aLIGO HSTS Damping Loops Design Comparison

J. Kissel, for the SUS and ISC Teams

3 Different Designs

LHO Current

- Began with P. Fritschel's "resg" design from LLO aLOG 4739
- Slight increase of design complexity to strict velocity damping
- Some attention paid to sensor noise reinjection
- Evolved into disarray on a SUS-by-SUS basis because of
  - disjointed install
  - disjointed tweaking
  - poor version control

LLO Current

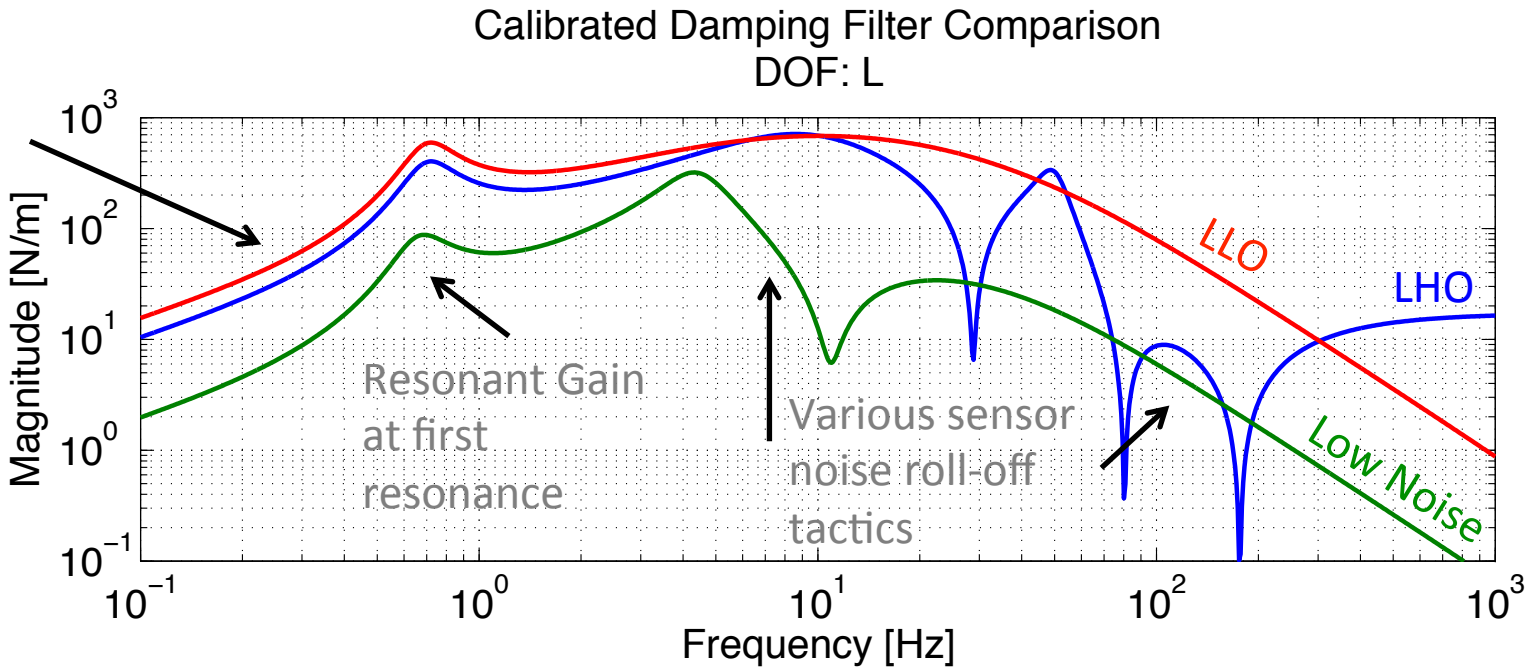
- Den's (?) design (can't find aLOGs)
- Focused on reducing Q's and impulse response
- Consistently installed in all L1 HSTS

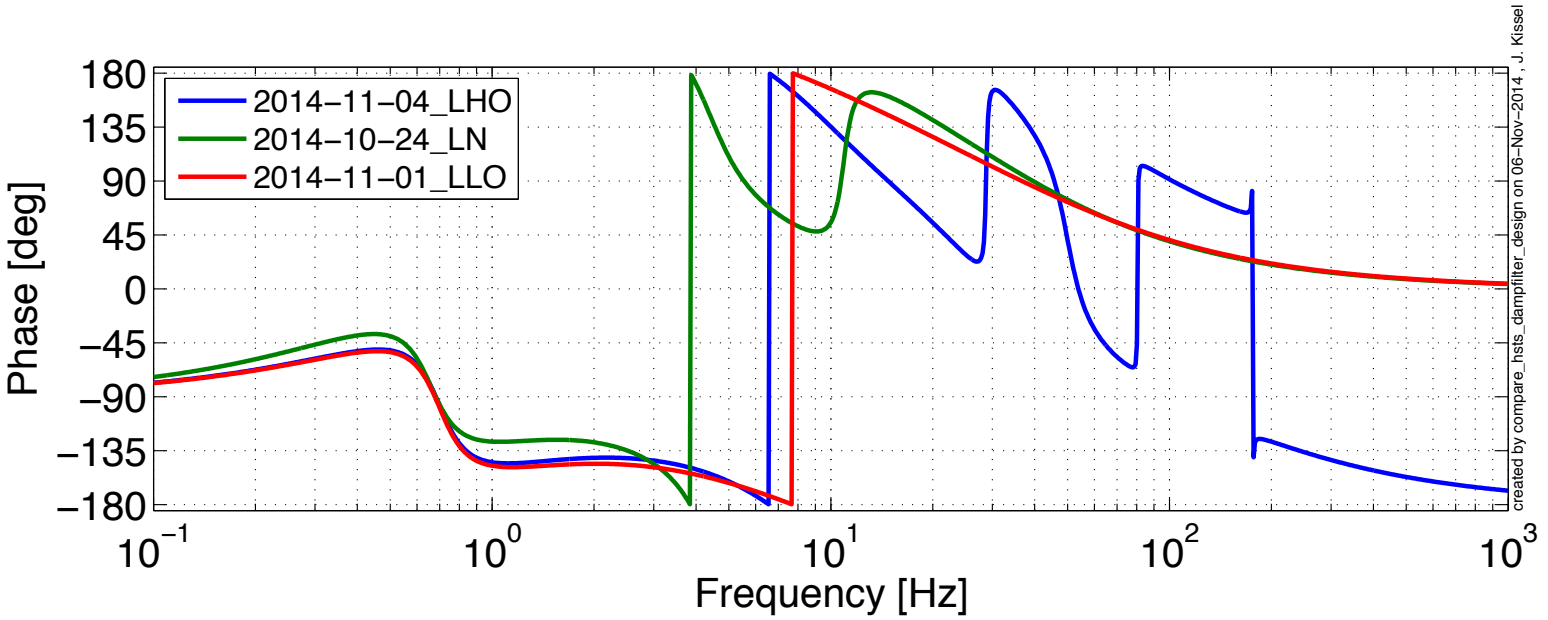
Low Noise

- Recently designed by Betsy / Kissel
- Not implemented anywhere
- Focused on 10-20 [Hz] noise performance, attempting to still get a good amount of damping

