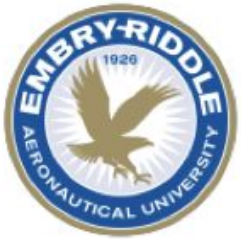
LIGO

Seismic Platform Interferometer (SPI) Pathfinder

Joshua Freed, Jeff Kissel, Sina Koehlenbeck, Brian Lantz, Bram Slagmolen, Arnaud Pele, Eddie Sanchez, Jason Oberling, Matthew Heintze, Calum Torrie, Gabriele Vajente, Peter Fritschel, Michele Zanolin, …



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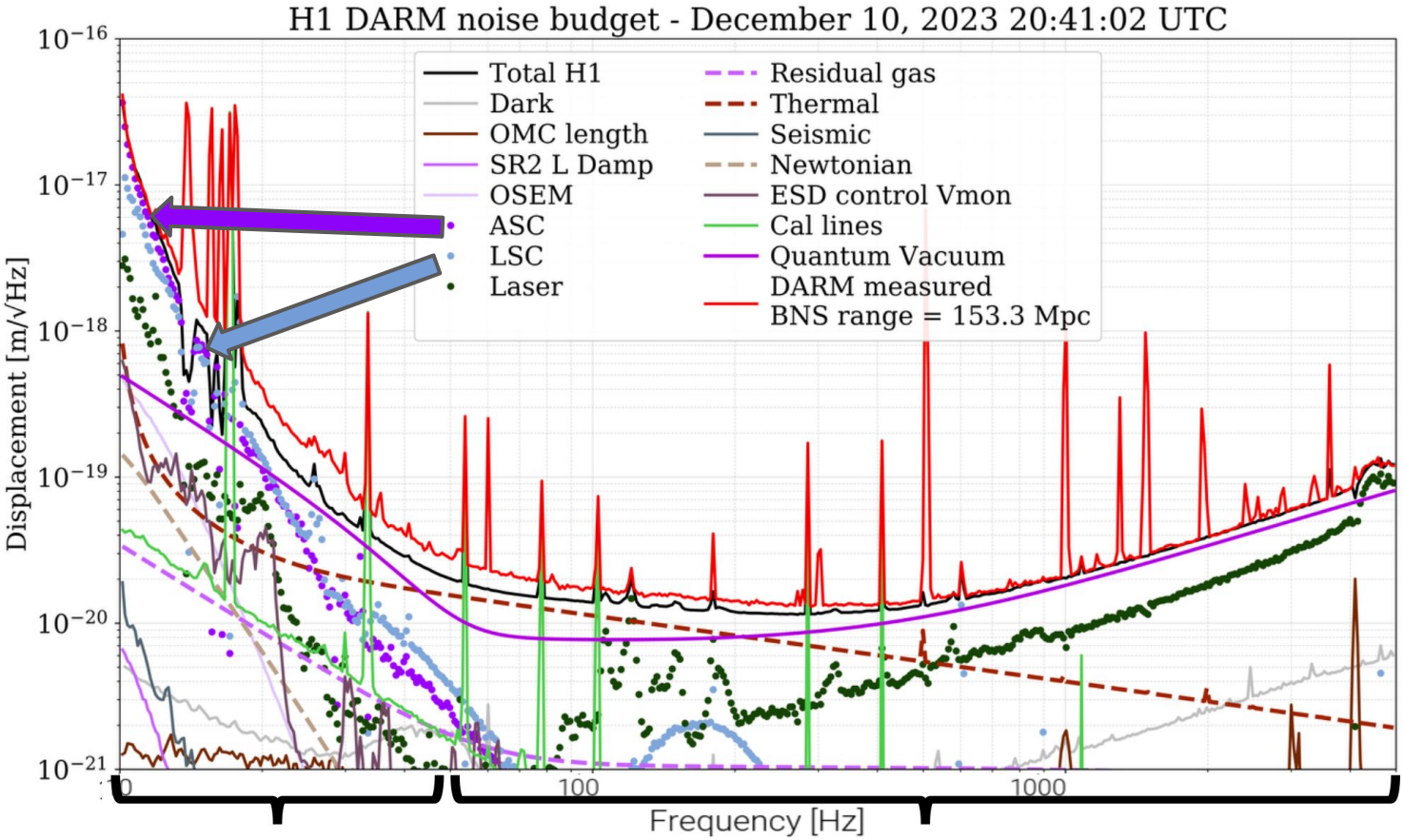
The Problem?



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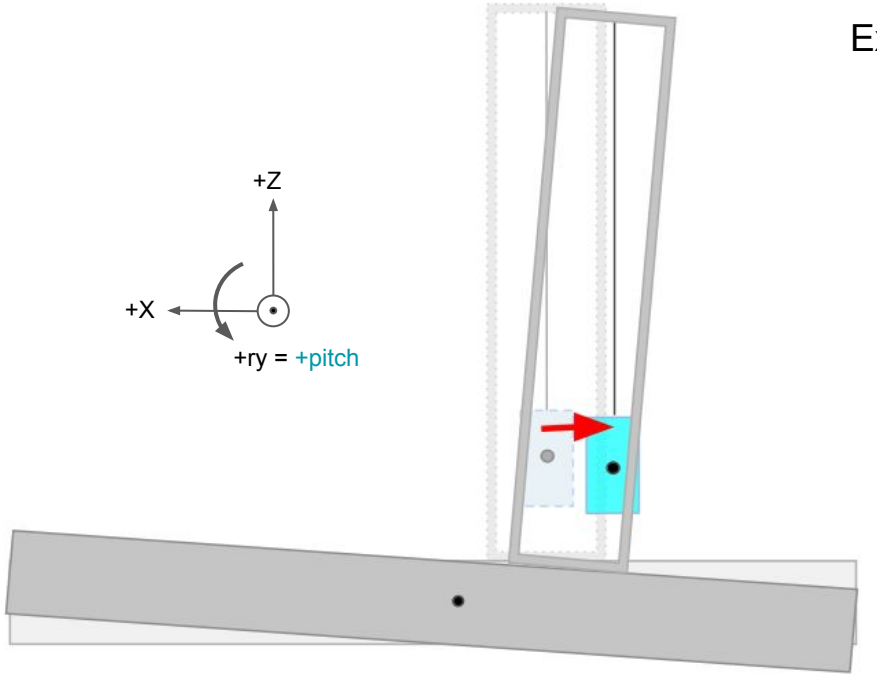
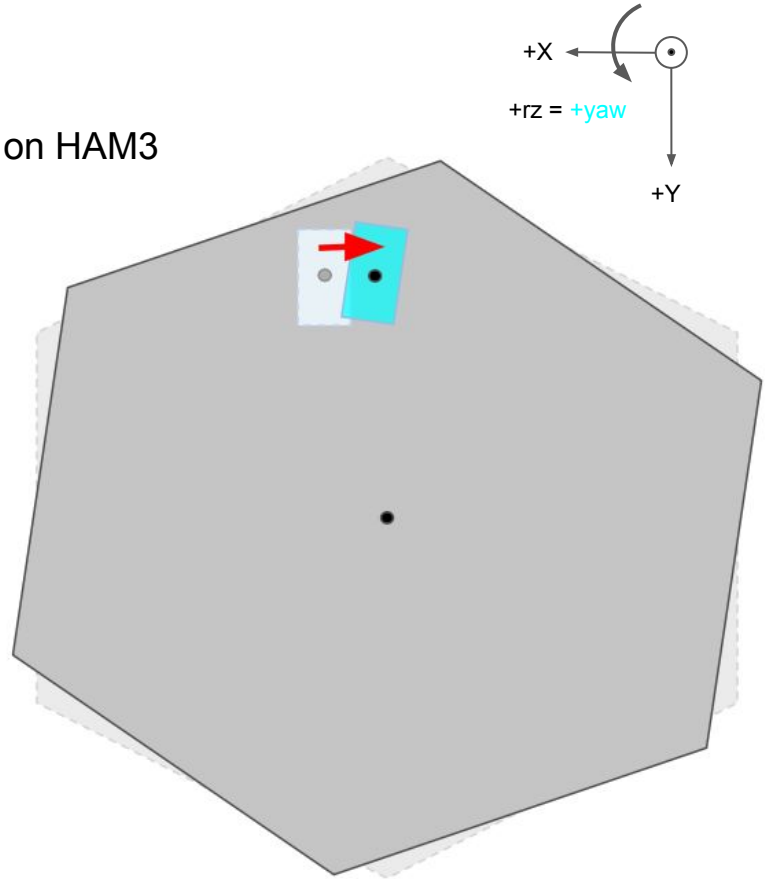
Tilt-to-Length Coupling



