The Angular Control System at LHO: Current Status

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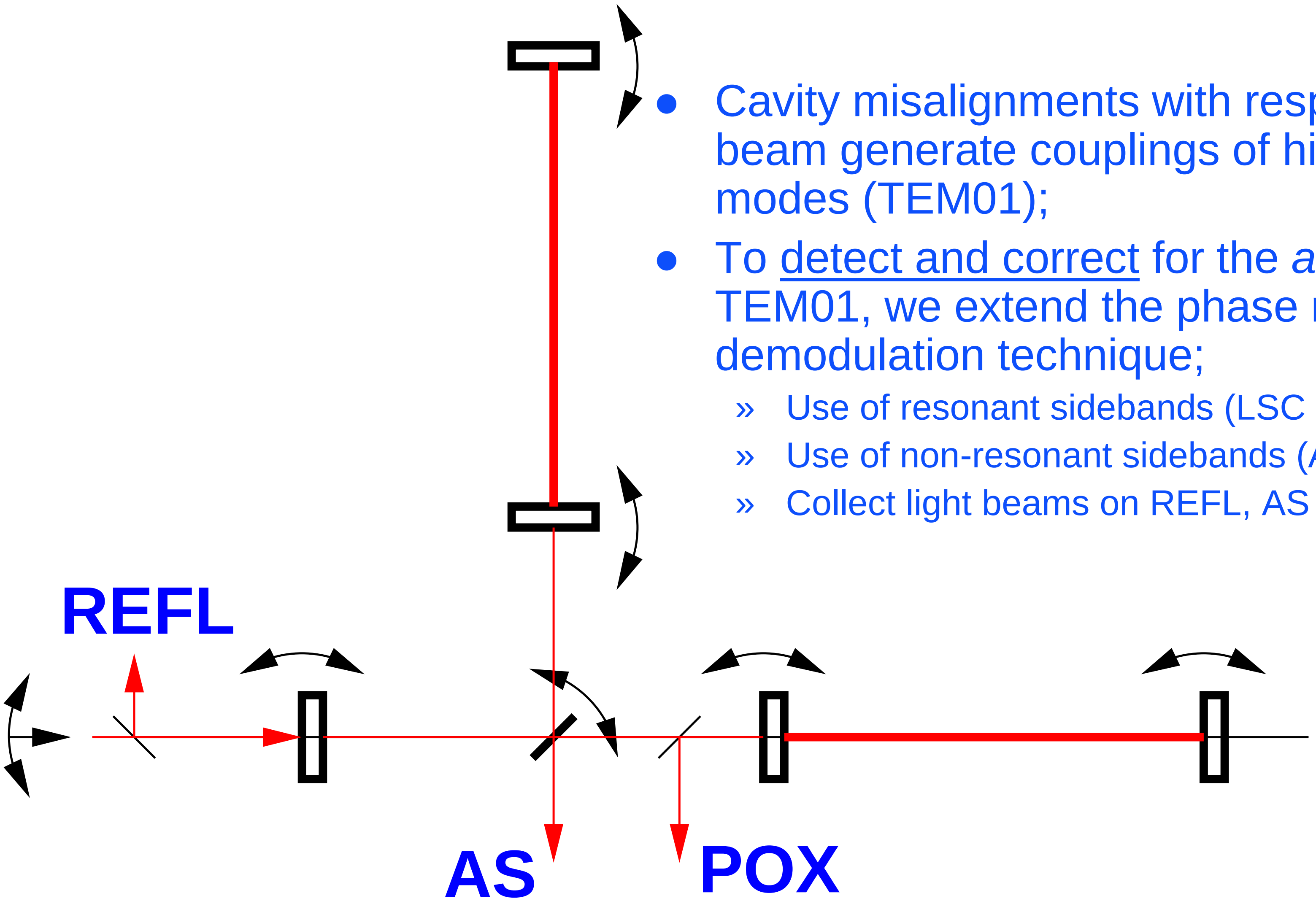
Requirements