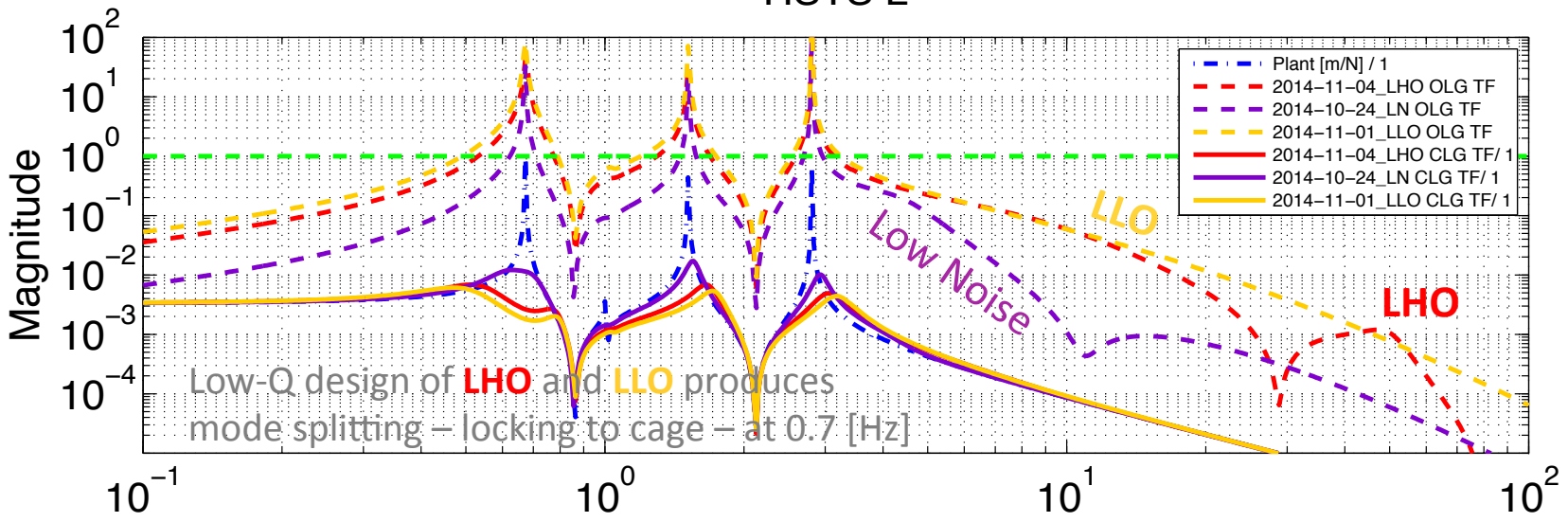
Remember: there are no optical levers on these SUS

AC coupled, rises as f^1, "velocity"