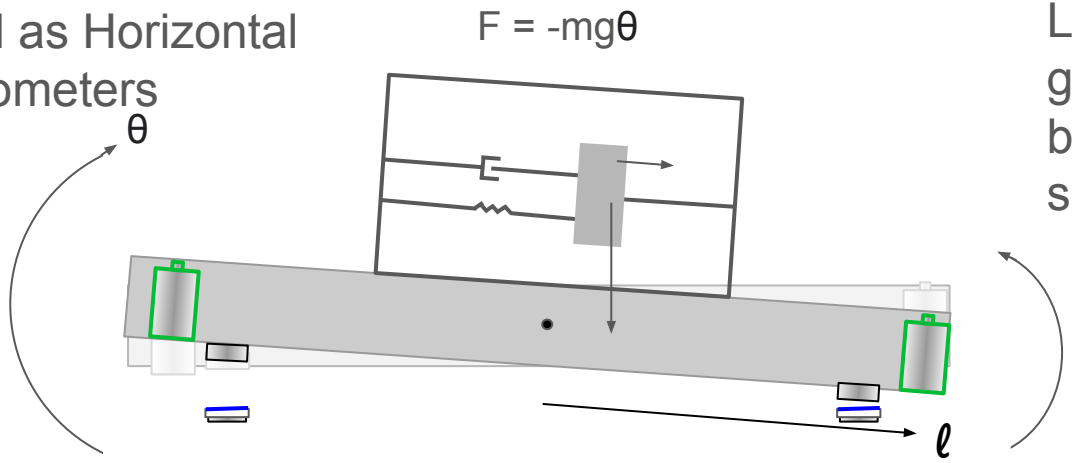
Example PR2 on HAM3



HAM: Horizontal Access Module (Vacuum Chamber)

