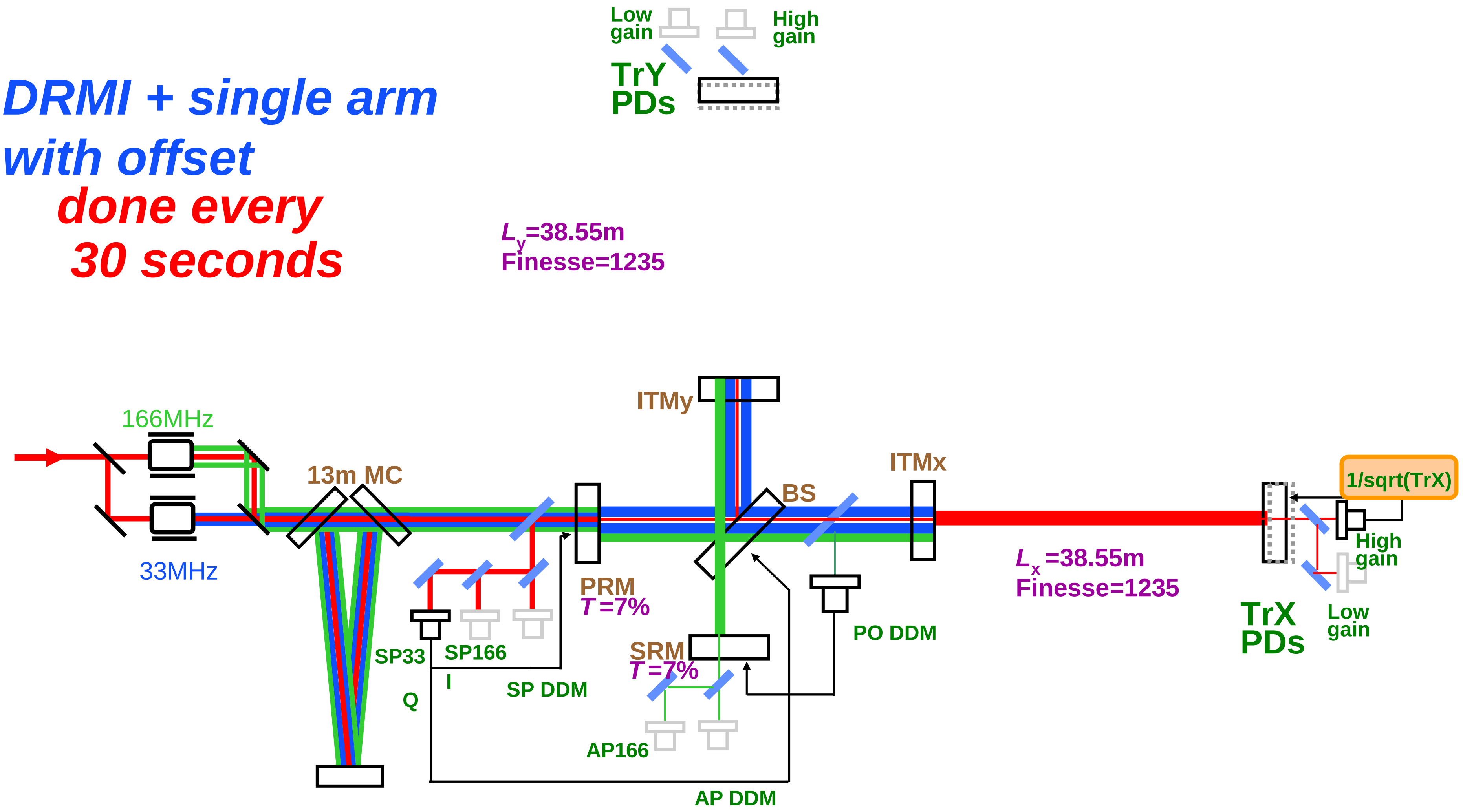
done every 10sec



Lock acquisition procedure towards detuned RSE

DRMI + single arm with offset

done every 30 seconds



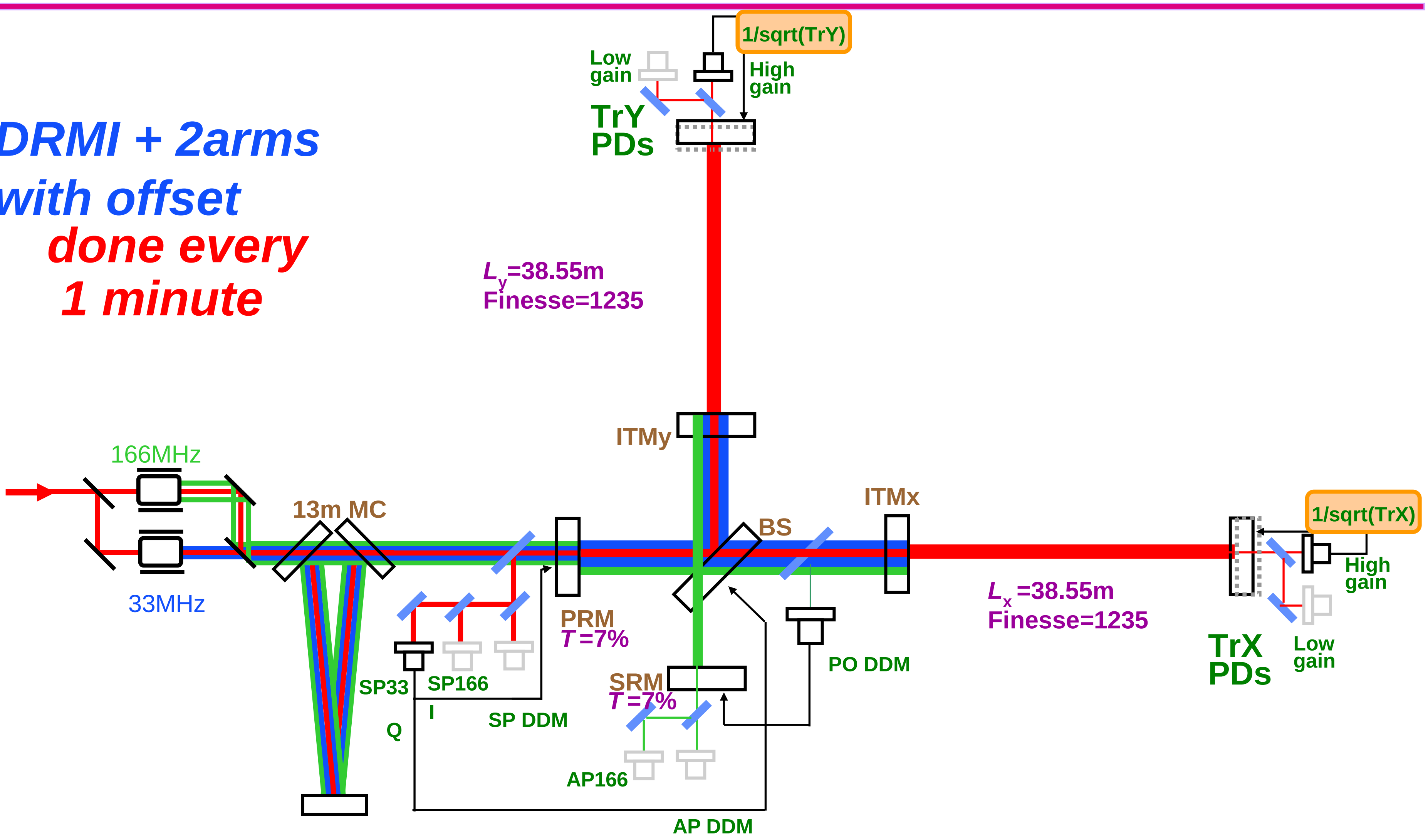
Lock acquisition procedure towards detuned RSE