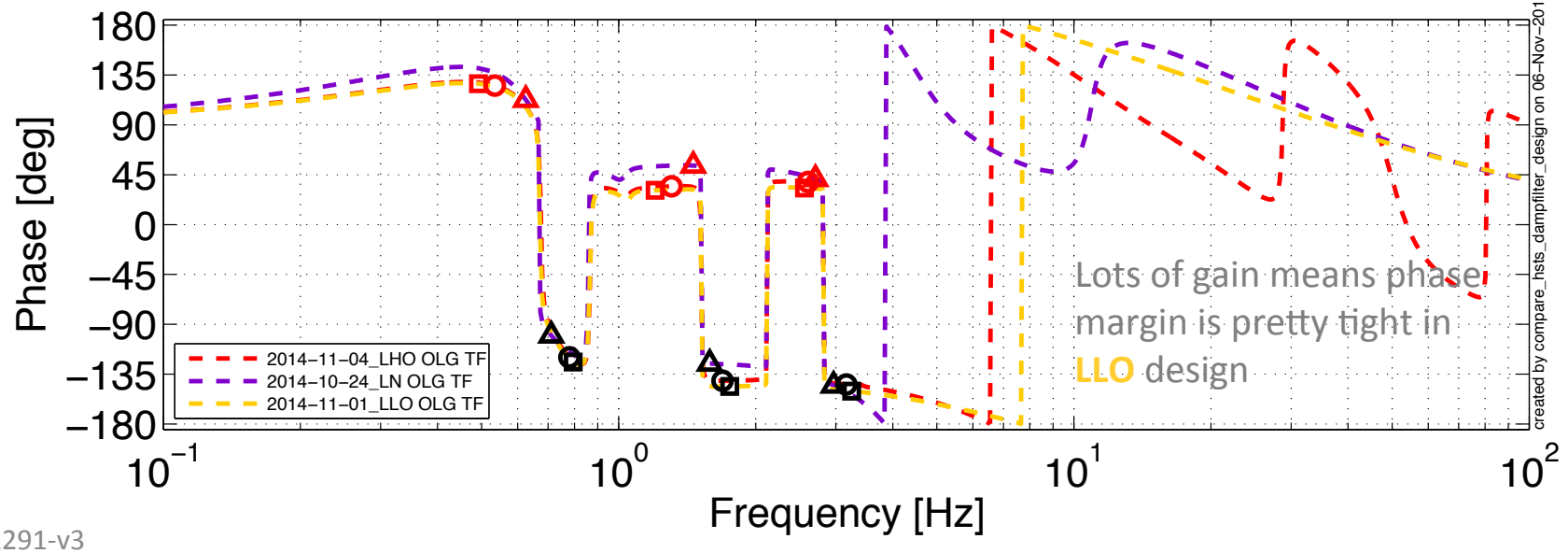


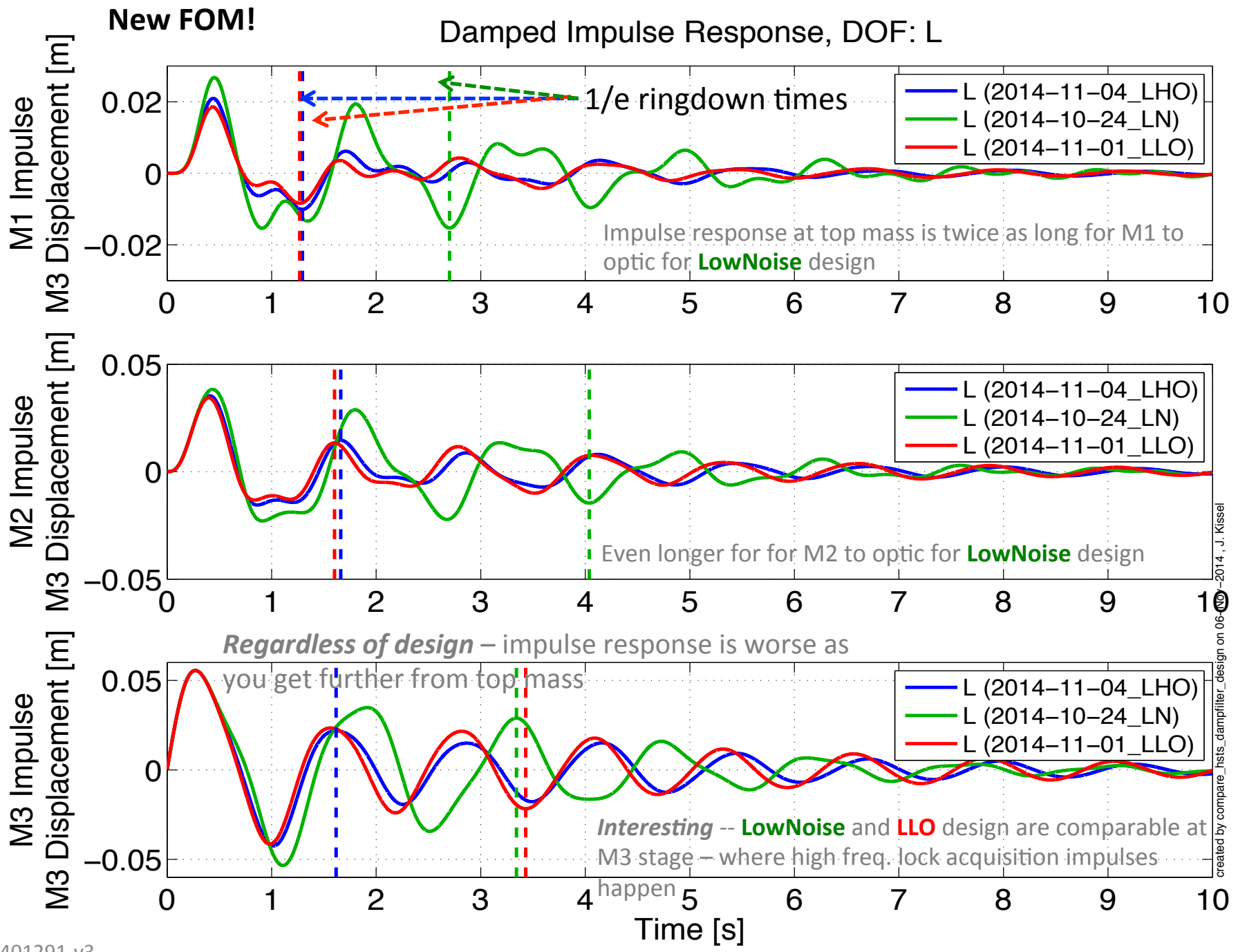


Damping Loop Design Comparison
HSTS L

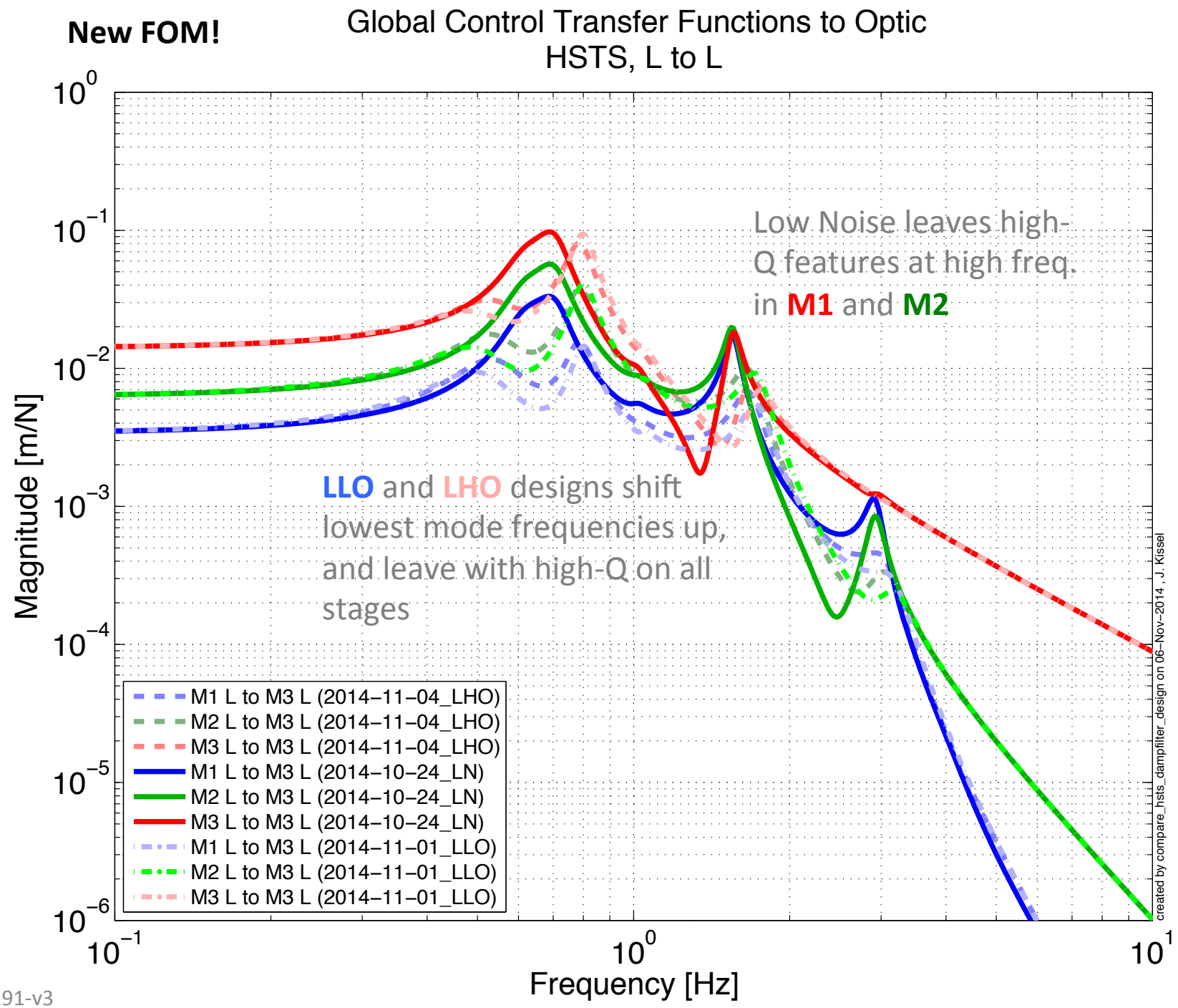


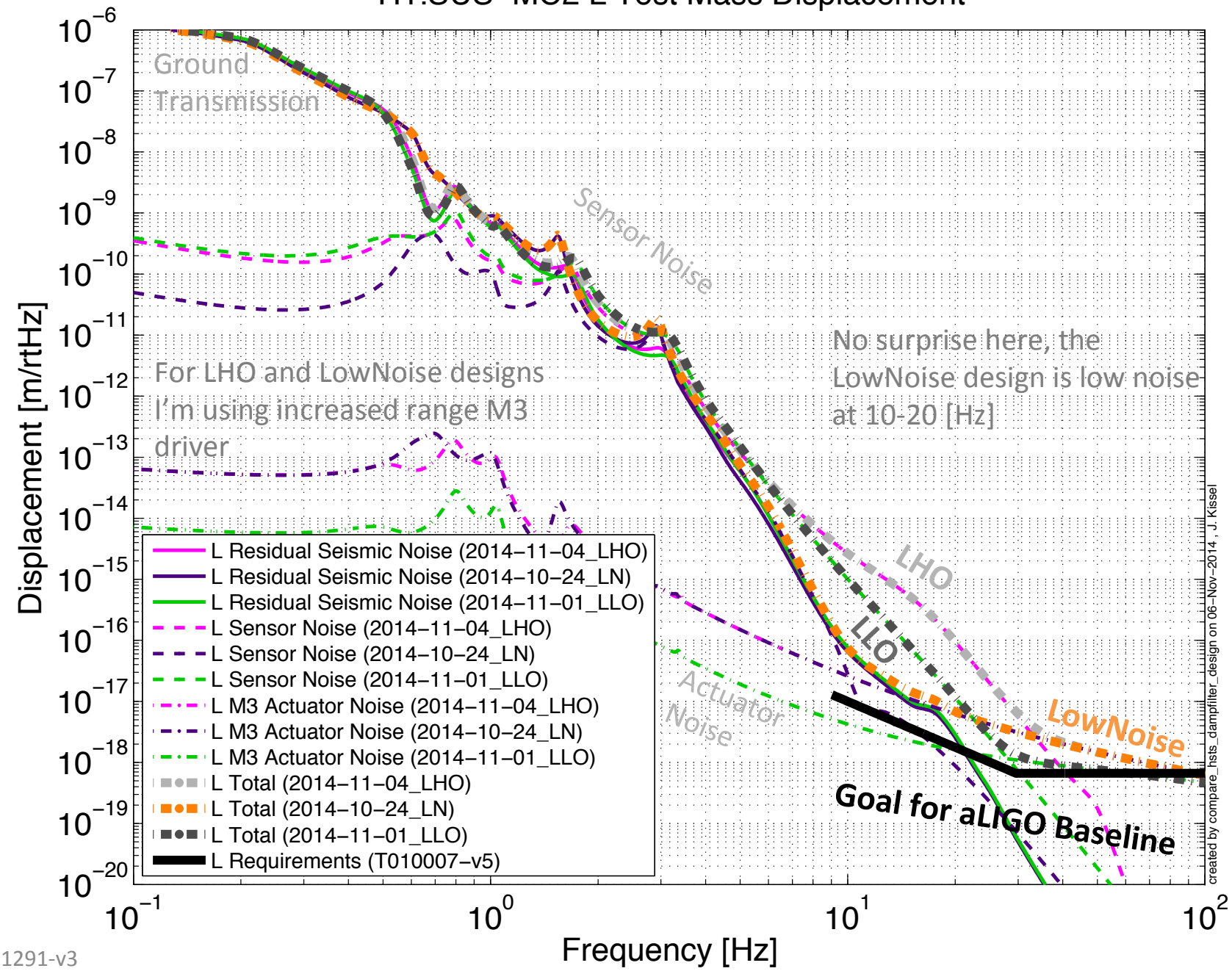
First LUGF [o,^,s] : [LHO, LN, LLO] : [54.6, 67.4, 52.9] [deg]
Last UUGF [o,^,s] : [LHO, LN, LLO] : [35.7, 34.9, 29.7] [deg]



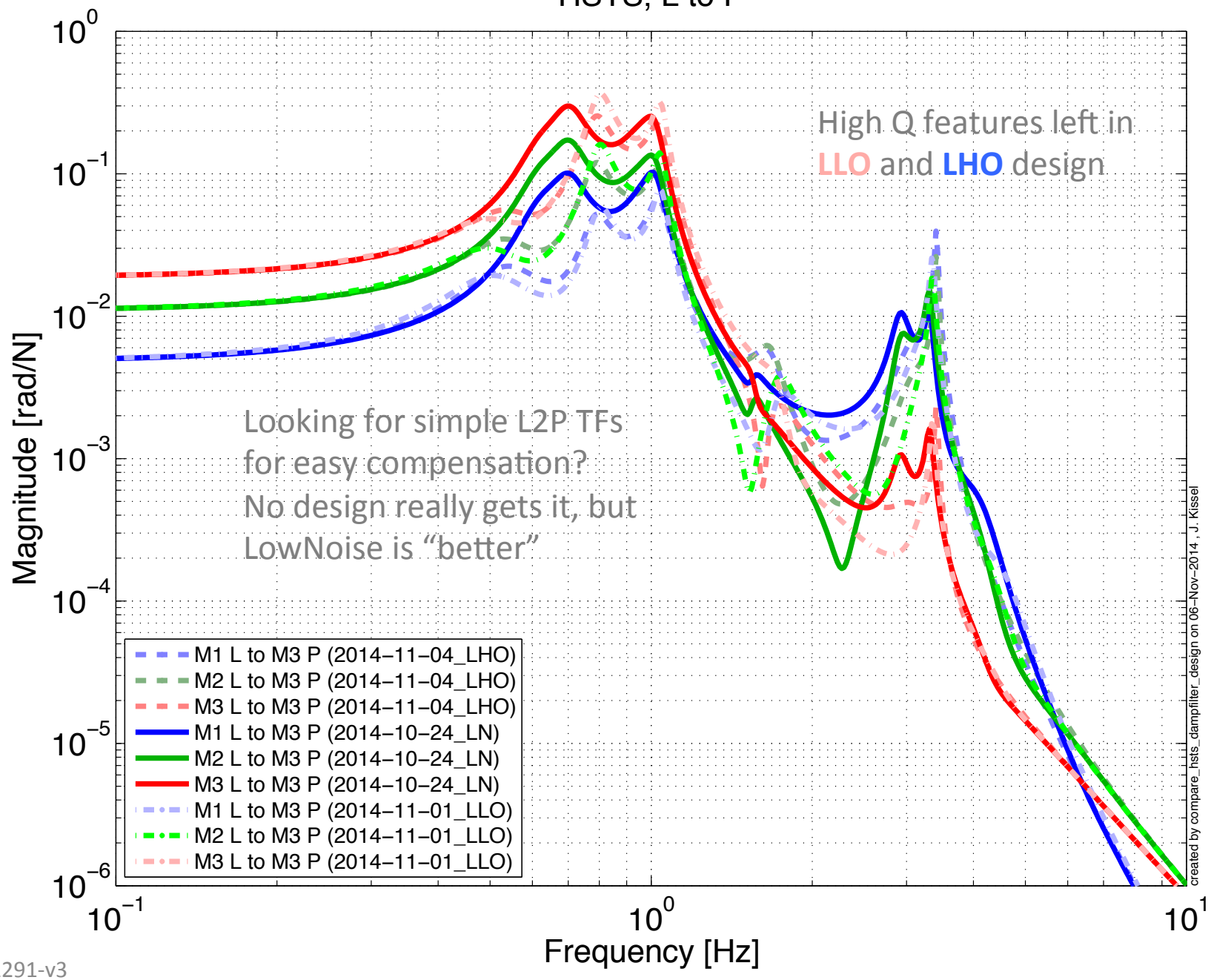

New FOM!
Damped Impulse Response, DOF: L
M1 Impulse
M3 Displacement [m]
1/e ringdown times
L (2014–11–04_LHO)
L (2014–10–24_LN)
L (2014–11–01_LLO)
Impulse response at top mass is twice as long for M1 to optic for LowNoise design
M2 Impulse
M3 Displacement [m]
Even longer for for M2 to optic for LowNoise design
Regardless of design – impulse response is worse as you get further from top mass
M3 Impulse
M3 Displacement [m]
Interesting -- LowNoise and LLO design are comparable at M3 stage – where high freq. lock acquisition impulses happen
Time [s]
created by compare_hsts_dampfilter_design on 06–Nov–2014 , J. Kissel

New FOM!