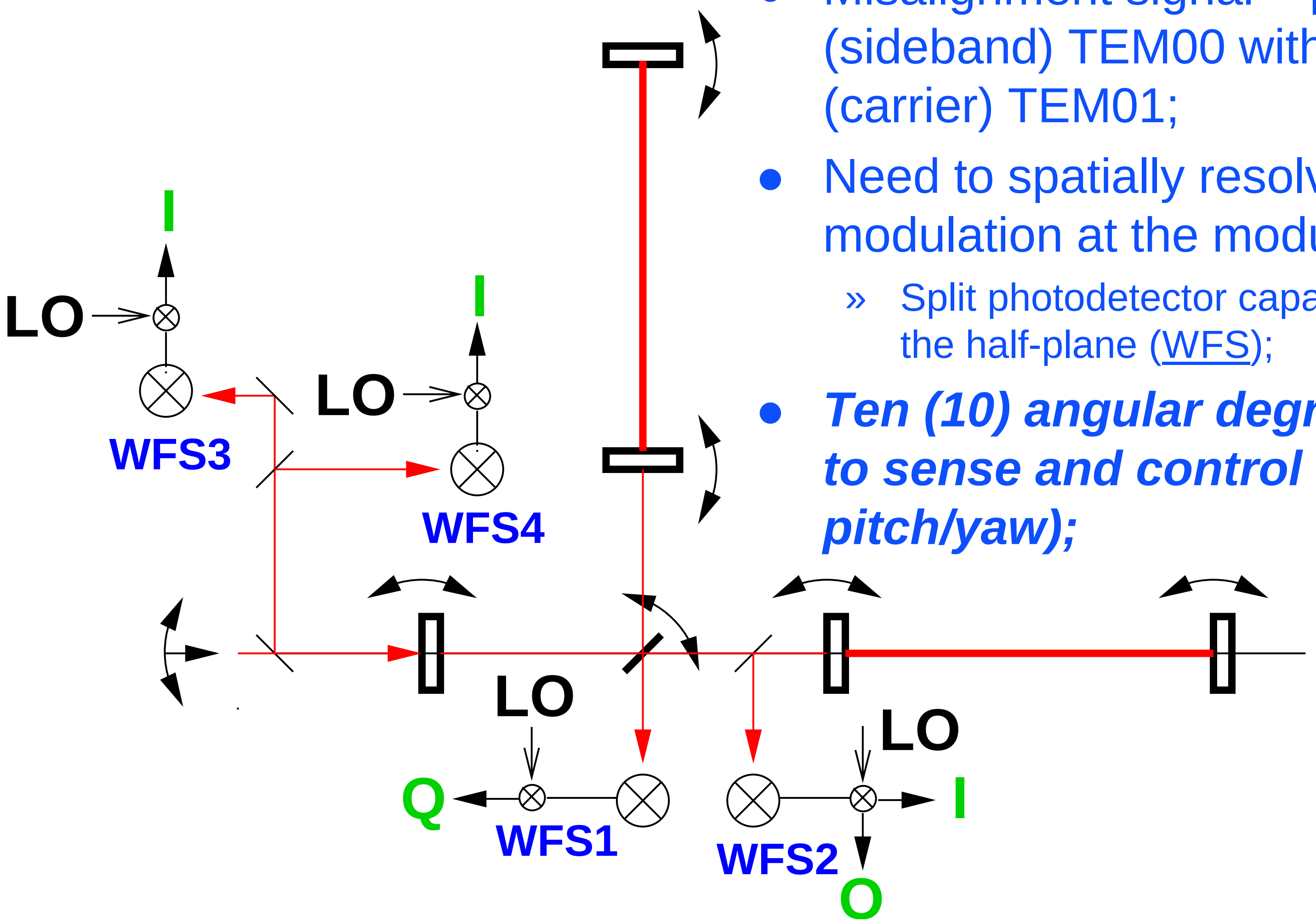
- Detector’s sensitivity deteriorates with
  - » misalignments of the Test Masses (decrease of the circulating power, increase of contrast defect, increase of shot-noise);
  - » beam miss-centering (angle-to-length coupling).
- <u>Need to have</u>
  - » Angular fluctuations of Test Masses : 10^{-8} rad-rms with respect to cavity axis;
  - » Sensing noise: 10^{-14} rad/rHz for f>40Hz (WFS1);
  - » Beam centering within 1mm.

How?

- Cavity misalignments with respect to input beam generate couplings of higher-order modes (TEM01);
- To <u>detect and correct</u> for the *amount* of TEM01, we extend the phase modulation-demodulation technique;
  - » Use of resonant sidebands (LSC 24MHz);
  - » Use of non-resonant sidebands (ASC 36MHz);
  - » Collect light beams on REFL, AS and POX.