DRMI + 2arms

with offset

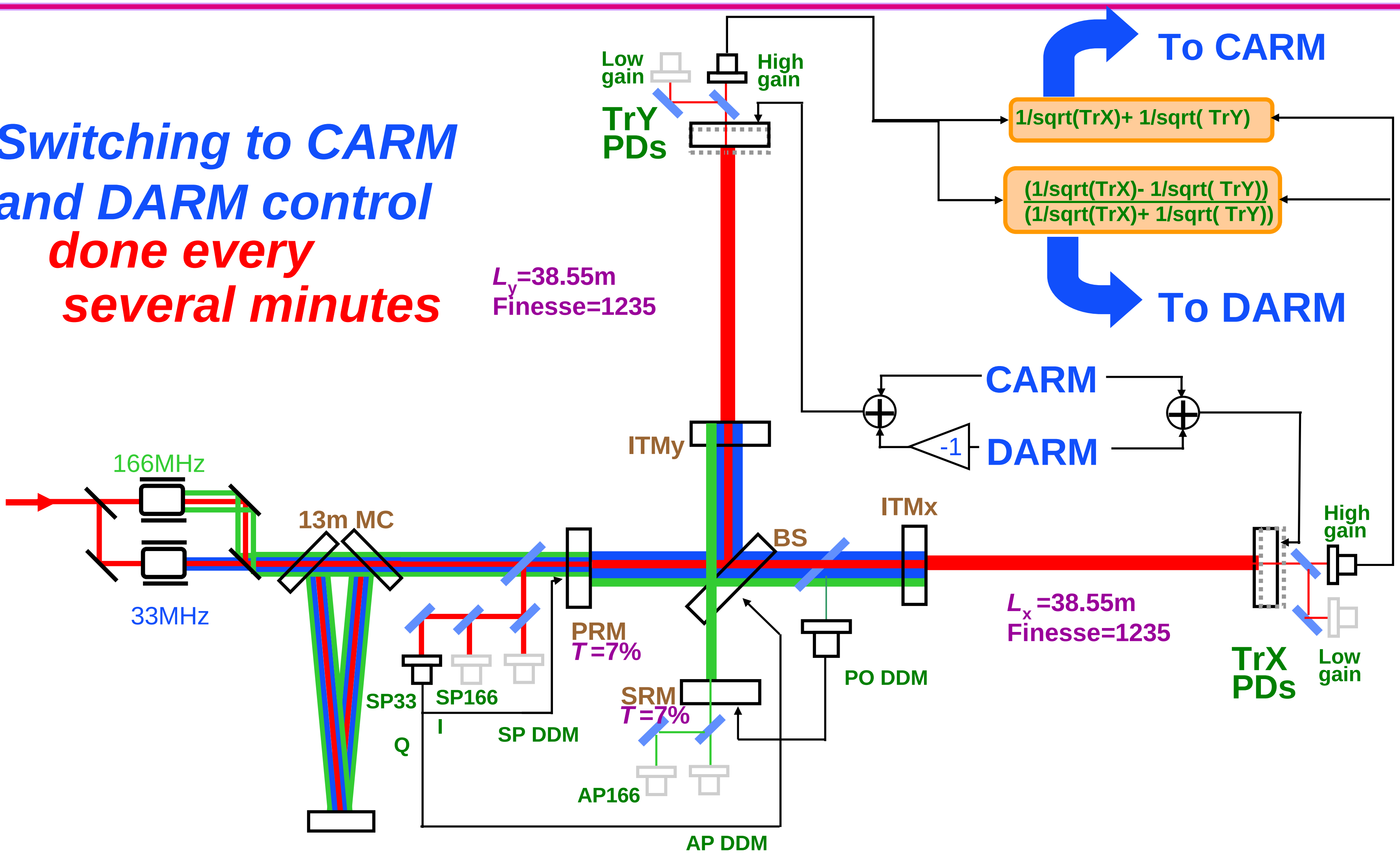
done every

1 minute



Lock acquisition procedure towards detuned RSE

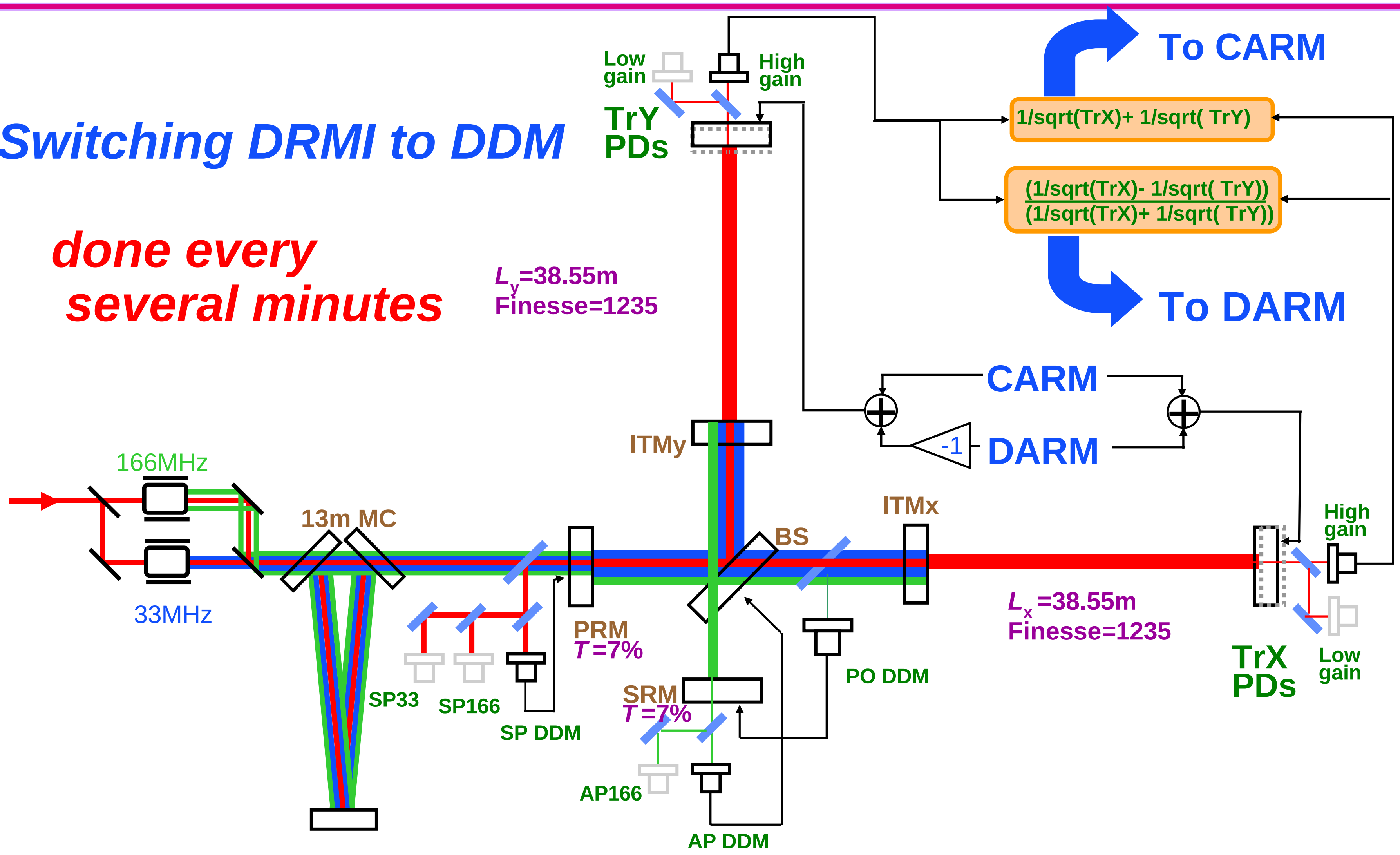
Switching to CARM and DARM control *done every several minutes*