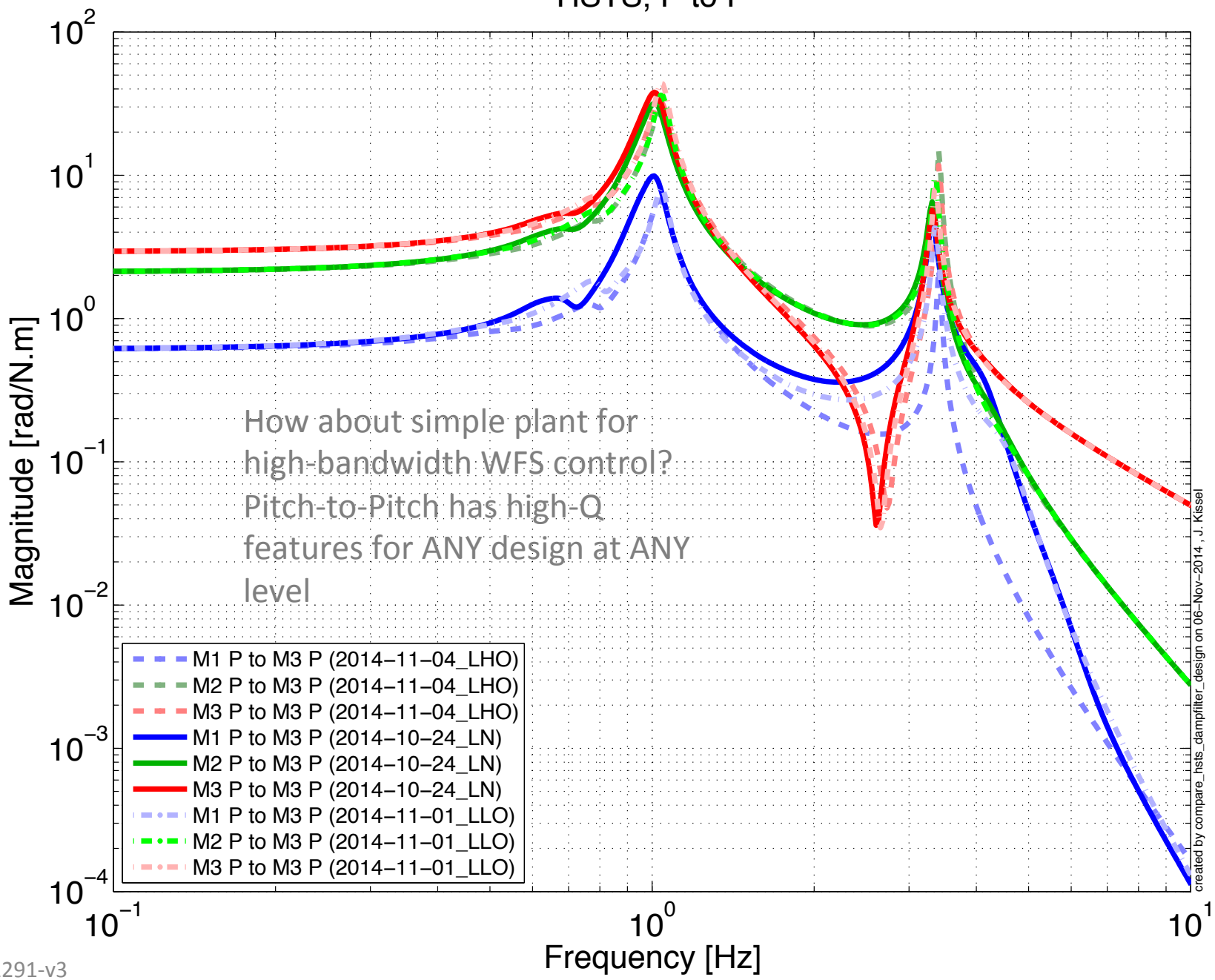

Global Control Transfer Functions to Optic
HSTS, L to L
Low Noise leaves high-Q features at high freq. in M1 and M2
LLO and LHO designs shift lowest mode frequencies up, and leave with high-Q on all stages
Magnitude [m/N]
Frequency [Hz]
M1 L to M3 L (2014–11–04_LHO)
M2 L to M3 L (2014–11–04_LHO)
M3 L to M3 L (2014–11–04_LHO)
M1 L to M3 L (2014–10–24_LN)
M2 L to M3 L (2014–10–24_LN)
M3 L to M3 L (2014–10–24_LN)
M1 L to M3 L (2014–11–01_LLO)
M2 L to M3 L (2014–11–01_LLO)
M3 L to M3 L (2014–11–01_LLO)
created by compare_hsts_dampfilter_design on 06–Nov–2014 , J. Kissel


Damping Loop Performance Comparison
H1:SUS–MC2 L Test Mass Displacement
Displacement [m/rtHz]
Frequency [Hz]
Ground
Transmission
Sensor Noise
Actuator
Noise
For LHO and LowNoise designs
I'm using increased range M3
driver
No surprise here, the
LowNoise design is low noise
at 10-20 [Hz]
LHO
LLO
LowNoise
Goal for aLIGO Baseline
L Residual Seismic Noise (2014–11–04_LHO)
L Residual Seismic Noise (2014–10–24_LN)
L Residual Seismic Noise (2014–11–01_LLO)
L Sensor Noise (2014–11–04_LHO)
L Sensor Noise (2014–10–24_LN)
L Sensor Noise (2014–11–01_LLO)
L M3 Actuator Noise (2014–11–04_LHO)
L M3 Actuator Noise (2014–10–24_LN)
L M3 Actuator Noise (2014–11–01_LLO)
L Total (2014–11–04_LHO)
L Total (2014–10–24_LN)
L Total (2014–11–01_LLO)
L Requirements (T010007–v5)
created by compare_hsts_dampfilter_design on 06–Nov–2014, J. Kissel