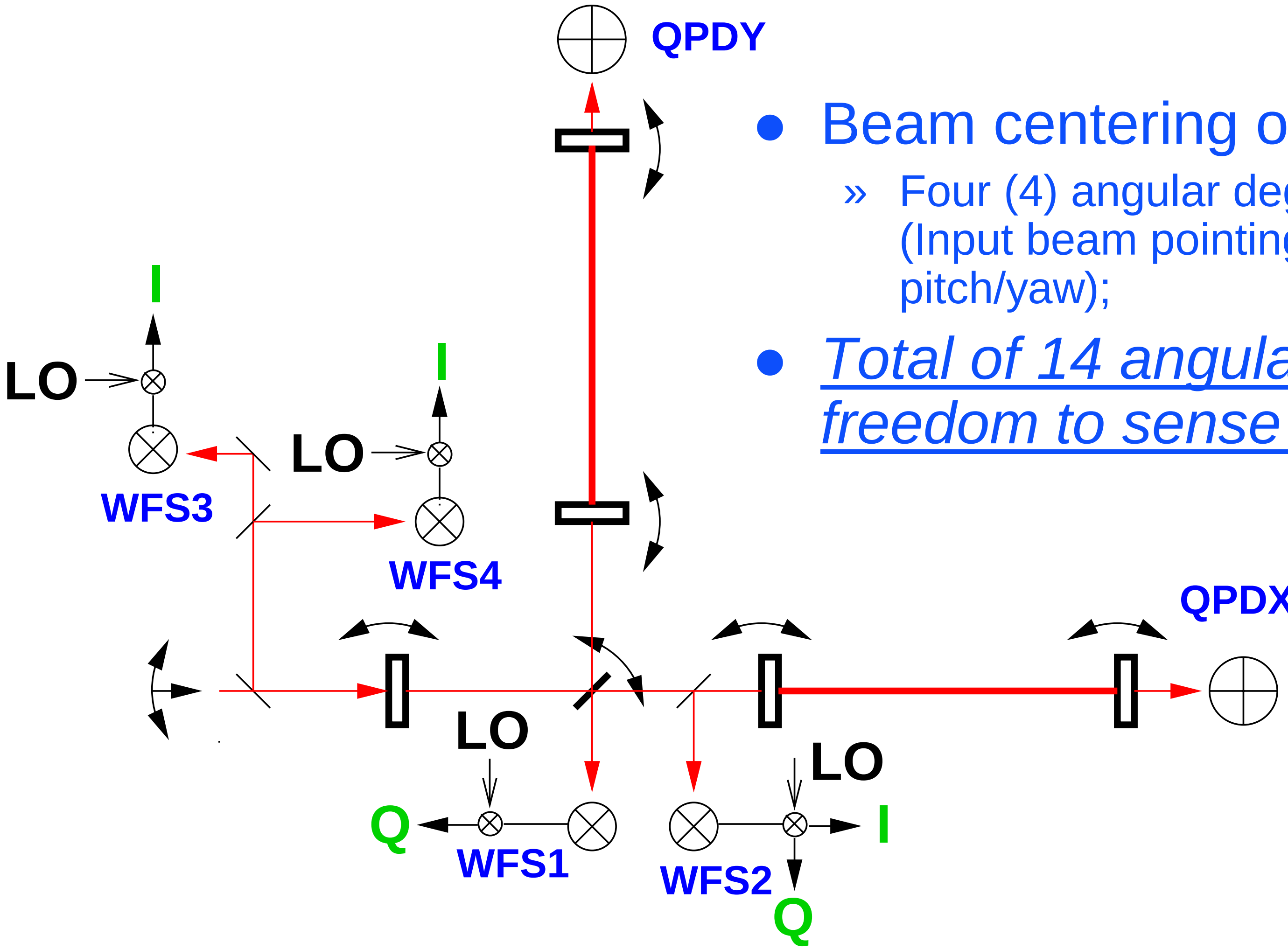


Wavefront Sensors (WFS)



- Misalignment signal = product of carrier (sideband) TEM00 with sideband (carrier) TEM01;
- Need to spatially resolve the amplitude modulation at the modulation frequency
  - » Split photodetector capable of integrating on the half-plane (WFS);
- ***Ten (10) angular degrees of freedom to sense and control (5 Test Masses, pitch/yaw);***

Beam Centering (QPDs)



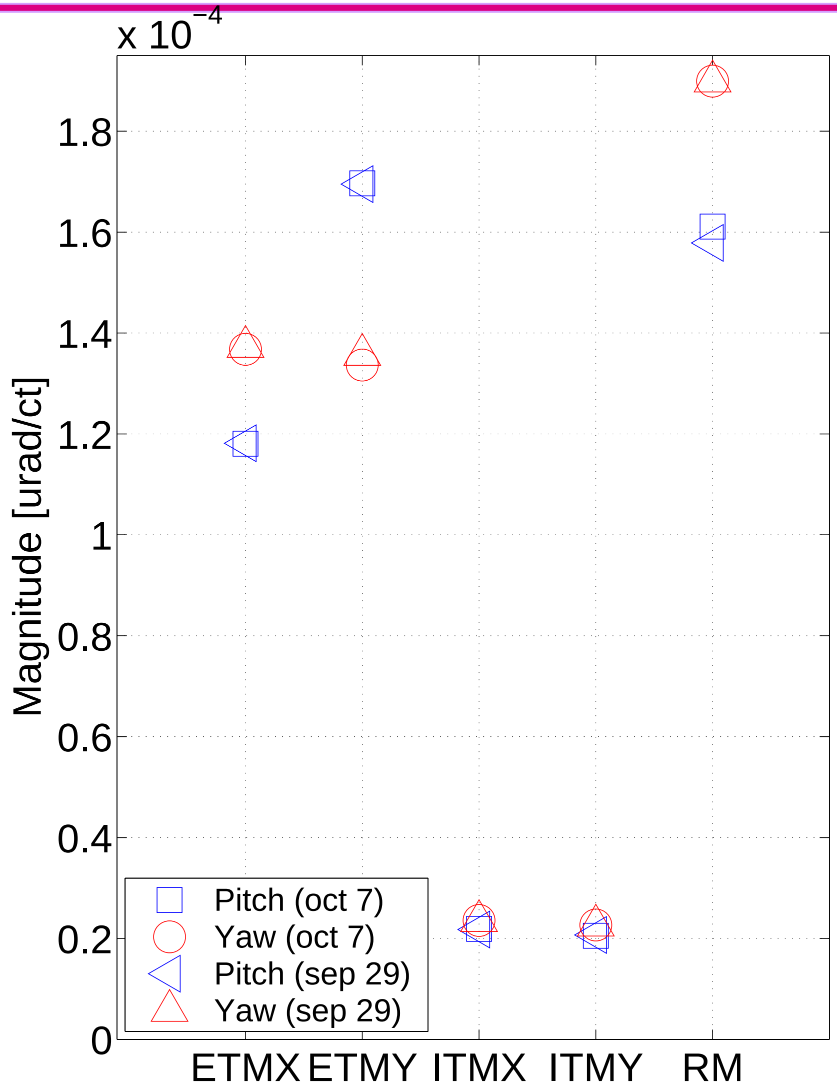
- Beam centering on ETMs
  - » Four (4) angular degrees of freedom (Input beam pointing and BS, pitch/yaw);
- <u>*Total of 14 angular degrees of freedom to sense and control.*</u>