Lock acquisition procedure towards detuned RSE

Switching DRMI to DDM

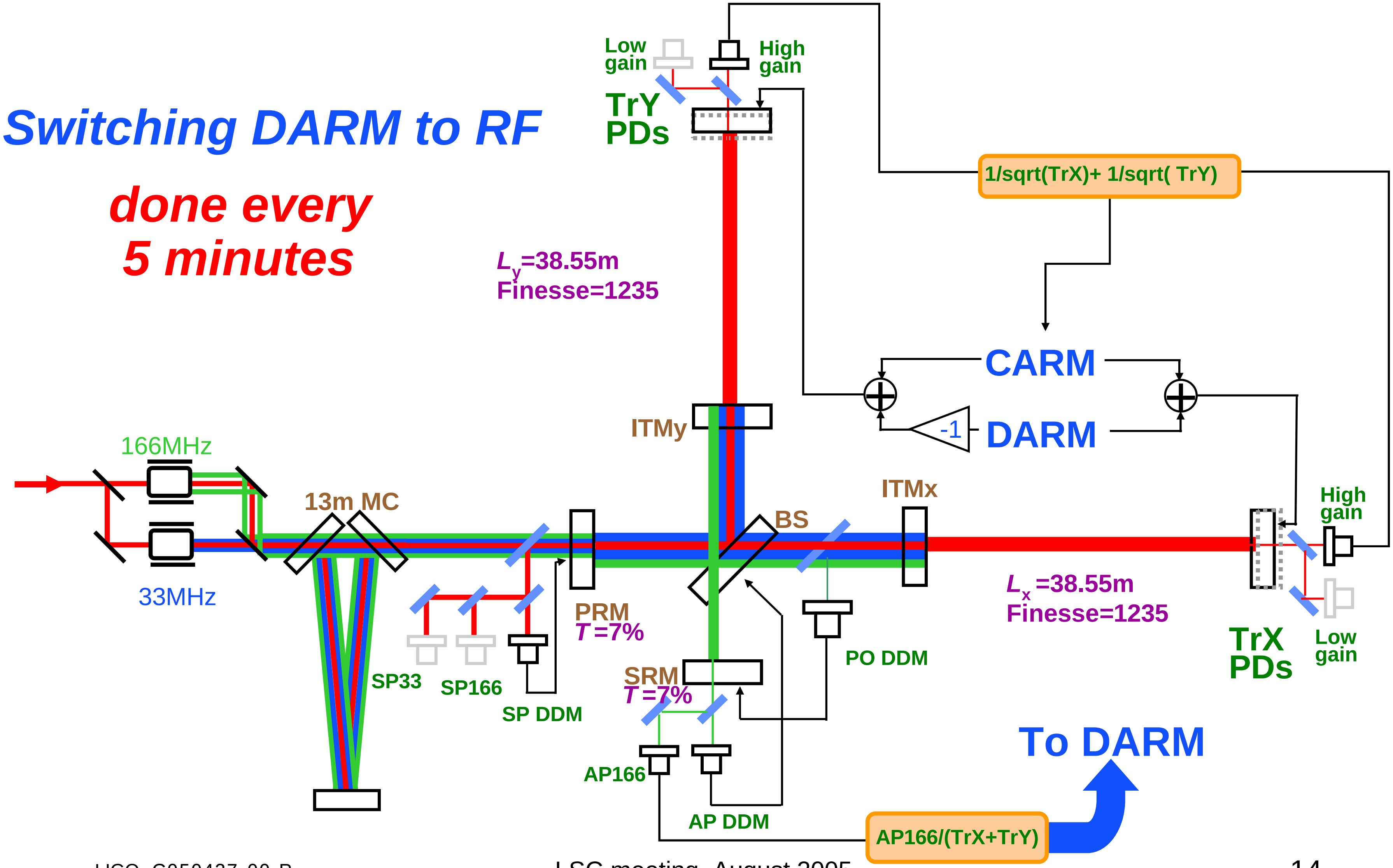
done every several minutes



Lock acquisition procedure towards detuned RSE

Switching DARM to RF

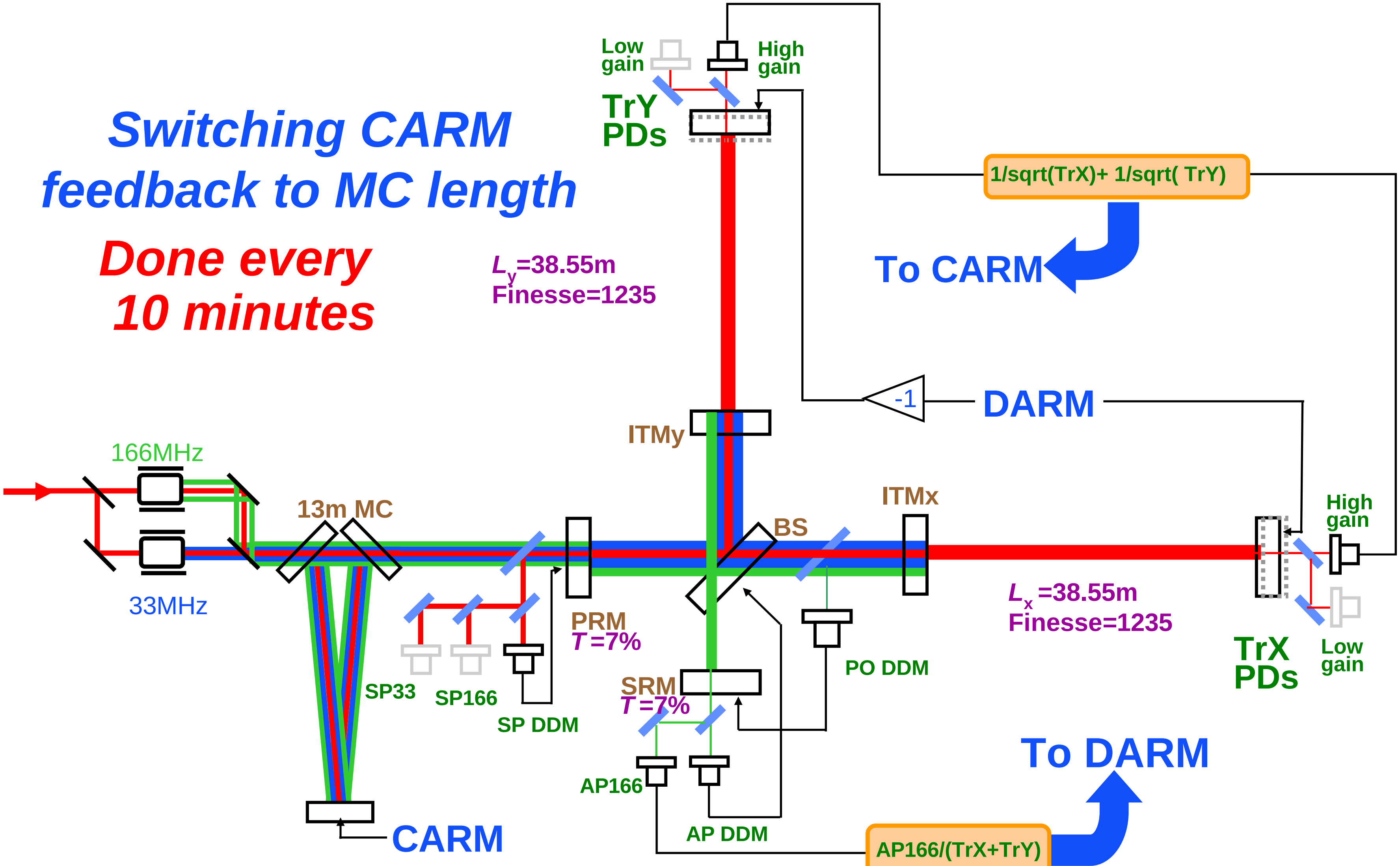
done every 5 minutes



Lock acquisition procedure towards detuned RSE

Switching CARM feedback to MC length

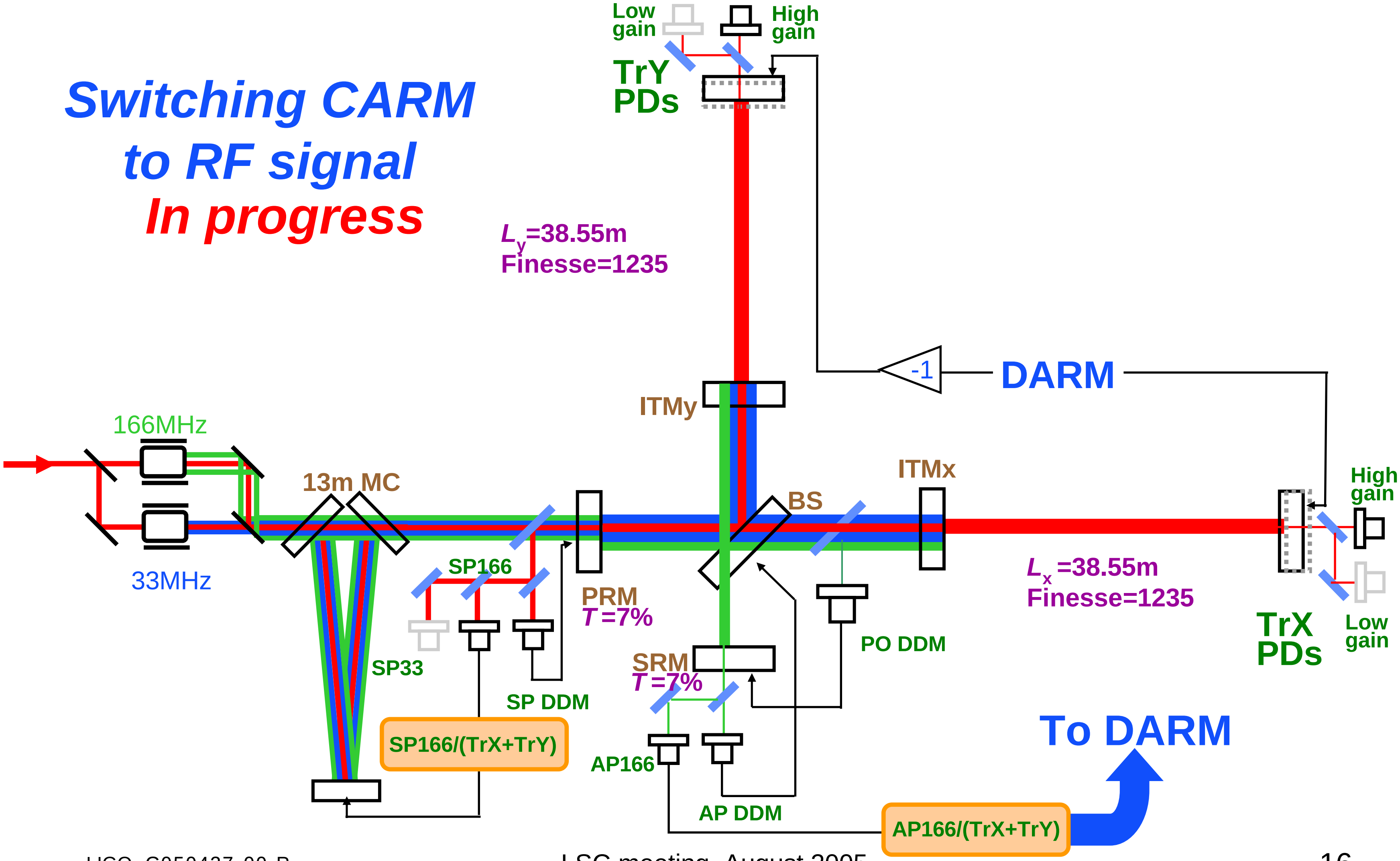
Done every 10 minutes



Lock acquisition procedure towards detuned RSE

Switching CARM to RF signal

In progress

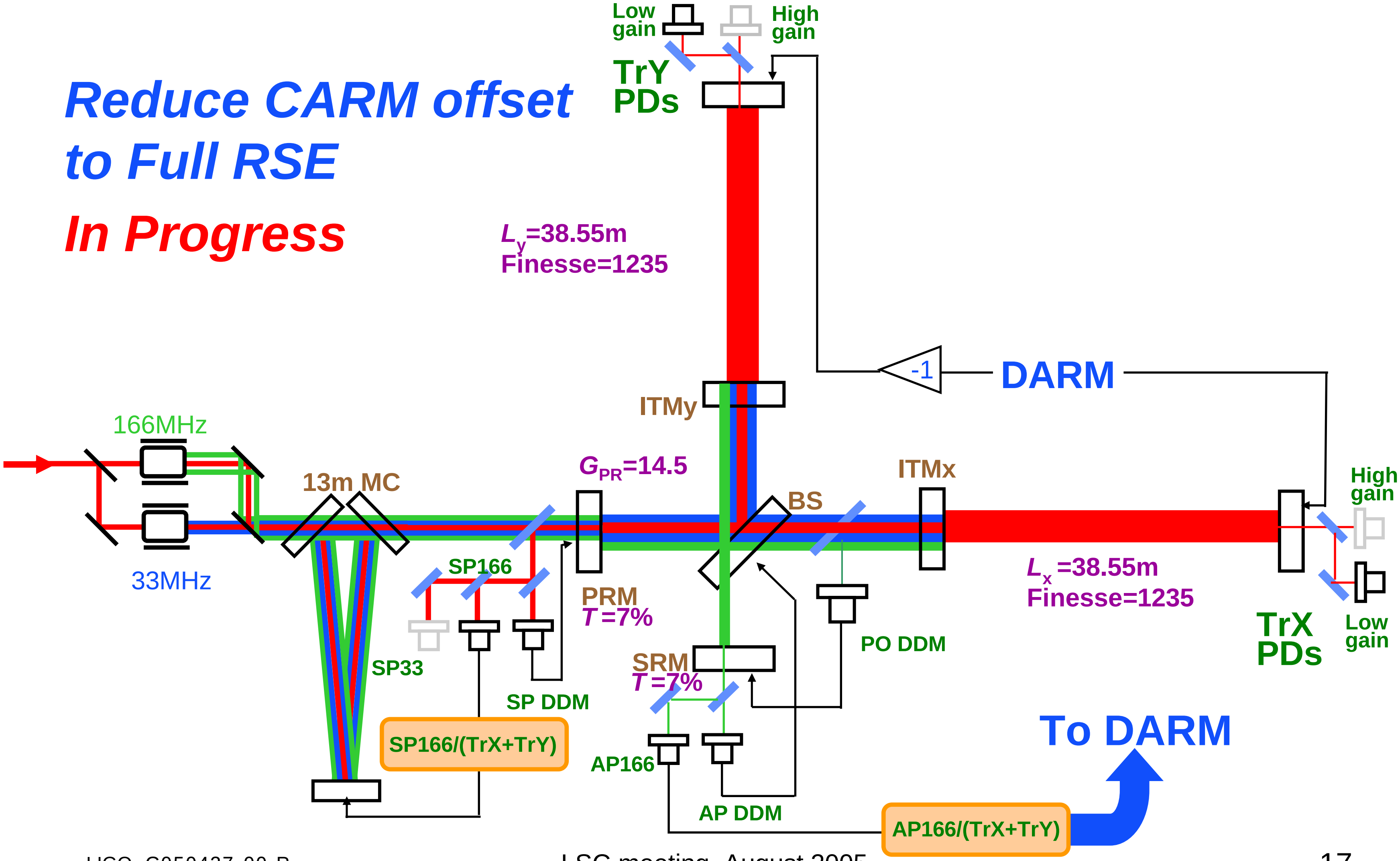