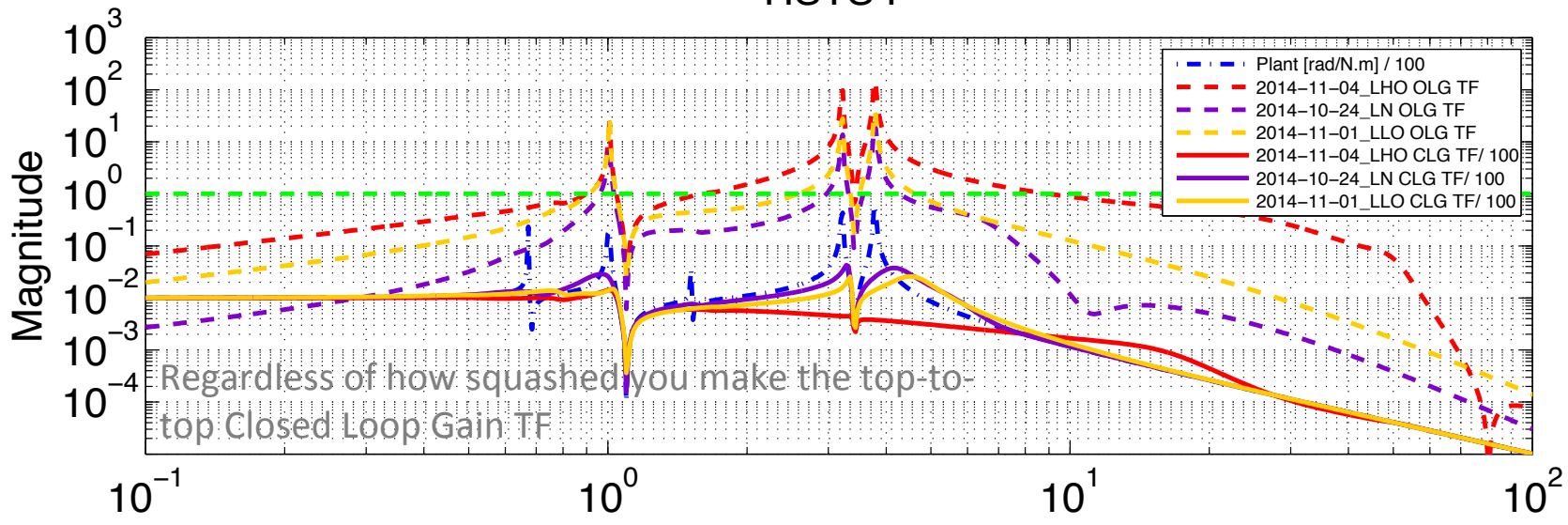
New FOM!


Global Control Transfer Functions to Optic
HSTS, L to P
High Q features left in
LLO and LHO design
Looking for simple L2P TFs
for easy compensation?
No design really gets it, but
LowNoise is "better"
Magnitude [rad/N]
Frequency [Hz]
M1 L to M3 P (2014–11–04_LHO)
M2 L to M3 P (2014–11–04_LHO)
M3 L to M3 P (2014–11–04_LHO)
M1 L to M3 P (2014–10–24_LN)
M2 L to M3 P (2014–10–24_LN)
M3 L to M3 P (2014–10–24_LN)
M1 L to M3 P (2014–11–01_LLO)
M2 L to M3 P (2014–11–01_LLO)
M3 L to M3 P (2014–11–01_LLO)
created by compare_hsts_dampfilter_design on 06–Nov–2014 , J. Kissel

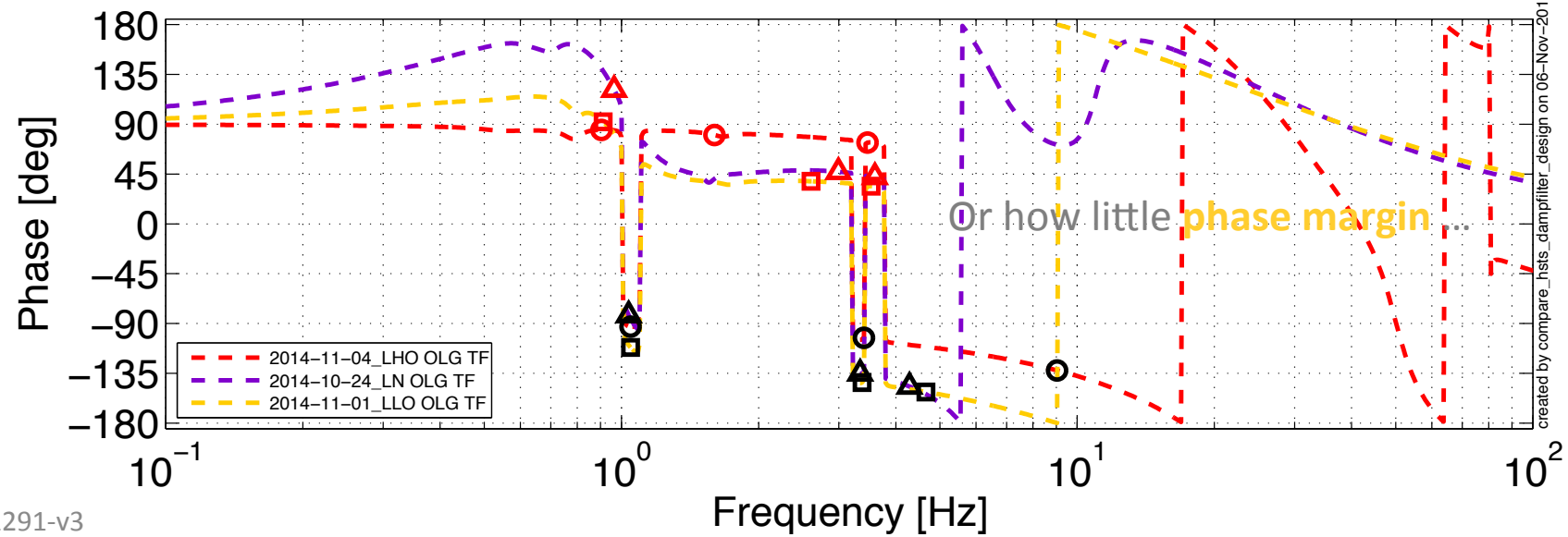
New FOM!