WFS Matrix - H1

	dETM	dITM	cETM	cITM	RM
WFS1	1	0.5			
WFS2A				1	1
WFS2B		1		?	?
WFS3			1	0.5	
WFS4			0.3	0.3	1

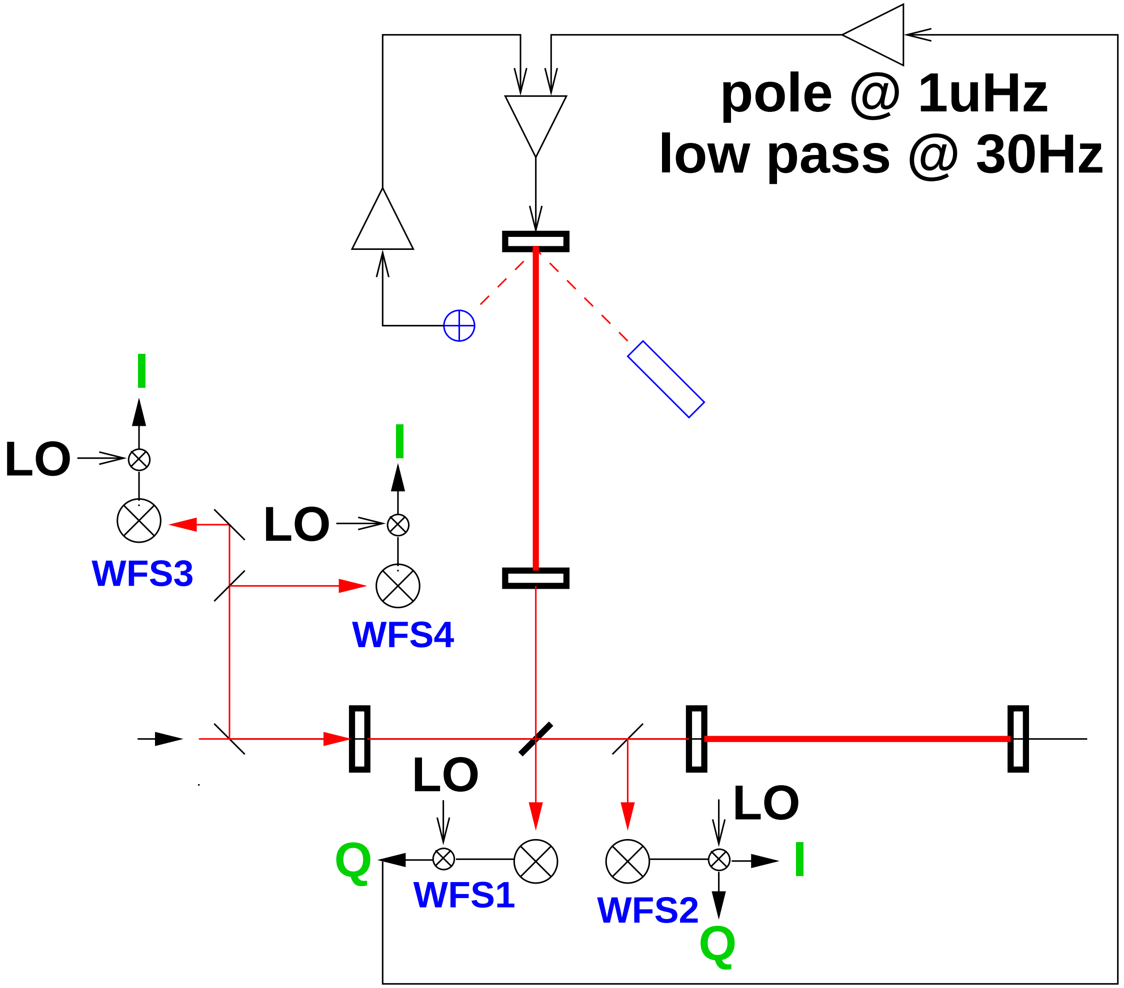
- Row normalized;
- Reproducibility: ~10%
  - » except for WFS2 (?);
- [green square] denotes expected term;
- [red circle] denotes feedback element;
- WFS3 and 4: low sensitivity (increase of modulation depth);
- Common PRM DOF: 2A->2B: wondering RF phase?