Lock acquisition procedure towards detuned RSE

L_y=38.55m
Finesse=1235

Reduce CARM offset to Full RSE

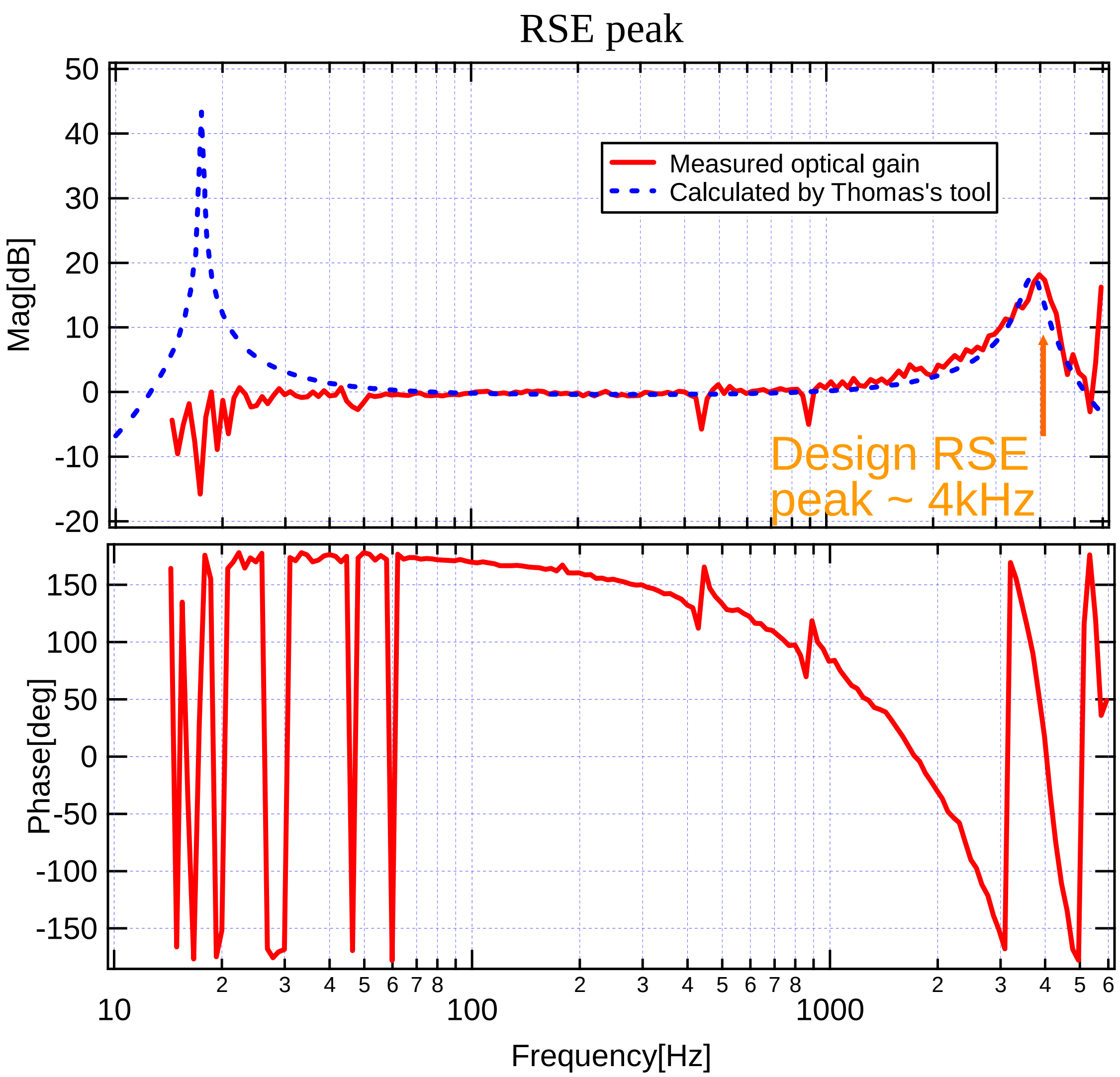
In Progress



Differential mode of Arm : RSE peak!
Common mode of Arm : small offset exists

Effectively the same as
low power recycling (G=1.4) RSE

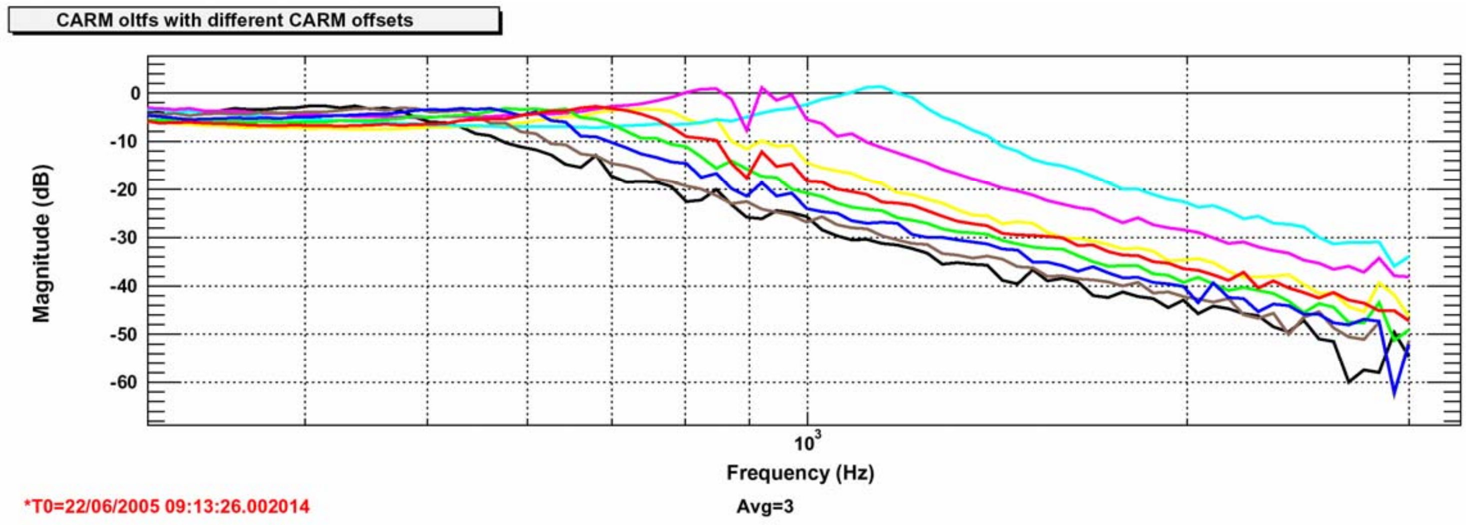
RSE peak!

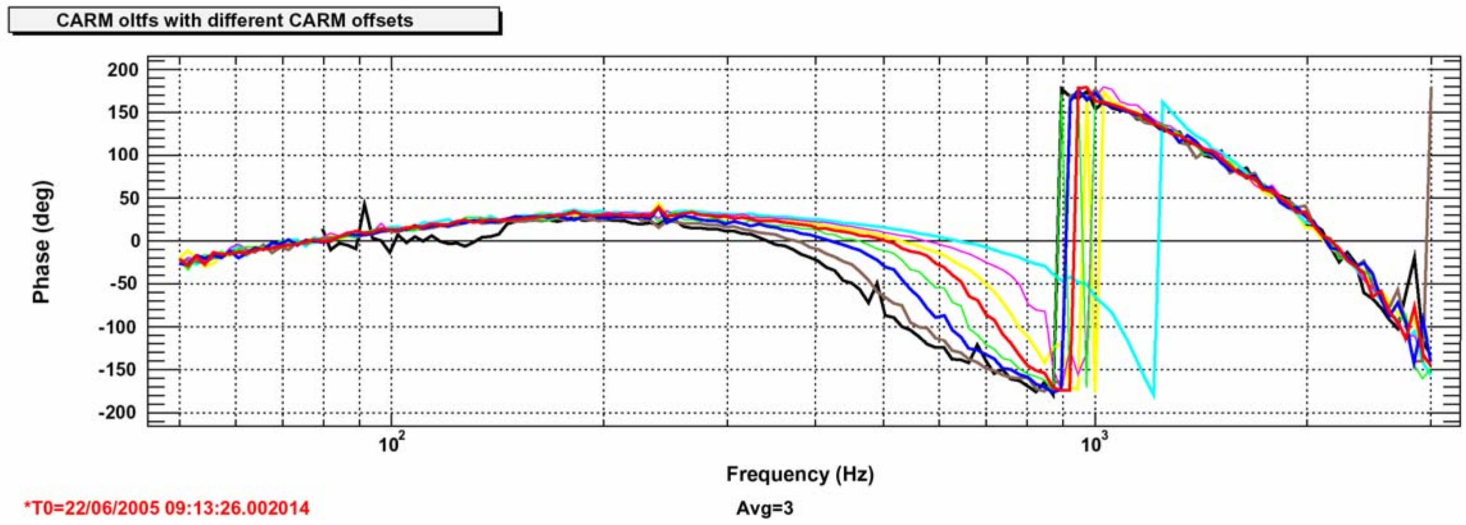


- Optical gain of *L*- loop
  DARM_IN1/DARM_OUT divided by pendulum transfer function
- No offset on *L*- loop
- ~60pm offset on *L*+ loop
- Phase includes time delay of the digital system.