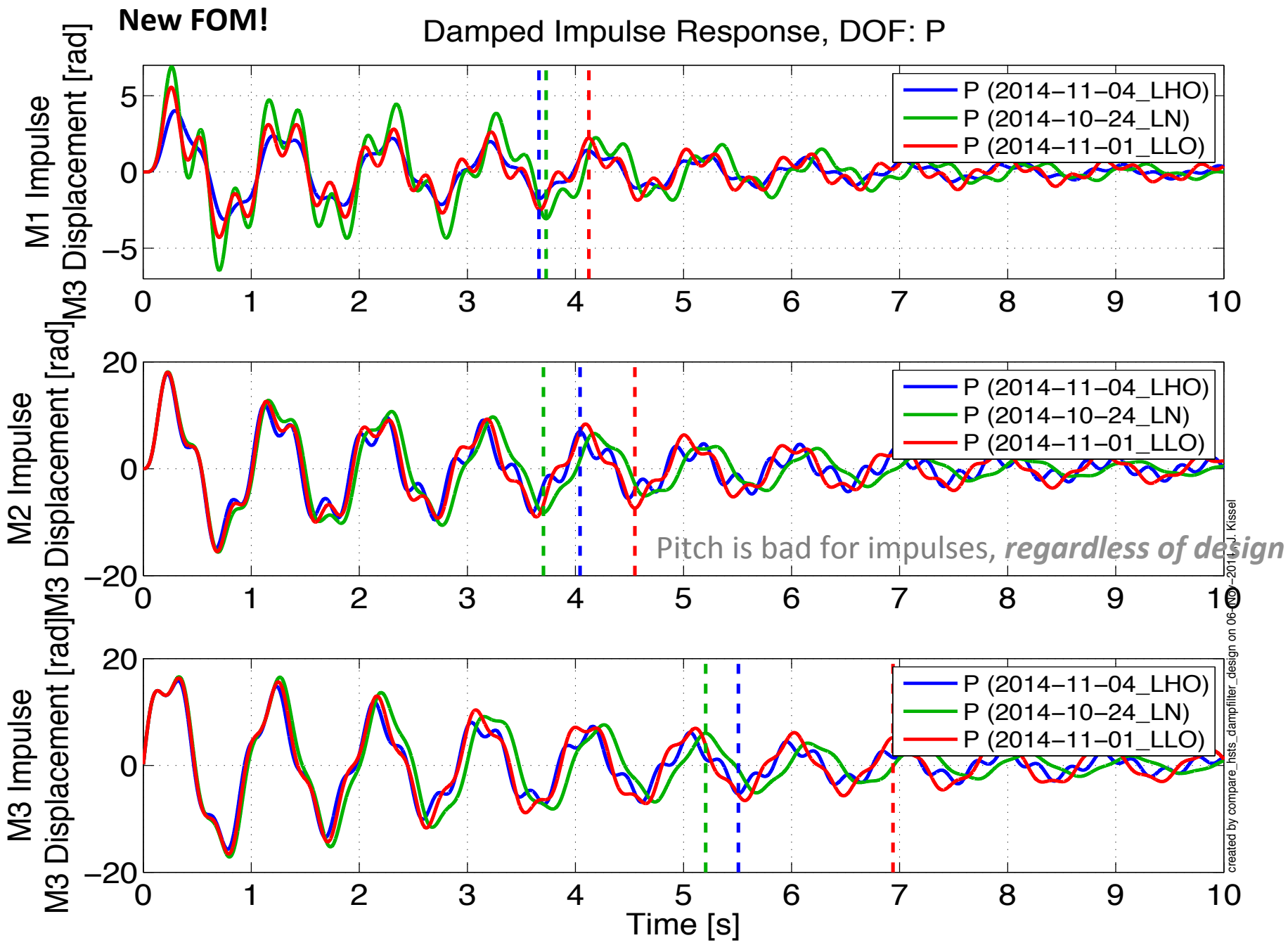

Global Control Transfer Functions to Optic
HSTS, P to P
Magnitude [rad/N.m]
Frequency [Hz]
How about simple plant for high-bandwidth WFS control? Pitch-to-Pitch has high-Q features for ANY design at ANY level
M1 P to M3 P (2014–11–04_LHO)
M2 P to M3 P (2014–11–04_LHO)
M3 P to M3 P (2014–11–04_LHO)
M1 P to M3 P (2014–10–24_LN)
M2 P to M3 P (2014–10–24_LN)
M3 P to M3 P (2014–10–24_LN)
M1 P to M3 P (2014–11–01_LLO)
M2 P to M3 P (2014–11–01_LLO)
M3 P to M3 P (2014–11–01_LLO)
created by compare_hsts_dampfilter_design on 06–Nov–2014 , J. Kissel