About calibrations…



- Reproducibility: 1-2%;
- But systematic:
  - » ~20% pitch/yaw;
  - » ~20% X/Y arm;
- This generates
  - » *in the calibrated Sensing Matrix (common/differential basis) the addition of non-existing cross-terms;*
  - » Use of nominal values;

Control Viewpoint



- 1/f loop (1uHz pole);
- Crossover with Optical Lever servos;
- Unconditionally stable.

A look back at S2 – H1 only

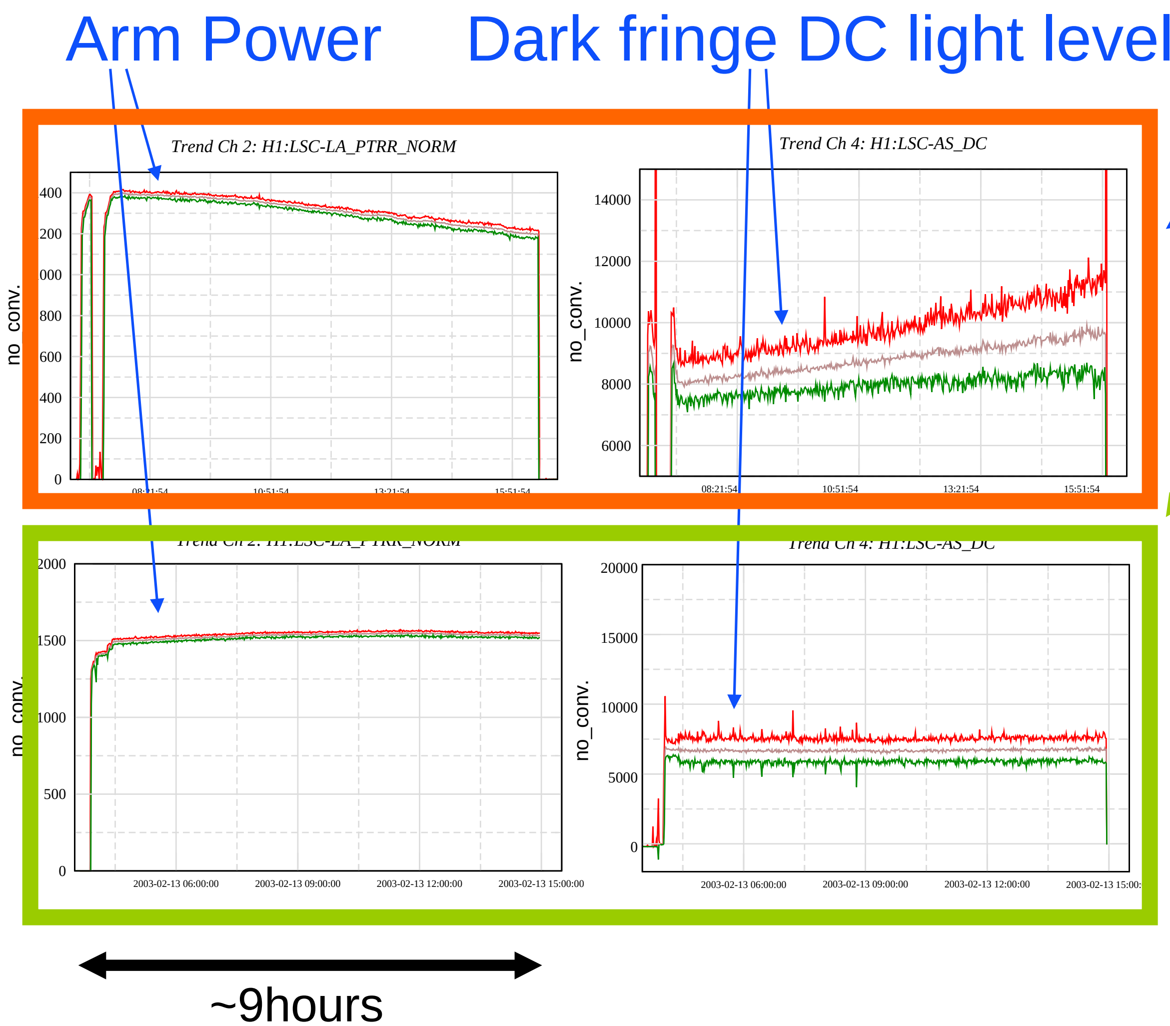
- 8/10 angular degrees of freedom controlled
  - » Problems closing WFS2B loop (dITM);
  - » QPDs loops not closed
    - – input beam pointing and BS free to drift.

- Low bandwidth (~100mHz)
  - » Cross-talk between WFS prevented raising the loop gain.

Observations during S2 – H1

WFS OFF

WFS ON



- The system provided
  - » Long term arm power stability;
  - » Significant reduction of first-order fluctuations.