- Optical resonance of detuned RSE can be seen around the design RSE peak of 4kHz.
- Q of this peak is about 7.
- Effectively the same as Full RSE with GPR=1.4 with 1W input laser.
- Model was calculated by Thomas’s tool.
- We will be looking for optical spring peak.

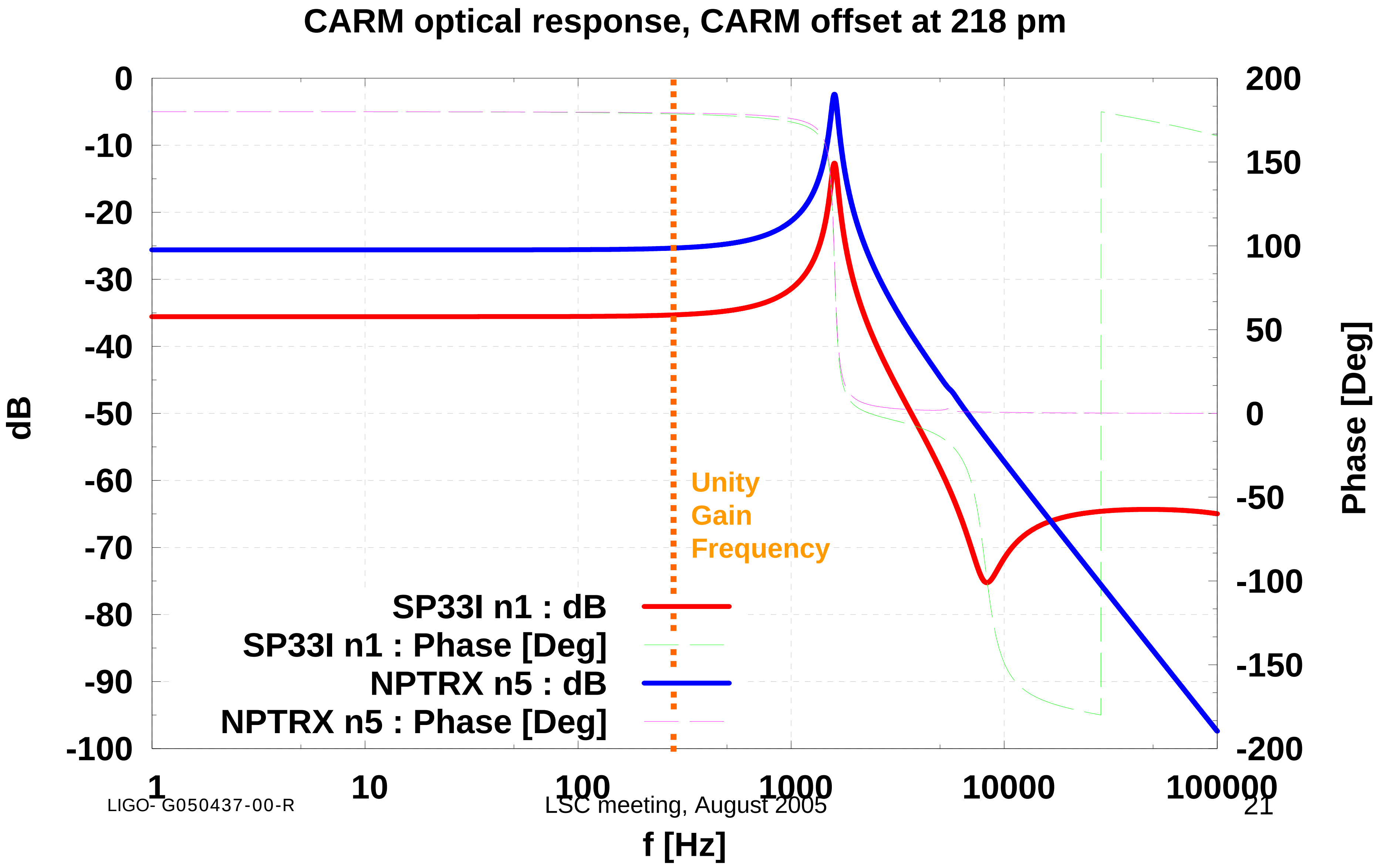
Peak in CARM loop



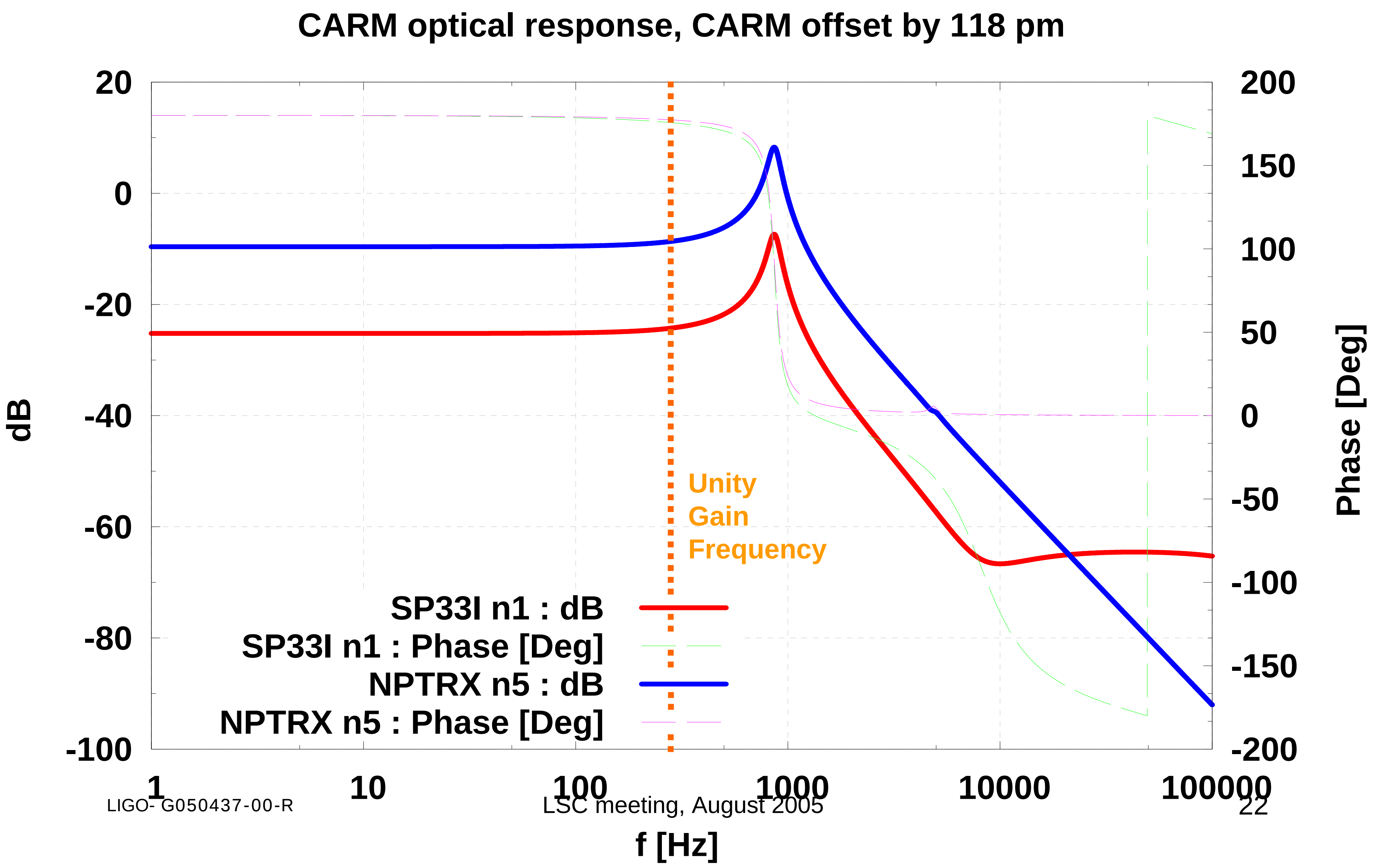


- CARM loop has small offset.
- Peak started from 1.6kHz and reached to ~450H, then lock was lost.
- This peak introduces phase delay around unity gain frequency.