Tilt-to-Horizontal Coupling

Tilt is interpreted as Horizontal Motion in seismometers

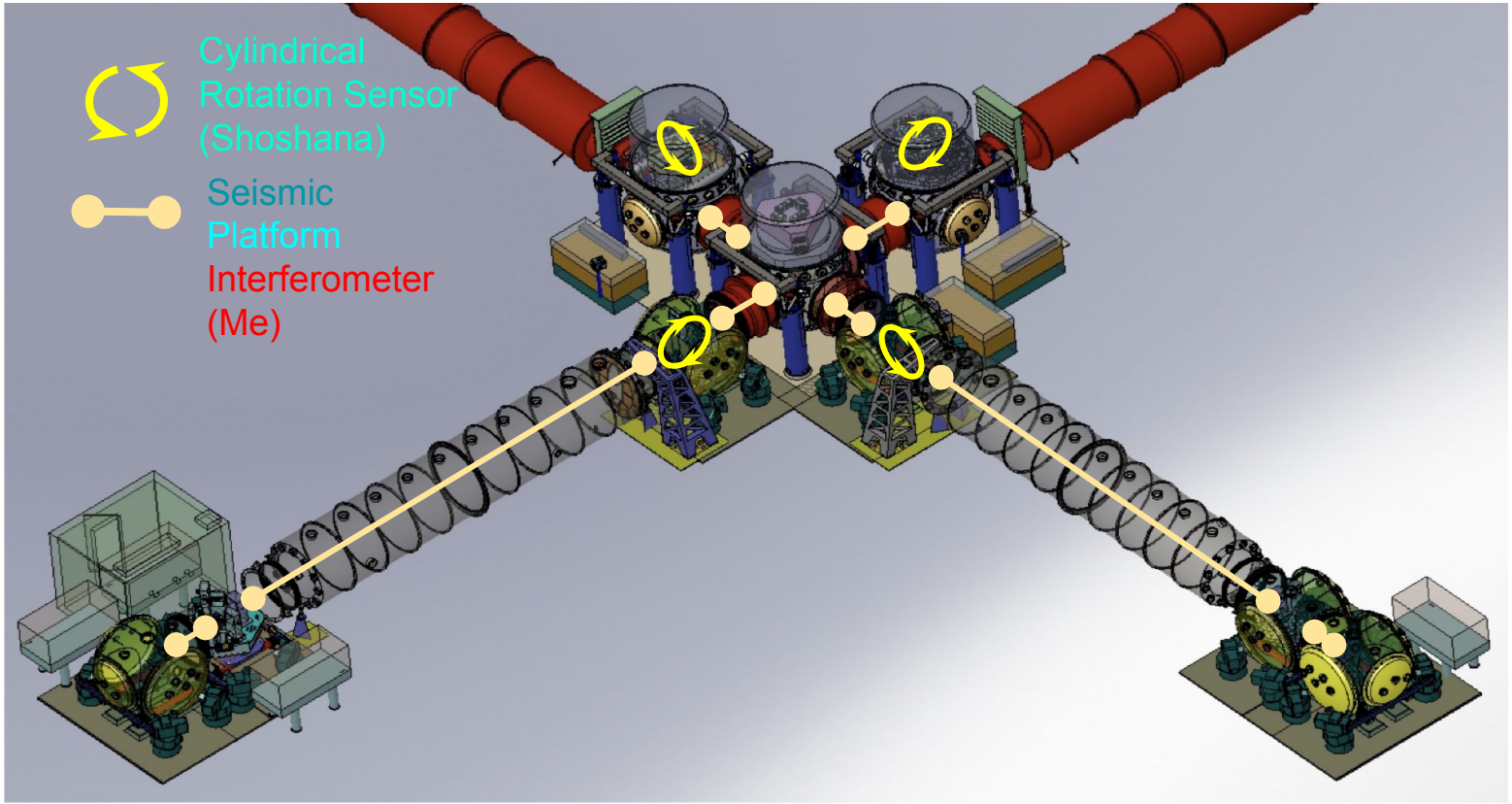


Limited by the gain difference between sensors

GS13s – Inertial Sensors
CPS – Displacement Sensors

Sensor Noise because lever is very short $\ell \approx 1$m

The Dream: Integrated Collection of Sensor Upgrades



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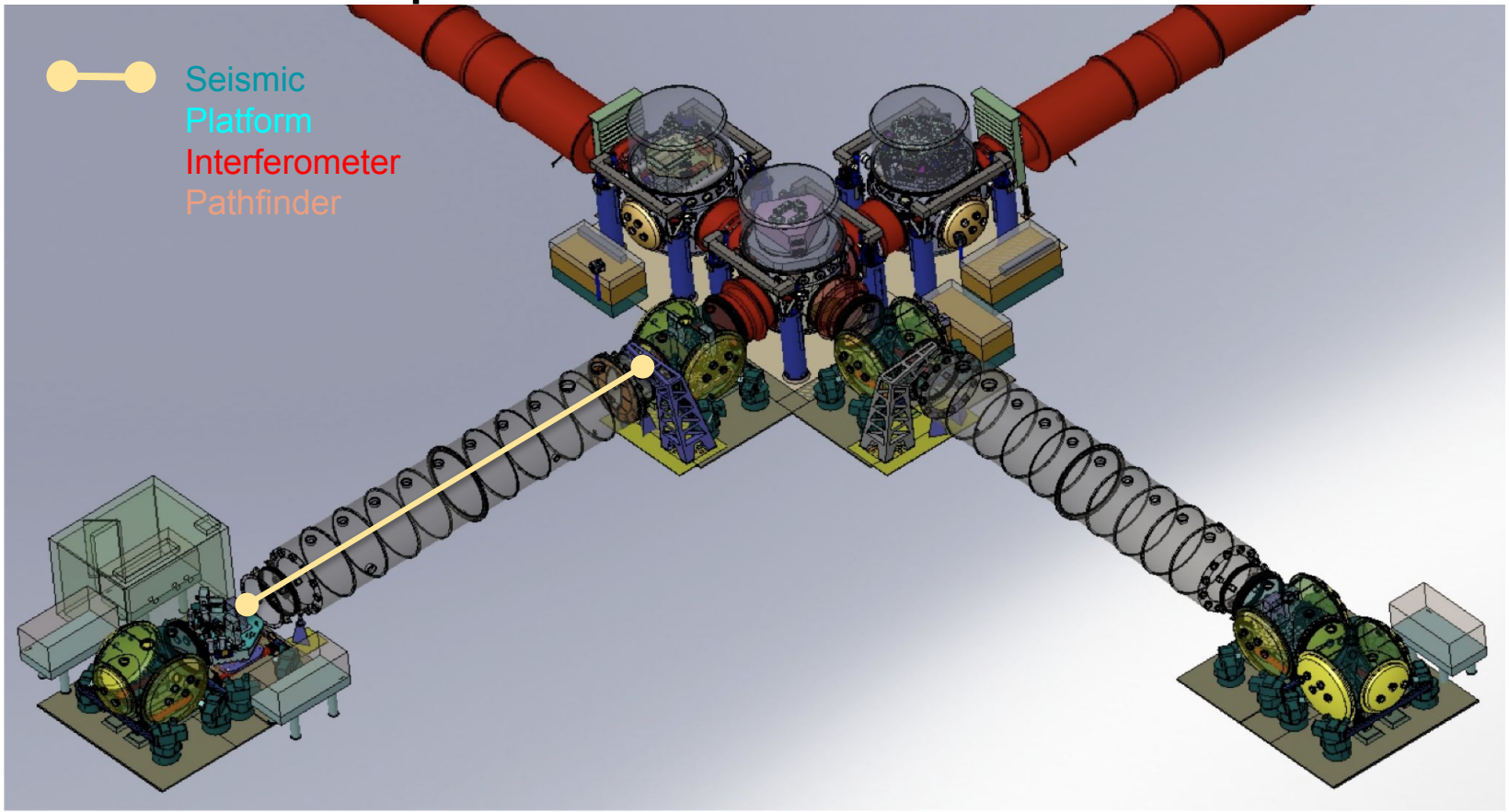
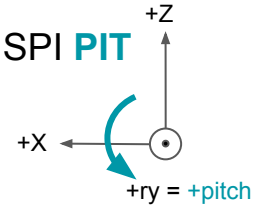
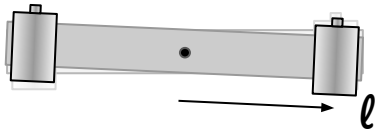
The First Step: SPI Pathfinder



SPI **PIT**



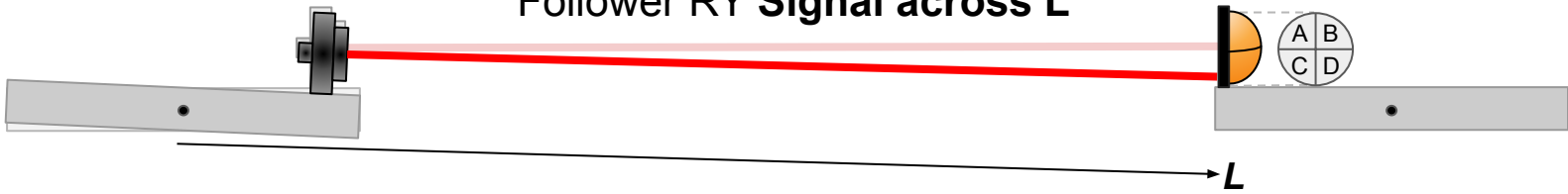
HAM3
“Follower”



Local RY Signal:
Differential Z across ℓ

HAM2
“Leader”

Follower RY **Signal across L**



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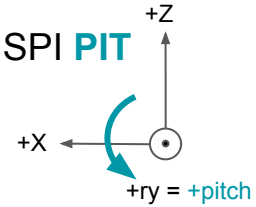
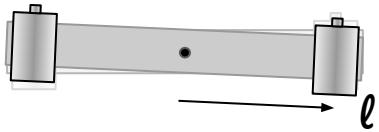
SPI PIT



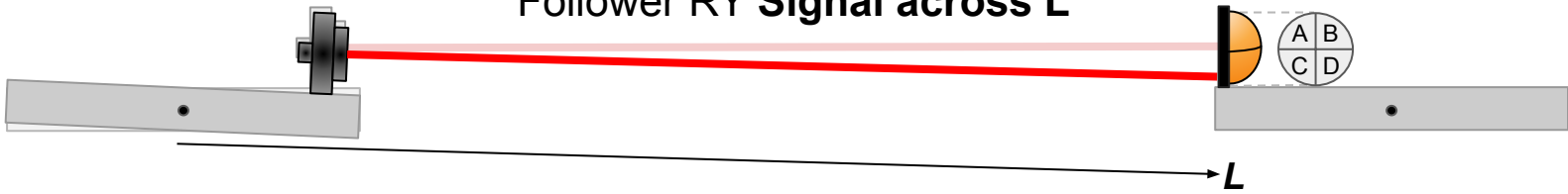
HAM3
“Follower”



Local RY Signal:
Differential Z across ℓ

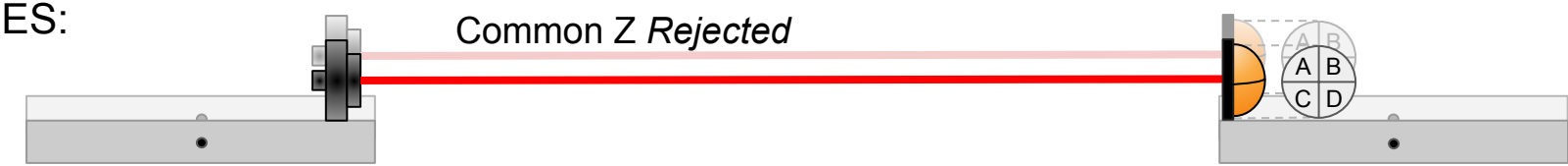
HAM2
“Leader”

Follower RY **Signal across L**

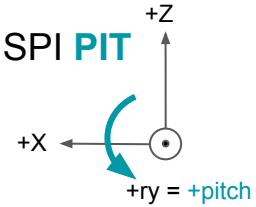


NOISES:

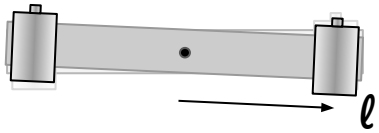
Common Z *Rejected*



SPI PIT



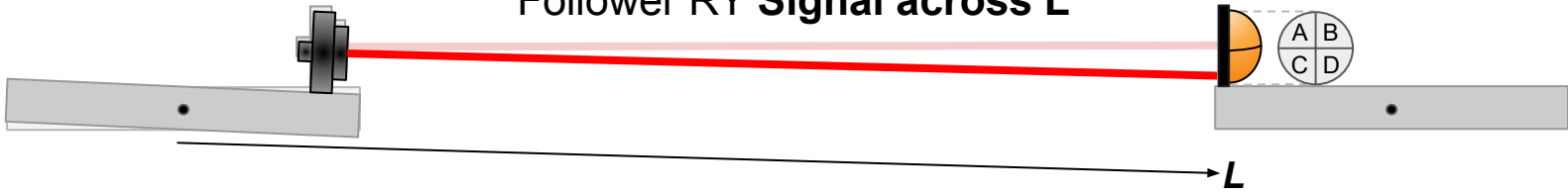
HAM3
“Follower”



Local RY Signal:
Differential Z across ℓ

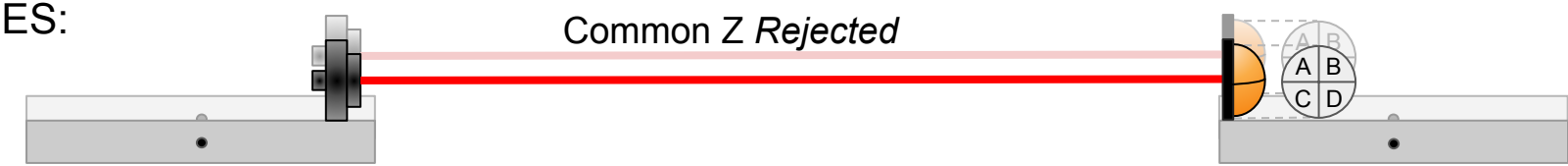
HAM2
“Leader”

Follower RY **Signal across L**

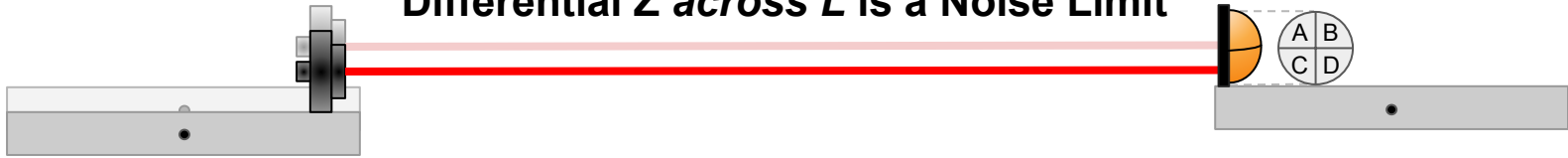


NOISES:

Common Z *Rejected*



Differential Z *across L* is a Noise Limit



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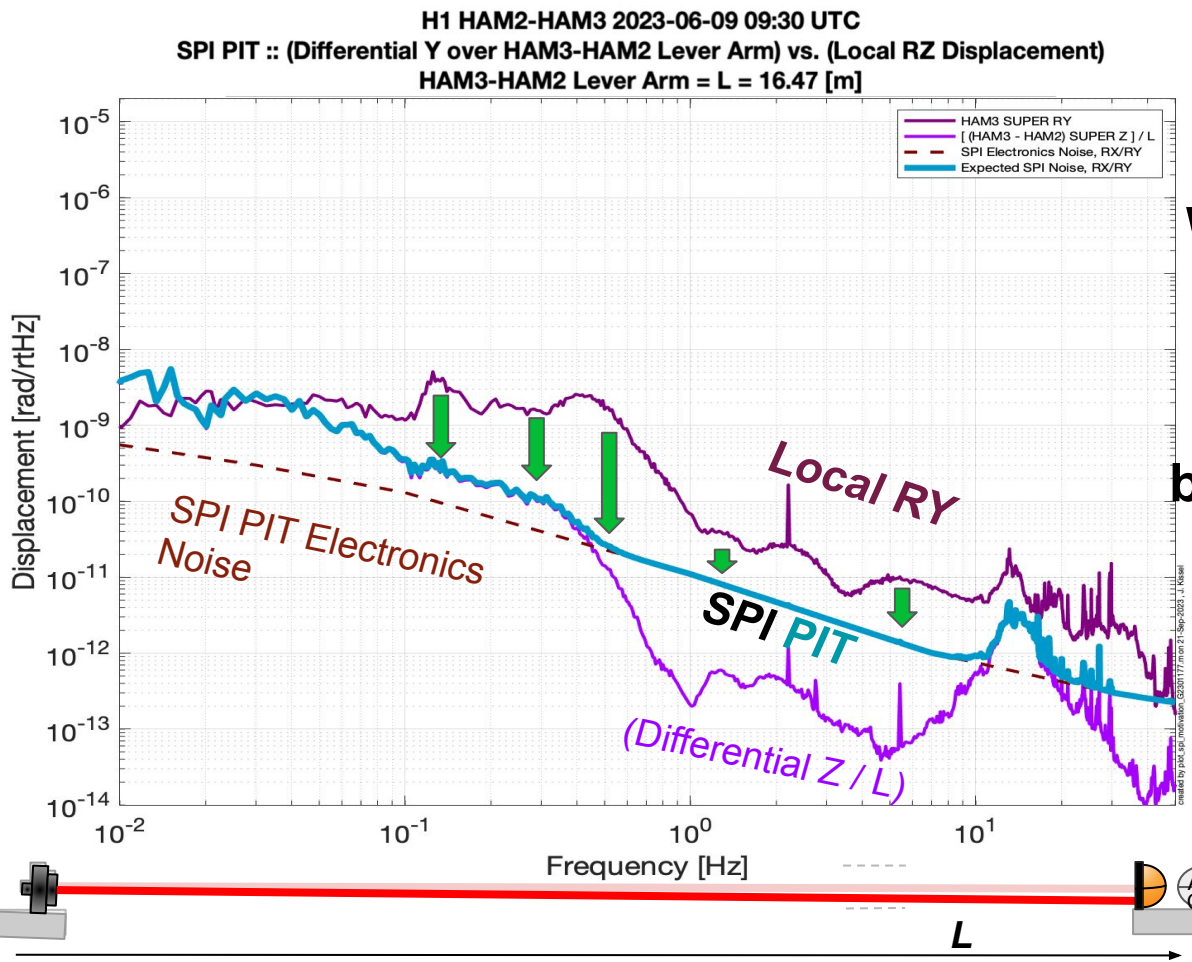
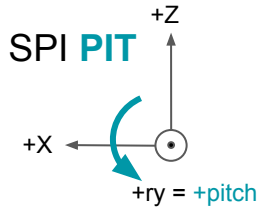
Expected SPI PIT Performance





We expect improve platform RY performance by as much as 10-50x between 0.08 - 10 Hz with SPI PIT.