H1 WFS Commissioning after S2

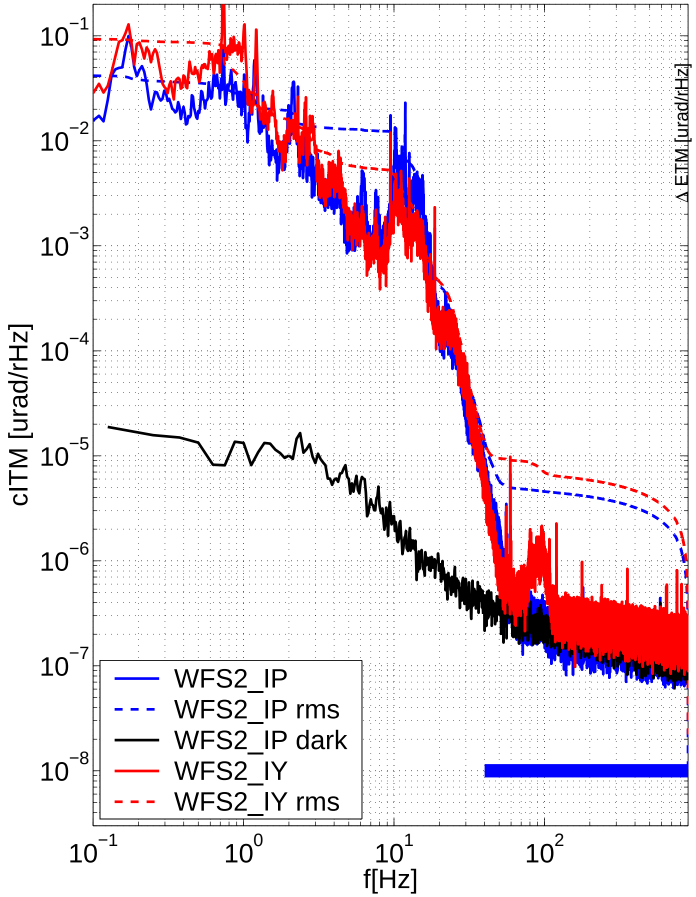
- 10/10 angular DOF controlled (~10-100mHz)
  - » Role of WFS3 and 4 swapped;
  - » WFS2 table work;

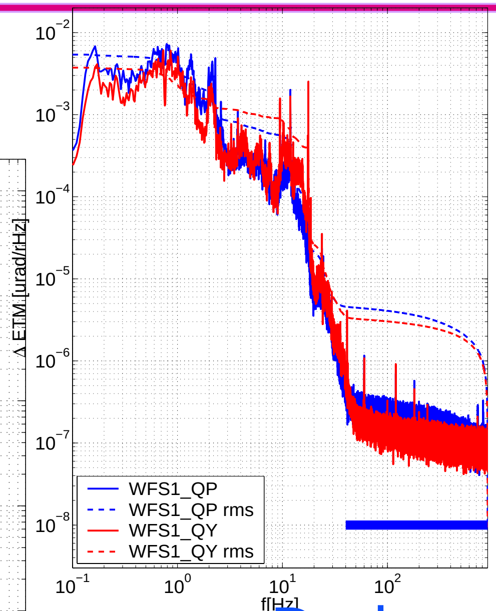
- Ready for next step
  - » Bandwidth, deal with the cross-talk;
  - » Include QPD;
  - » Noise study and loop shaping;
  - » ***BUT…***

Laser Power Increased - S3

- To improve the modal overlap between the carrier and the sidebands;
- But WFS system unstable
  - » Tracked down to an RF phase rotation in WFS2 (?)
    - – Phase rotation correlated to NSPOB;
    - – Significant decrease in WFS2B response;
- Resolution: Gouy phase adjustment for WFS2
  - » decreased the phase rotation swing (30deg);
  - » Recuperated WFS2B response to dITM;
- **WFS system for S3 (H1 and H2)**
  - » **10/10 angular DOF controlled (10-100mHz);**
  - » **Input beam pointing and BS using QPDs (<10mHz)**