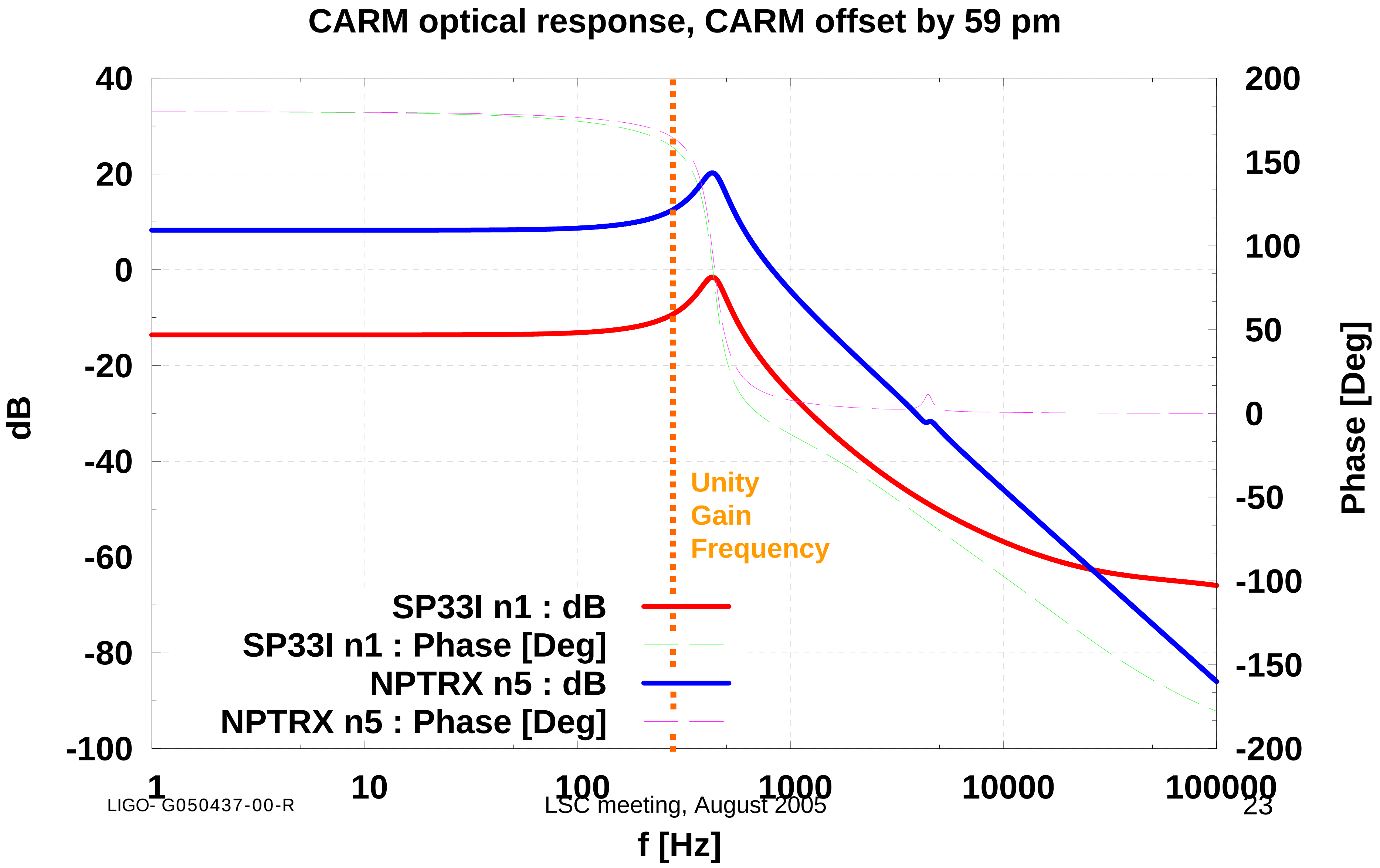
CARM at 218 pm offset (~locking point)



CARM at 118 pm offset

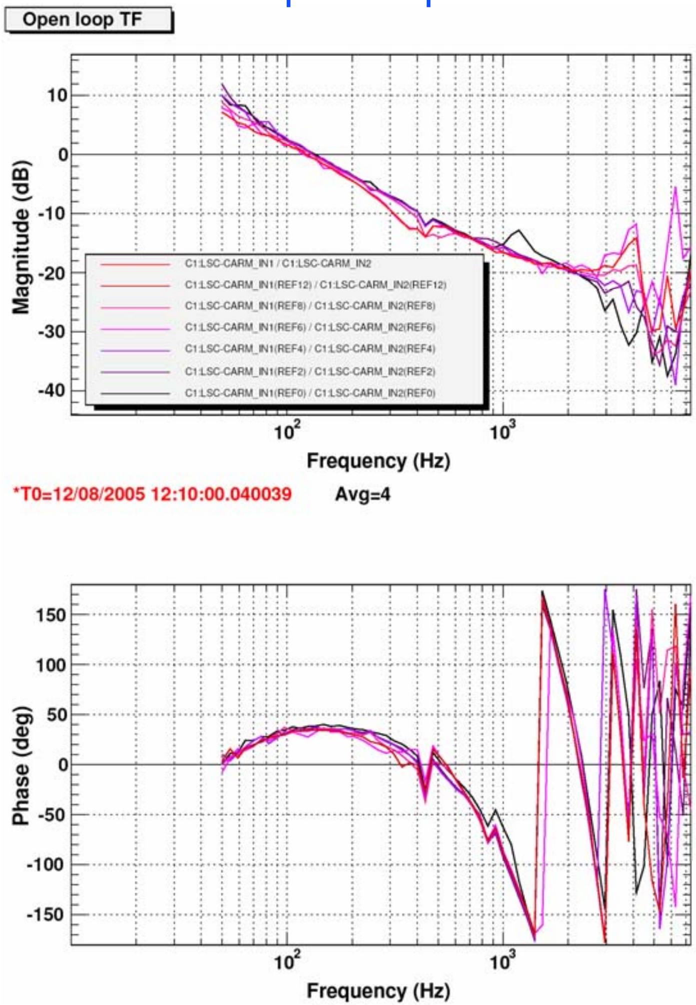


CARM offset at 59 pm (losing lock)

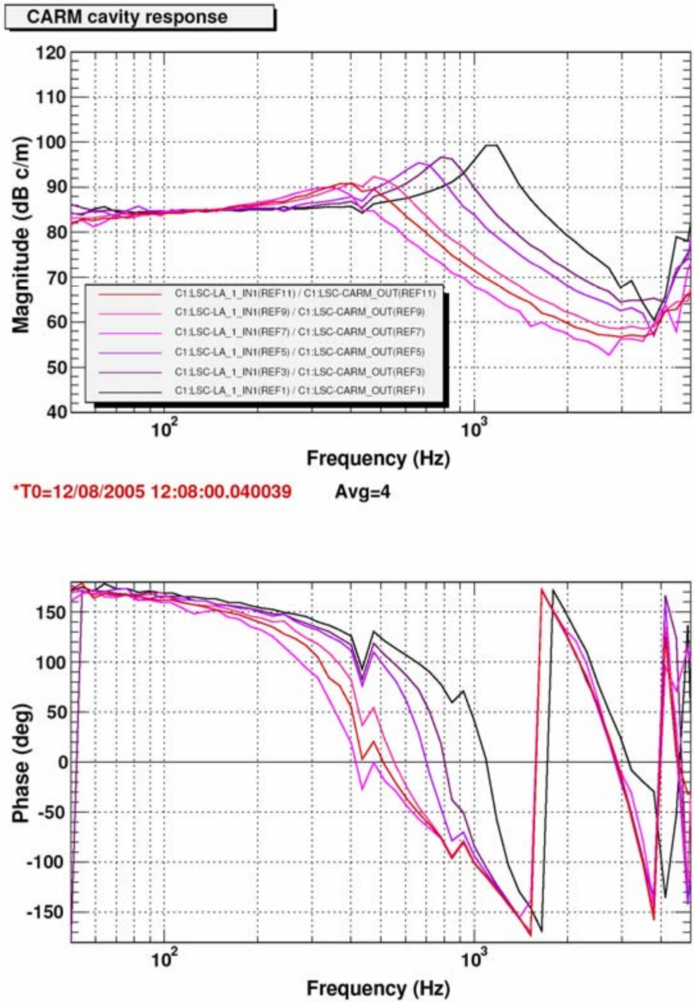


Dynamic compensative filter for CARM servo by Rob Ward

Open loop TF of CARM



Optical gain of CARM



- Optical gain (normalized by transmitted power) shows moving peaks due to reducing CARM offset.
- We have a dynamic compensative filter having an exactly the same shape as optical gain except for upside down.
- Open loop transfer function has no phase delay in all CARM offset.

How large is the CARM offset? Evaluation of power recycling gain

	Design	Measured(calculated)
Cavity reflectivity	93%	85%(X arm 84%, Yarm 86%)
PRM reflectivity	93%	92.2%
Loss in PRC	0%	2.3%
Achievable PRG	14.5	5.0
Coupling	Over coupled	Under coupled

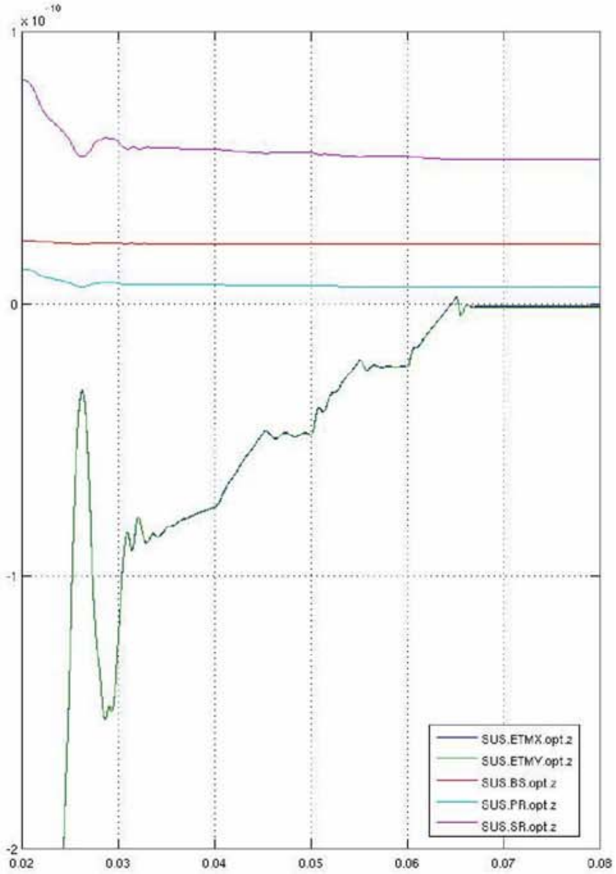
- Estimated actual power in arms with 1W input and smallest CARM offset achieved is

0.5kW of ~2kW(25% of the way to full resonance).