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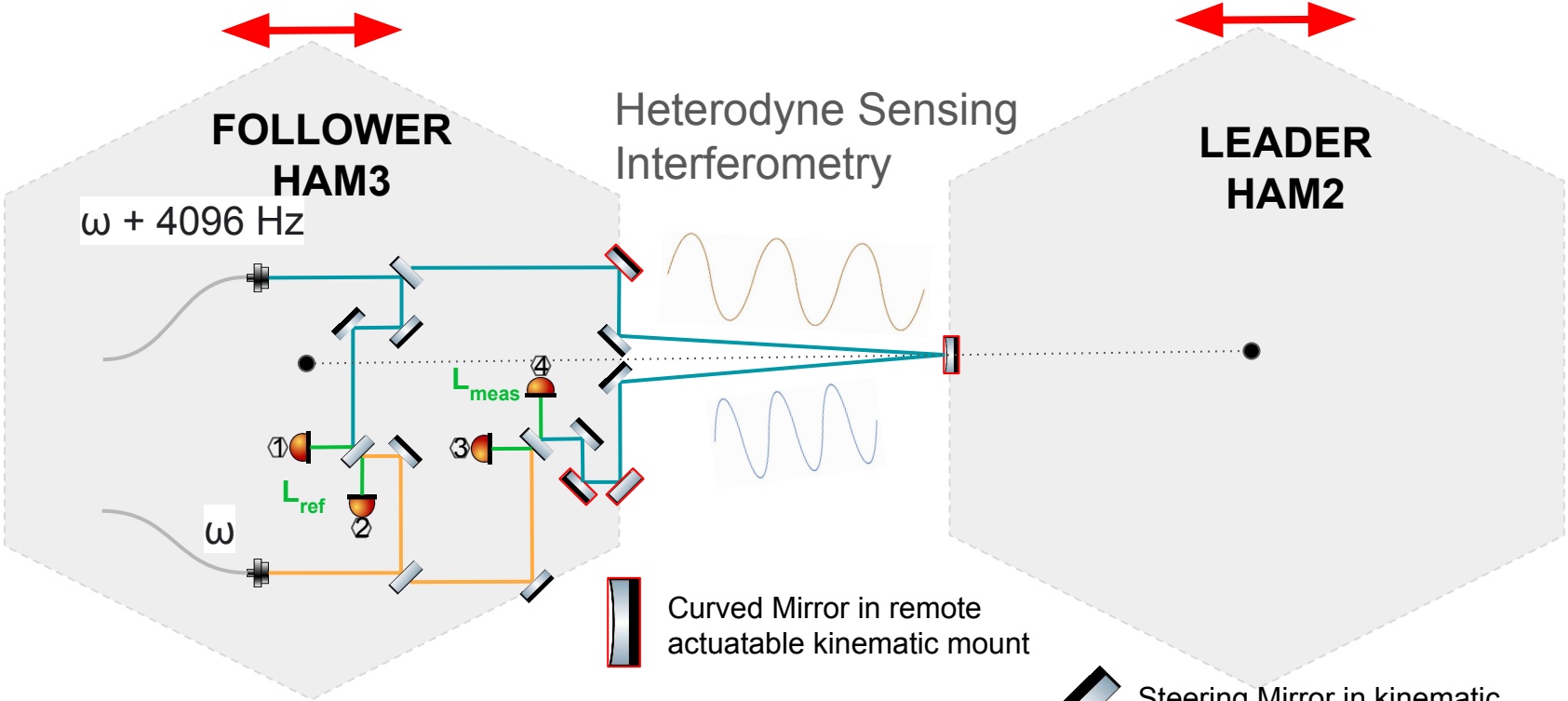
Conceptual SPI **LONG** In-vac Layout

SPI
LONG



Curved Mirror in remote actuatable kinematic mount

Steering Mirror in kinematic mount

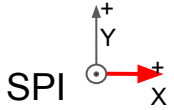
PD in fixed mount:
2 pin + shield feedthrough

Fiber collimator
in fixed mount

Steering Mirror in remote actuatable kinematic mount

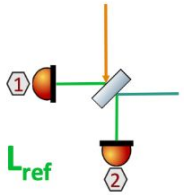
Beamsplitter in kinematic mount

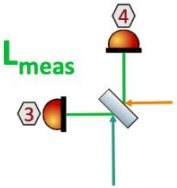
Heterodyne Sensing



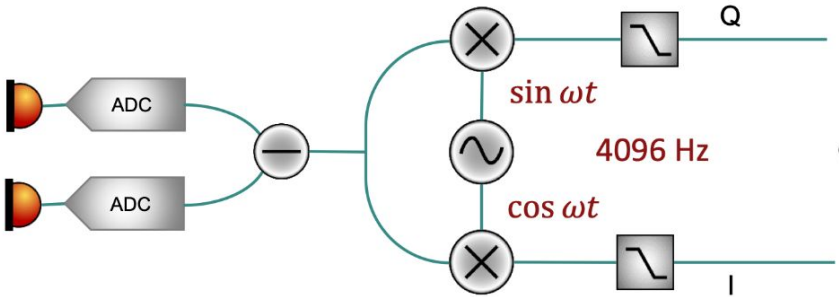
SPI
LONG

$$A_{\text{meas}} = a_{\text{meas}} \cdot \cos(\omega t + \varphi_{\text{common}} + \varphi_{\text{ISI}})$$





$$A_{\text{ref}} = a_{\text{ref}} \cdot \cos(\omega t + \varphi_{\text{common}})$$



$$\varphi = \tan^{-1}\frac{Q}{I}$$

$$\delta L = \frac{\lambda}{2\pi} \cdot \delta\varphi$$

Displacement ΔL between two ISI:

$$\Delta L = \delta L_{\text{meas}} - \delta L_{\text{ref}}$$

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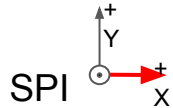
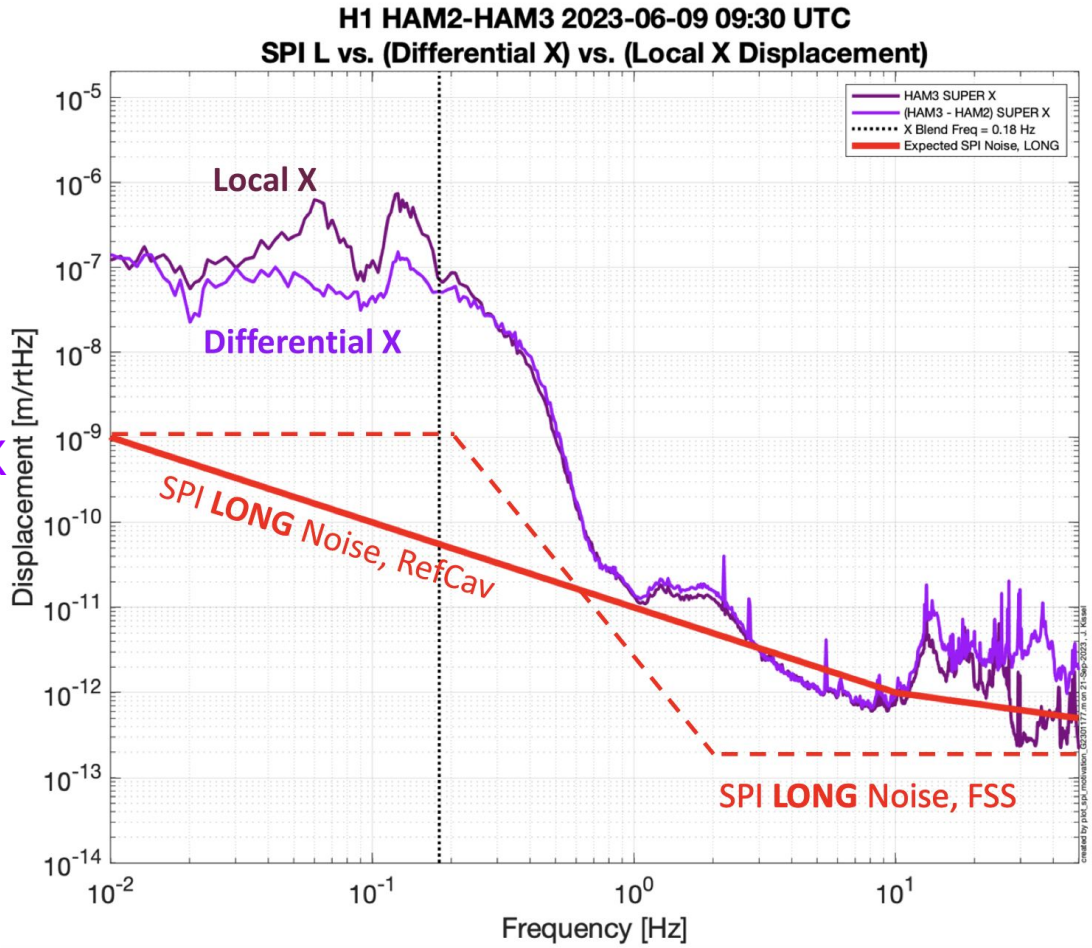
https://dcc.ligo.org/LIGO-G2400623

Expected SPI **LONG** Performance



Local X
CPS DIff
OFF

Differential X
CPS DIff
ON



Laser frequency noise for FSS: LHO Logbook: 73976

Laser frequency noise RefCav: LHO logbook: 38817

We won't be able to get all the way down to SPI LONG noise we'll still be limited by rolling off GS13 noise, its still MUCH less than current performance.