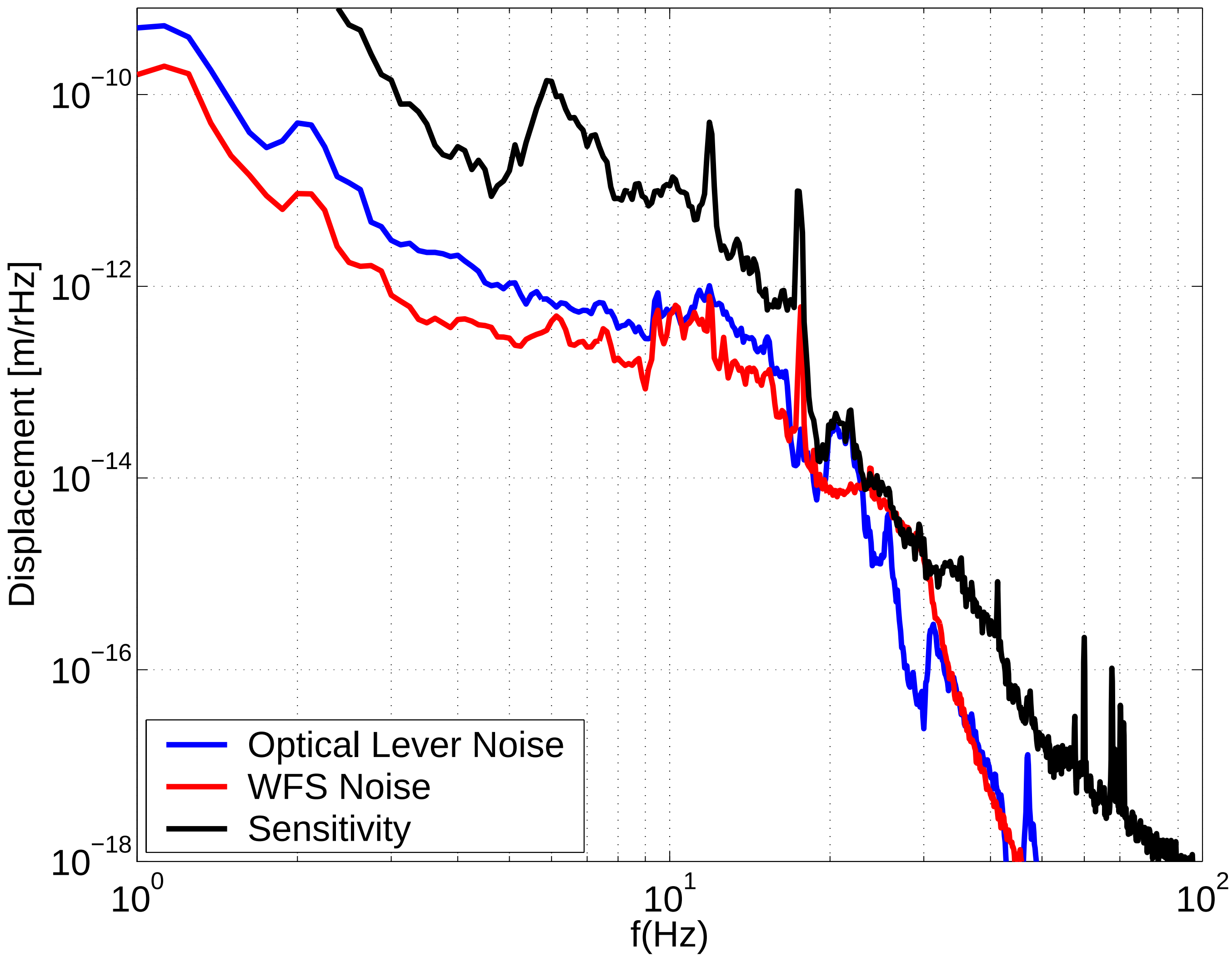
H1: Calibrated Error Points



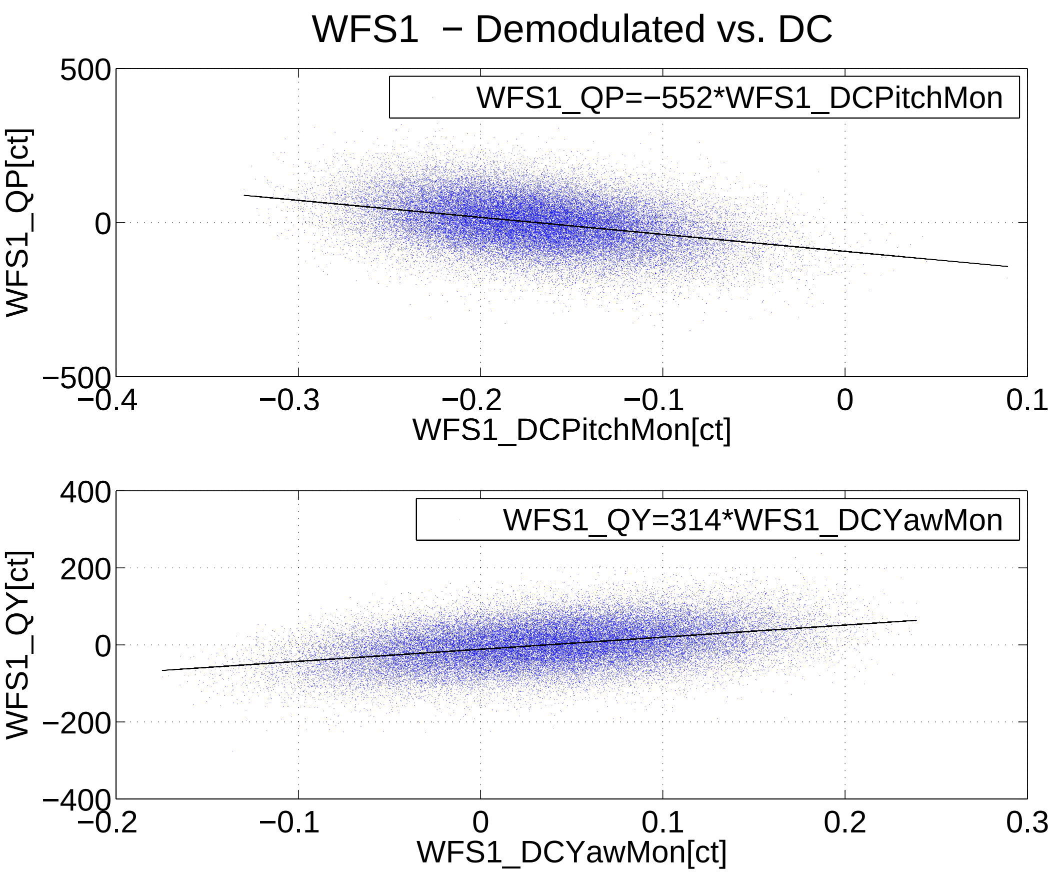


- Dark noise limited above 80Hz
  - » Above requirement;
  - » Increase of RF gain, whitening gain, NR modulation depth;
  - » Decrease of electronic/ADC noise;
- Residual Angular fluctuations
  - » 10^{-7}-10^{-8} rad-rms