CARM switching from DC to RF signal

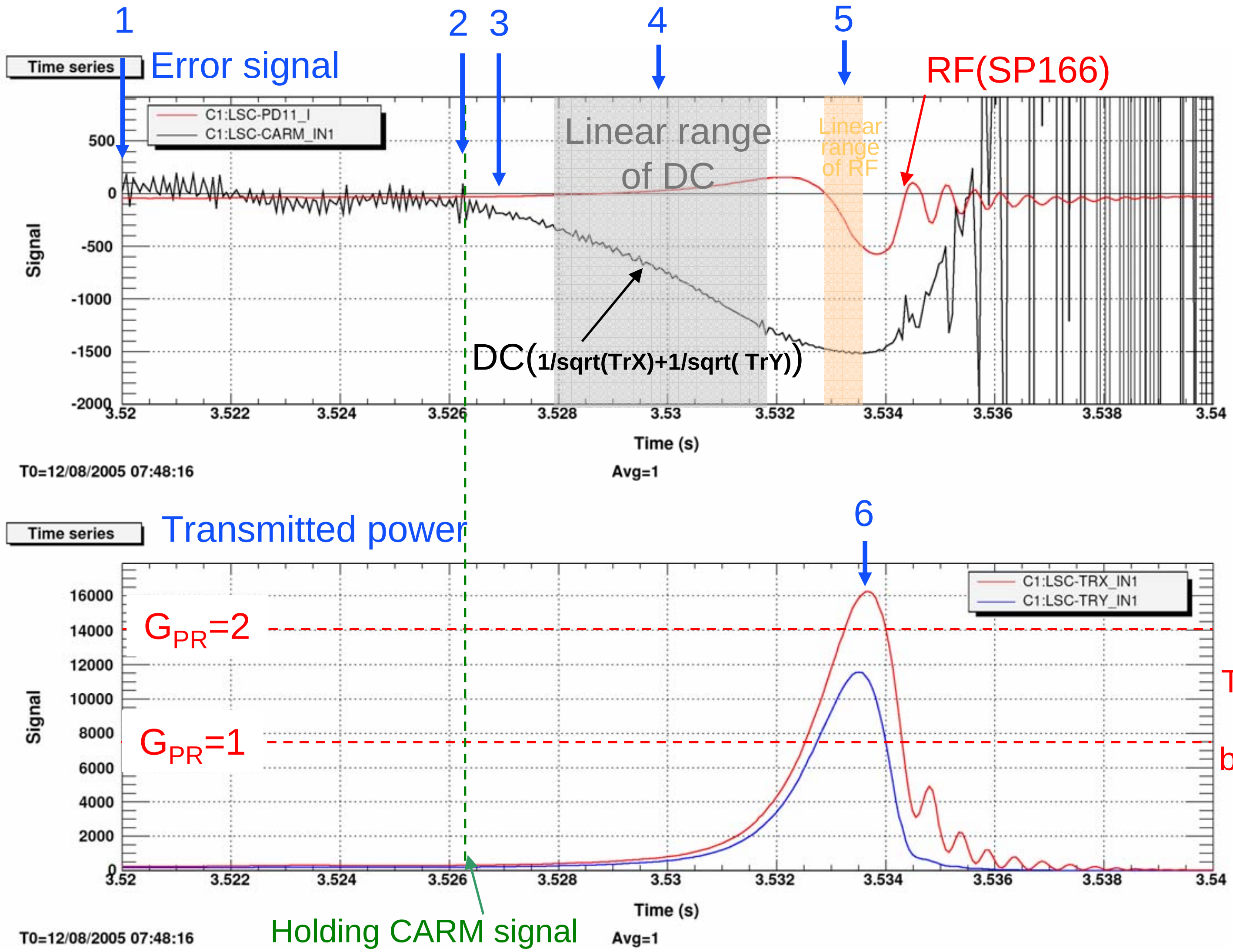
E2E simulation by Matthew Evans in June 2005

- CARM moved to RF signal
  - » Not yet done at 40m
  - » REFL port HF demod (a.k.a., SP166)
  - » Normalized by arm power
  - » Offset and gain matched at hand over
  - » Offset swept to zero slowly
  - » Coupled-Cavity pole compensation required
    - – Pole (actually more complicated) moves down as resonance is approached
    - – Compensation filter uses sum to make a “moving zero”
    - – More detail may be required for 40m



- Simulation verifies that controlled reduction of CARM offset should work.

CARM switching from DC to RF signal



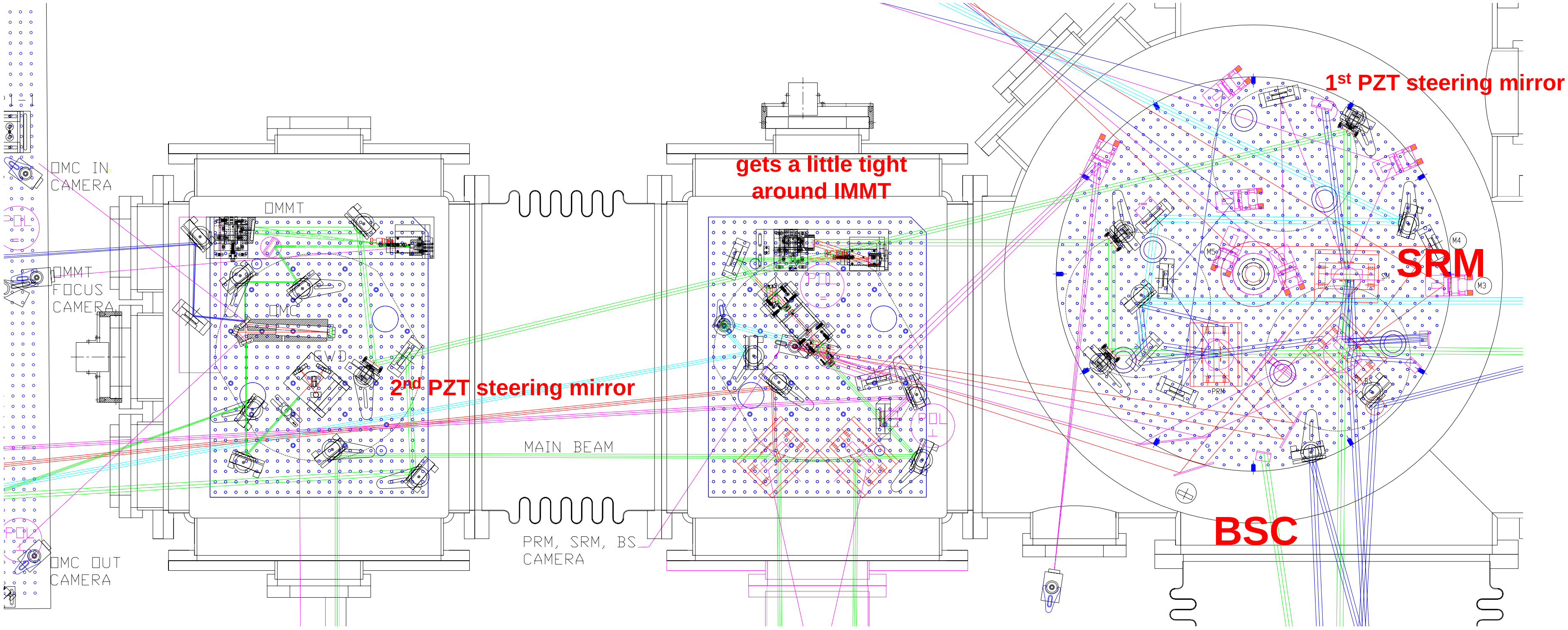
1. CARM is locked by DC signal with offset
2. Let's hold CARM feedback signal and mirror speed is zero.
3. Mirror start moving
4. Linear response of DC can bee seen.
5. Linear response of RF can be seen.
6. Power is stored.

This result shows RF(SP166) should work well, but still we have not yet done.

DC Readout at the 40m

- 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 may not be able to see shot noise at low frequency, given our noise environment. We may not even see any noise improvements, but we might!
- The most important thing we will learn is : How to do it
  - » How to lock it?
  - » How best to control the DARM offset?
  - » What are the unforeseen noise sources associated with an in-vacuum OMC?
  - » How do we make a good in-vac photodiode? What unforeseen noise sources are associated with it?

Output Optical Train



1st PZT steering mirror

gets a little tight around IMMT

SRM

2nd PZT steering mirror

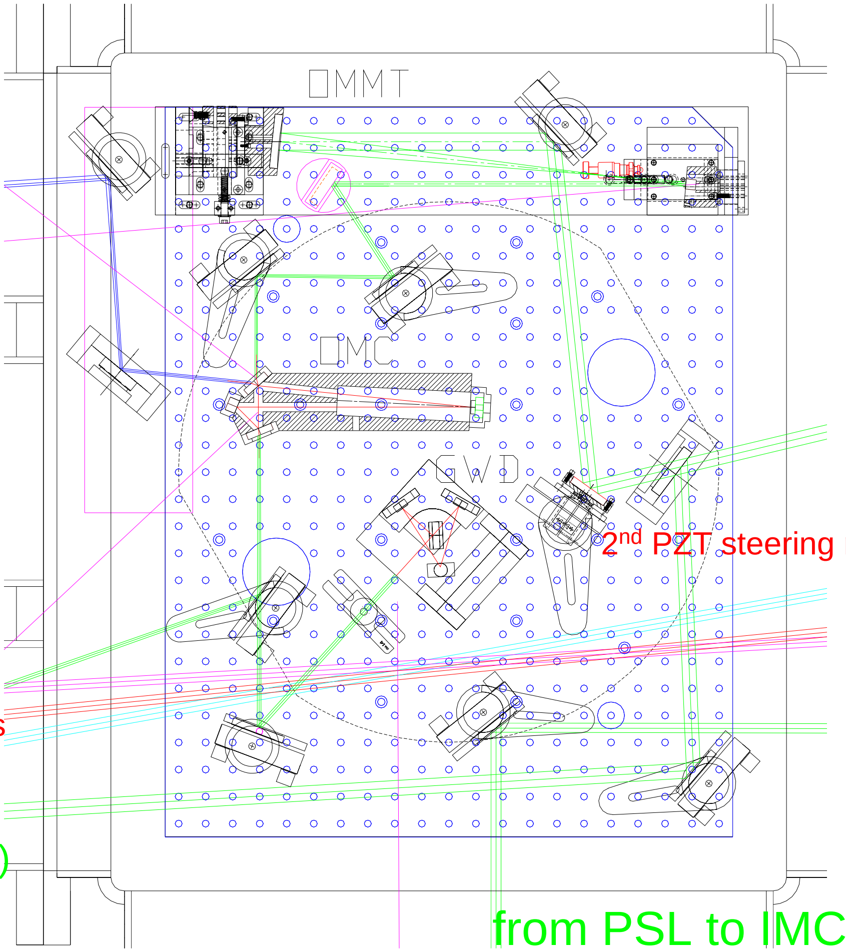
BSC

OOC

IOC

Mike Smith

Output Optic Chamber



to OMCR beamline

from SRM

2nd PZT steering mirror

PZT steering mirrors and their controls are duplicates of a pair that we have already installed and commissioned for steering from IMC to main IFO (in-vac); controls are fully implemented in the ASC system (by Rolf). Similar systems can be used for “LIGO I.V”.