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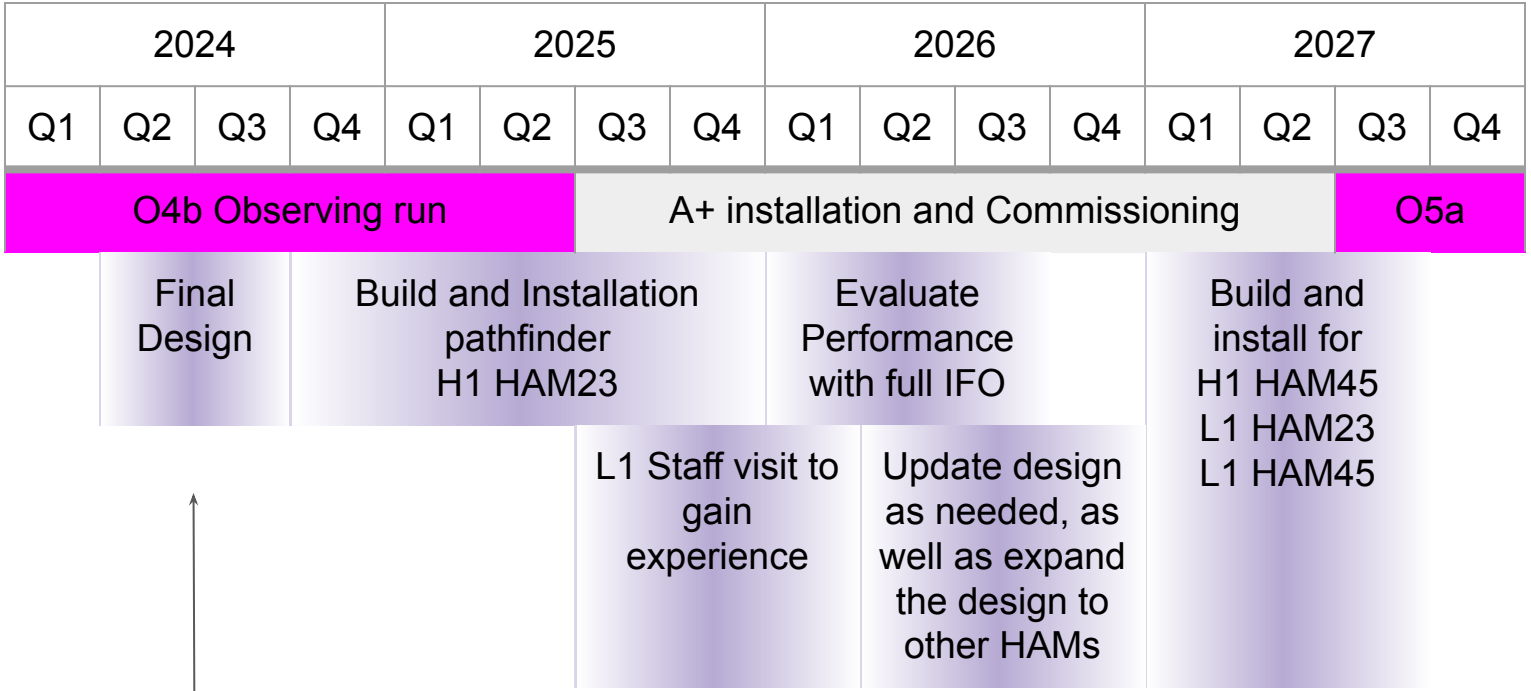
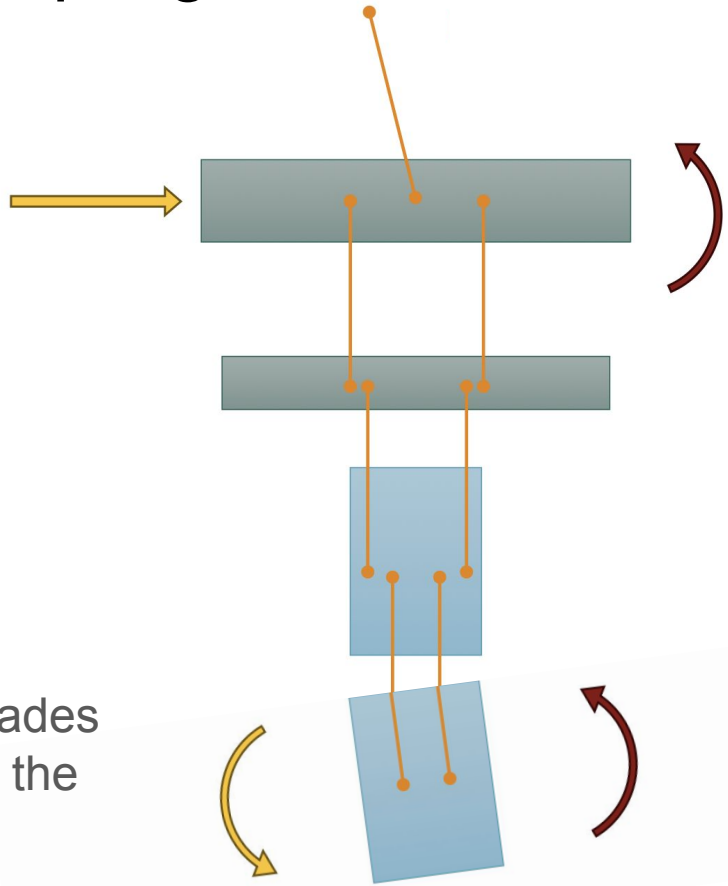
Timeline


2024
2025
2026
2027
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
O4b Observing run
A+ installation and Commissioning
O5a
Final Design
Build and Installation pathfinder H1 HAM23
Evaluate Performance with full IFO
Build and install for H1 HAM45 L1 HAM23 L1 HAM45
L1 Staff visit to gain experience
Update design as needed, as well as expand the design to other HAMs
We are here

Extra Slides (If time permits)