Angular Control Noise Contribution to the Displacement Sensitivity (H1)



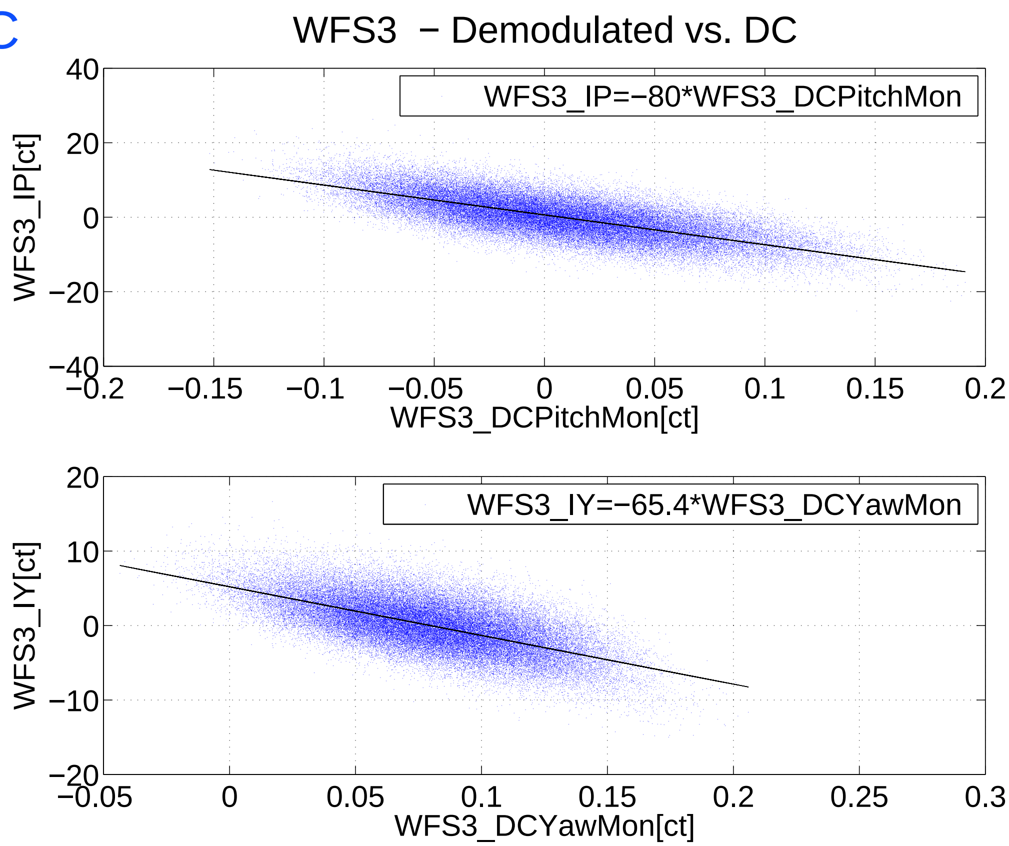
H1: Beam positioning on WFS



- Linear dependence between demodulated signals and DC asymmetry
  - » Pitch
    - – Defined as (DC top half-DC bot half)/DC total
    - – $4*10^{-8}$ * DC pitch asym [rad]
  - » Yaw
    - – $2*10^{-8}$ * DC yaw [rad]
- 25% DC asymmetry corresponds to 10^{-8} rad offset;
- Asymmetry jitter
  - » Spectral component;
  - » Faster than 1Hz;
  - » Reduced as WFS bandwidth increased?

H1: Beam positioning on WFS

- Linear dependence between demodulated signals and DC asymmetry
  - » Pitch/Yaw
    - – 10^{-6} * DC pitch asym [rad]
- <u>10% DC asymmetry introduces 10^{-7} rad offset;</u>
- Feedback? Need to investigate…



To Do…

- Increase NR modulation depth;
- Fine tune Gouy phases (2, 3, 4)
  - » Eliminate cross-terms in WFS3;
- WFS matrix in W/urad;
- Increase bandwidth
  - » Non-diagonal terms in output matrix;
  - » Loop shaping;
- Explore beam centering on TM
  - » Currently running off-center on ETMX;
  - » Angle-to-length coupling;
- WFS2 RF phase rotation/heating effect ?
- Investigate beam centering effect on WFS;
- Goal for S4: full bandwidth (2-3Hz) angular control.