to OMCT beamline

IMCR, IMCT, and SP beamlines

to ASRF beamline

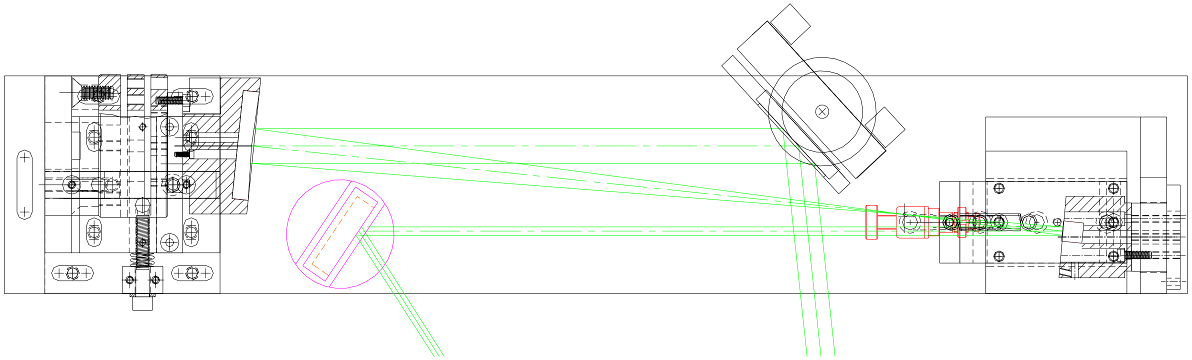
(roughly 1/3 of AS power)

also a convenient path
for autocollimator beam,
for initial alignment in air

from PSL to IMC

Piezosystem Jena PSH 5/2 SG-V, PZT tilting mirror mount with strain gauge, and associated drivers and power supplies

OMMT layout

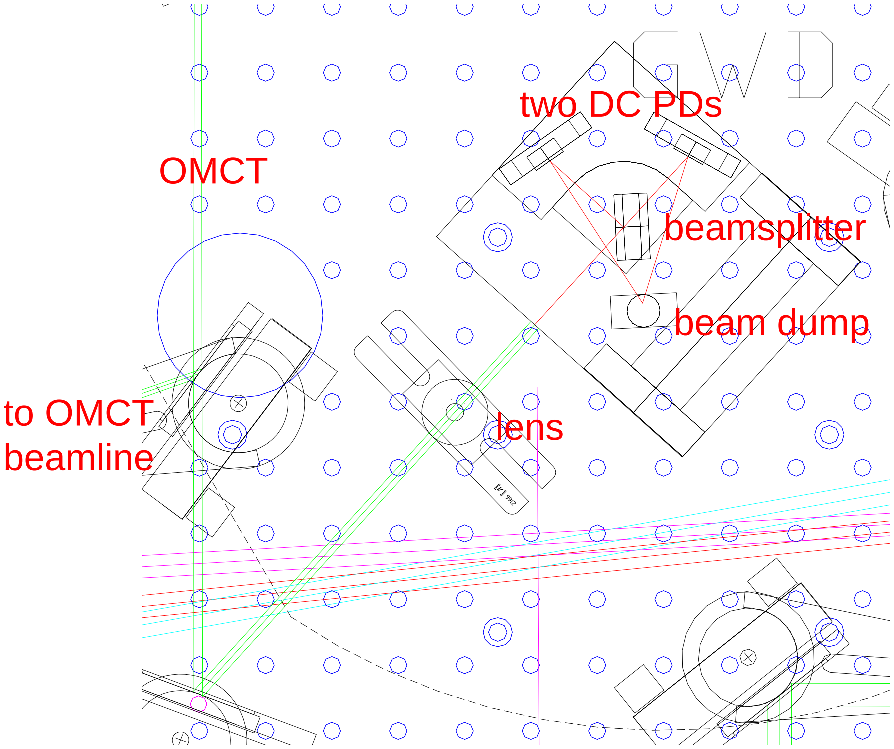


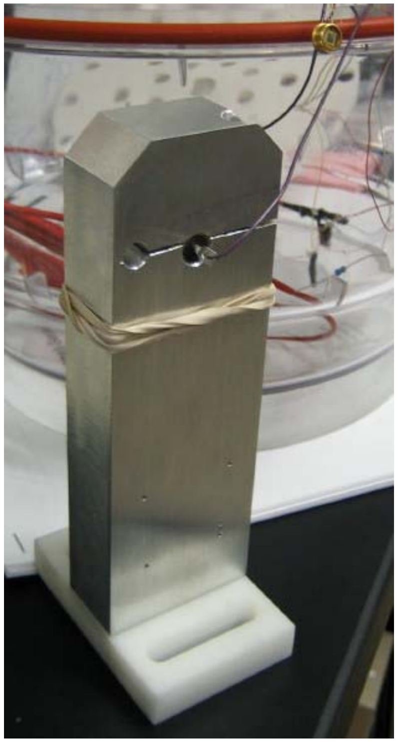
Primary radius of curvature, mm	618.4
Secondary radius of curvature, mm	150
Defocus, mm	6.3
Input beam waist, mm	3.03
Output beam waist, mm	0.38

Make mirror(s) by coating a cc lens
to get larger selection of ROC

Mike Smith

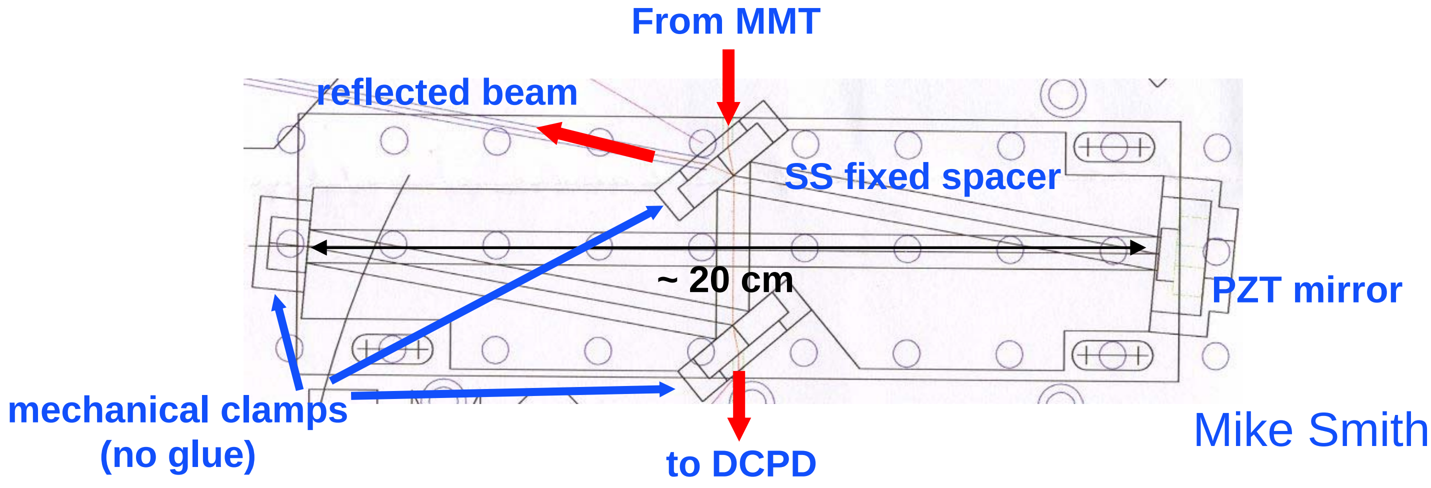
Two in-vac DC PDs





- Ben Abbott has designed an aluminum stand to hold a bare photodiode, and verified that the block can radiate 100 mW safely.
- A small amplifier circuit will be encased in the stand, and vacuum-sealed with an inert, RGA detectable gas.
- Two such assemblies will be mounted together with a 50:50 beamsplitter to provide in-loop and out-of-loop sensors.

OMC, four mirror design



Mike Smith

- Mirrors mounted mechanically, on 3 points (no glue)
- curved mirror: off-the-shelf CVI laser mirror with ROC = 1 m ± 0.5%
- Fixed spacer should be rigid, vented, offset from table
- OMC length signal:
  - Dither-lock? >> Should be simple; we'll try this first.
  - PDH reflection? >> There's only one sideband, but it will still work.
- Servo:
  - Will proceed with a simple servo, using a signal generator and a lock-in amp.
  - Feedback filters can easily be analog or digital.
    - Can use a modified PMC servo board for analog.
    - Can use spare ADC/DAC channels in our front end IO processor for digital.
  - PZT actuation