Length-to-Tilt Coupling

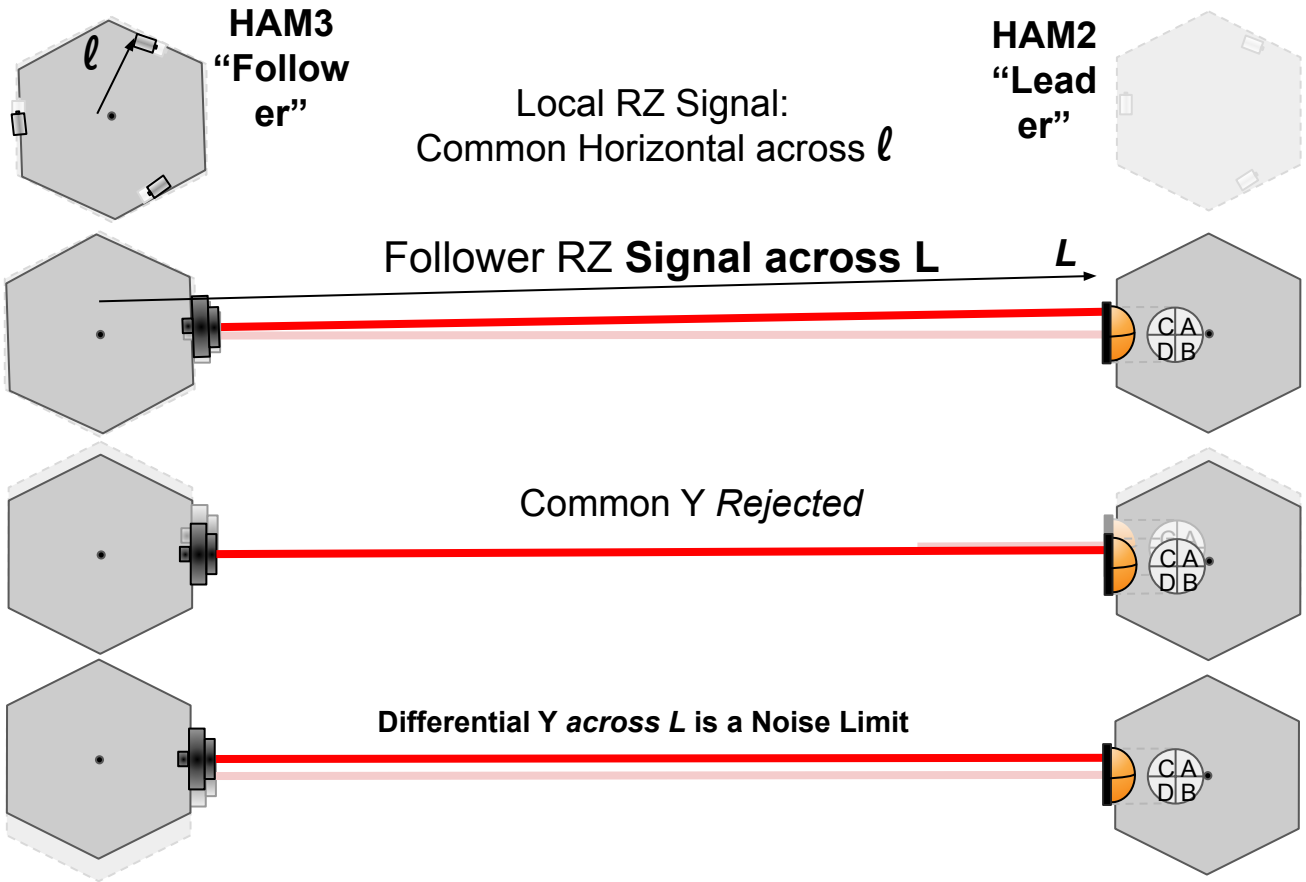


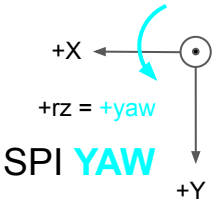
Driving in length causes pitch in top mass

This cascades down into the test mass

https://dcc.ligo.org/LIGO-G2400623

Measuring YAW w/ ONE-WAY Optical Lever





Since we are using QPDs we also get the **YAW** "for free"

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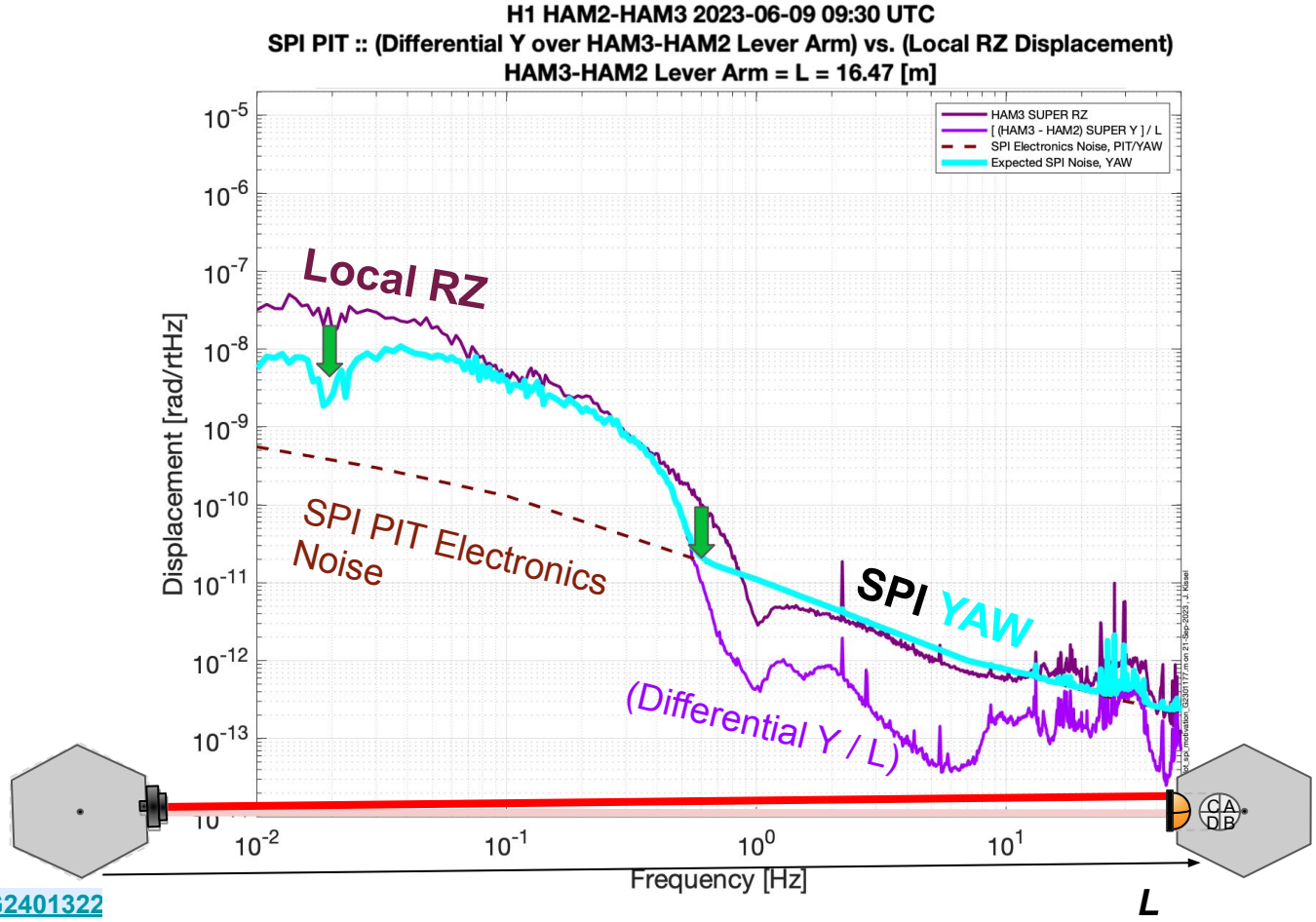
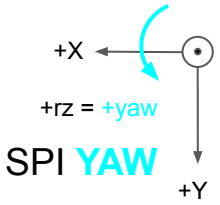
Expected SPI YAW Performance





It is unclear if the Differential Y / L noise limit for **SPI YAW** is better than **Local RZ**

But that is what the pathfinder is for!!

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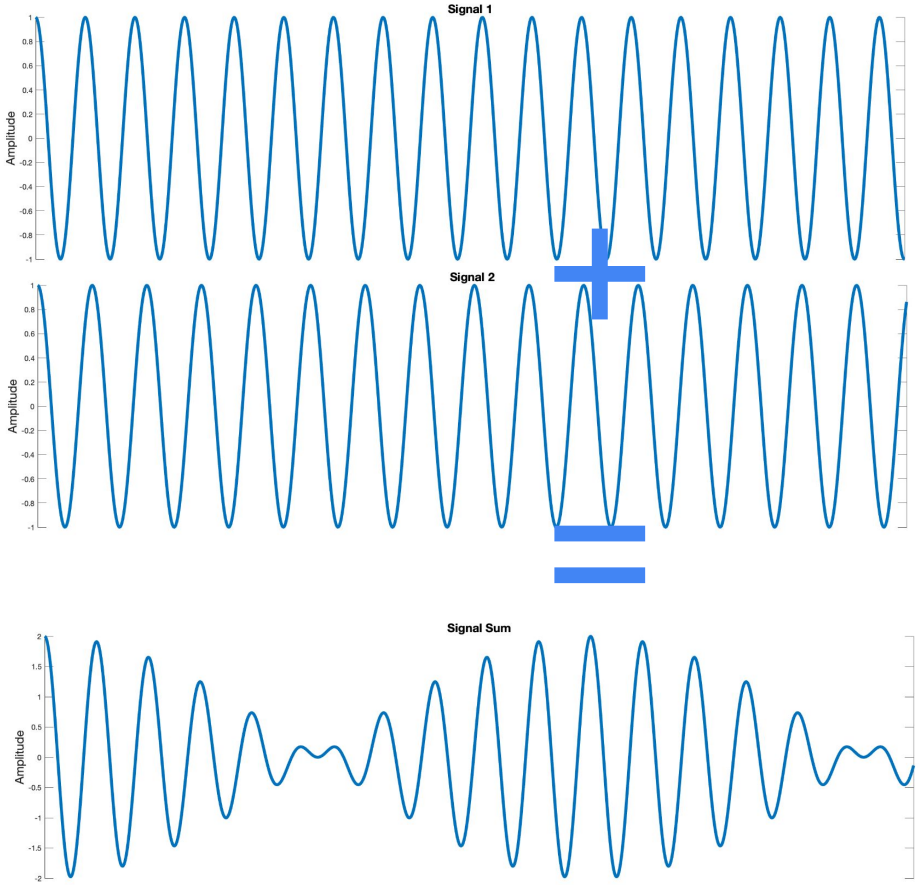
Heterodyne Sensing Intro

Superposition (sum) with slightly different frequencies

$$\cos\omega_1 + \cos\omega_2 = 2\cos\frac{\omega_1 - \omega_2}{2}\cos\frac{\omega_1 + \omega_2}{2}$$

Made up of 2 components, sum and difference, of the frequencies of the original signals



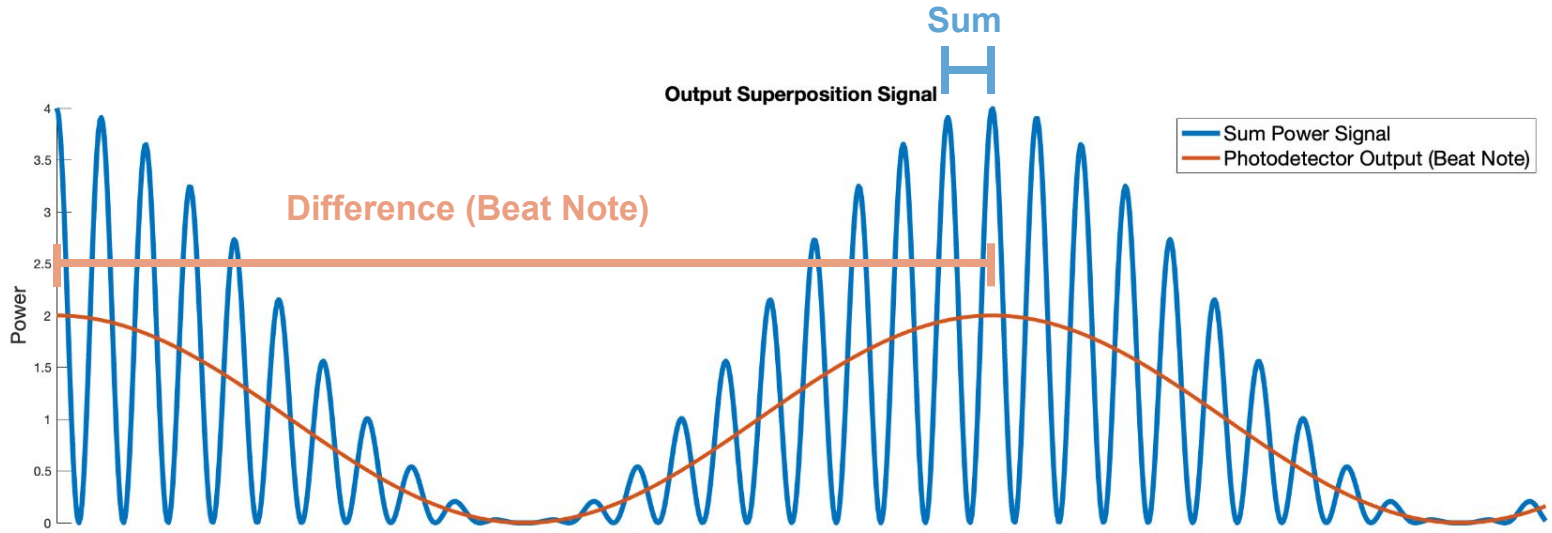
Photodiode Output sees power which is the square of this signal

SPI
LONG

SPI
LONG

Power Output on Photodiode (not to scale)

The true signal is the Sum Power Signal, however, the frequency is so high (about 3×10^{14} Hz in pathfinder case) that the photodiode will only detect the average power of the signal Beat Note (4096 Hz in pathfinder case)



SPI
LONG

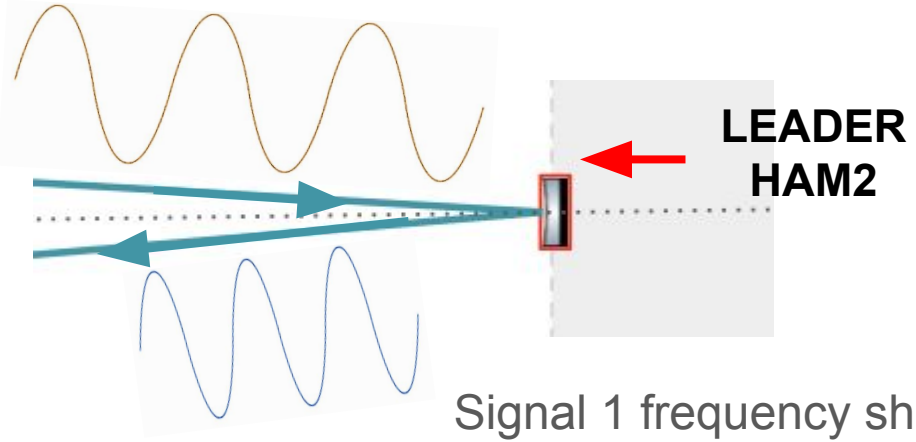
Doppler Shift

The Output will be fluctuating at the beat note frequency

Any longitudinal shifts between the tables will doppler shift the frequency of the beam

This will cause a shift in the frequency of the beat output signal which produces our error signal

Signal 1



Signal 1 frequency shifted

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