Damping Loop Design Comparison
HSTS P

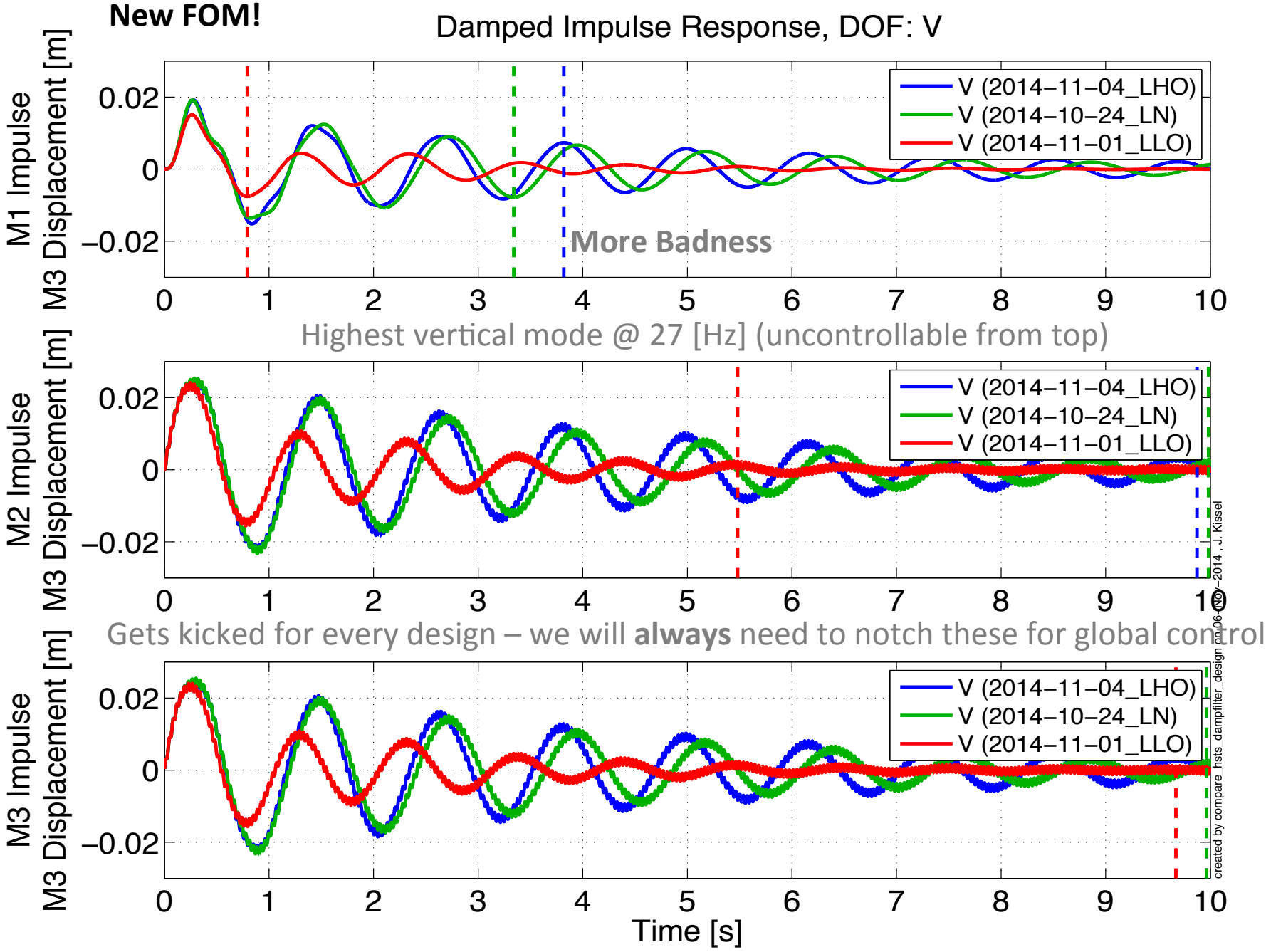


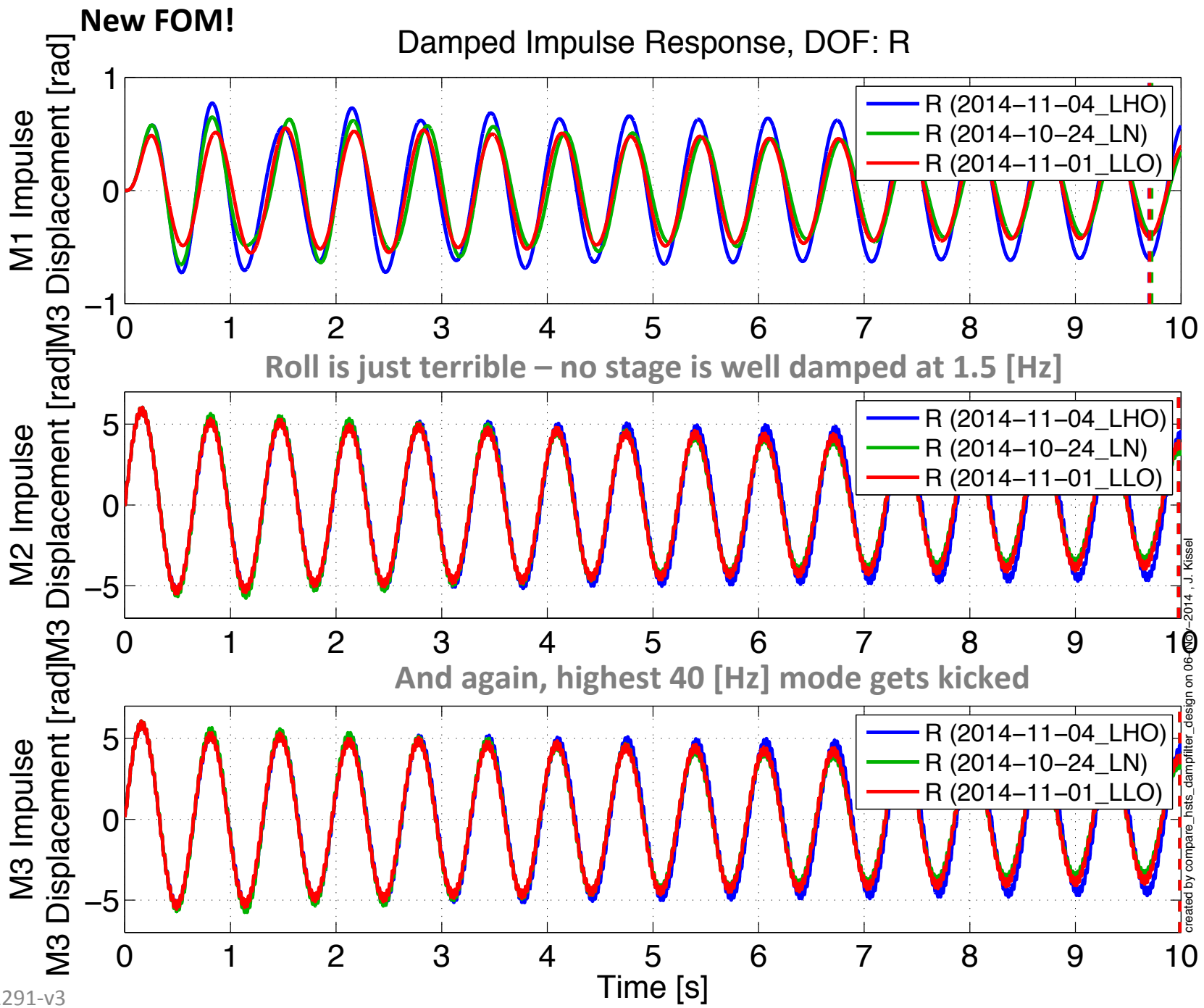
First LUGF [o,^,s] : [LHO, LN, LLO] : [95.1, 58.9, 87.9] [deg]
Last UUGF [o,^,s] : [LHO, LN, LLO] : [47.6, 33.2, 28.2] [deg]



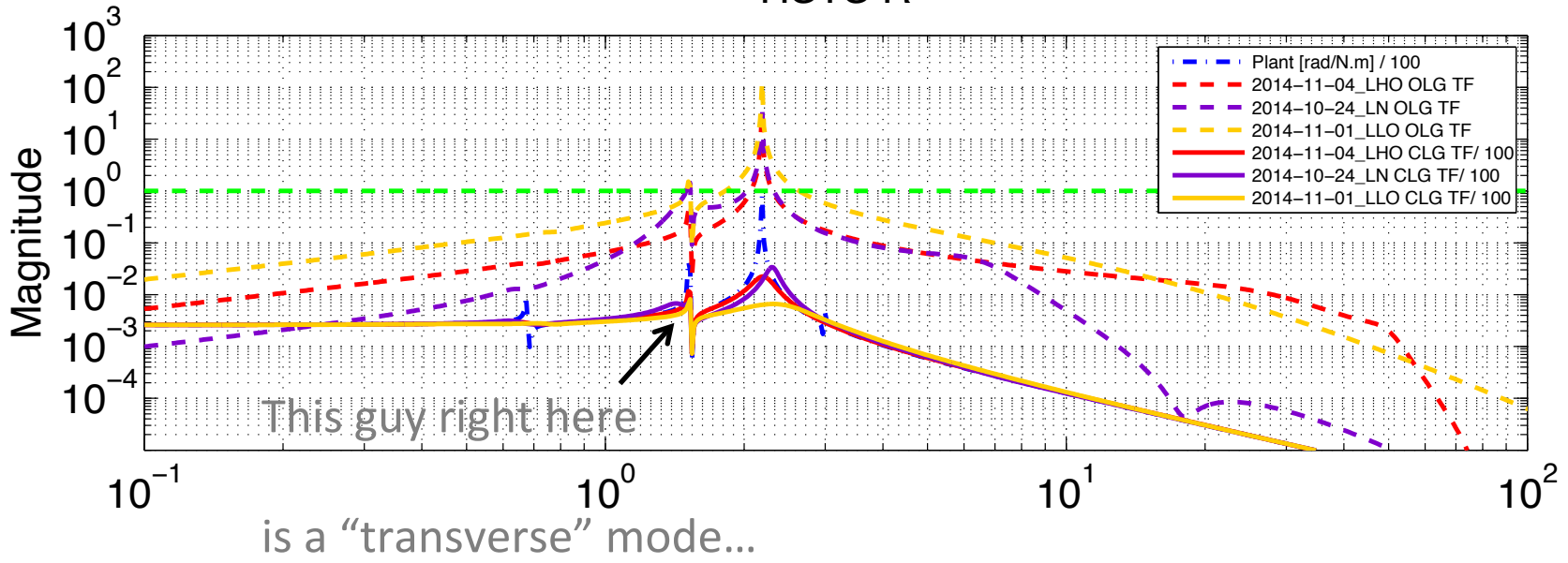

New FOM!
Damped Impulse Response, DOF: P
M1 Impulse
M3 Displacement [rad]
M2 Impulse
M3 Displacement [rad]
M3 Impulse
M3 Displacement [rad]
P (2014–11–04_LHO)
P (2014–10–24_LN)
P (2014–11–01_LLO)
Pitch is bad for impulses, regardless of design
Time [s]
created by compare_hsts_dampfilter_design on 06-Nov-2014 J. Kissel

New FOM!


Damped Impulse Response, DOF: V
M1 Impulse
M3 Displacement [m]
V (2014–11–04_LHO)
V (2014–10–24_LN)
V (2014–11–01_LLO)
More Badness
Highest vertical mode @ 27 [Hz] (uncontrollable from top)
M2 Impulse
M3 Displacement [m]
Gets kicked for every design – we will always need to notch these for global control
M3 Impulse
M3 Displacement [m]
Time [s]
created by compare_hsts_dampfilter_design on 06-NOV–2014 , J. Kissel

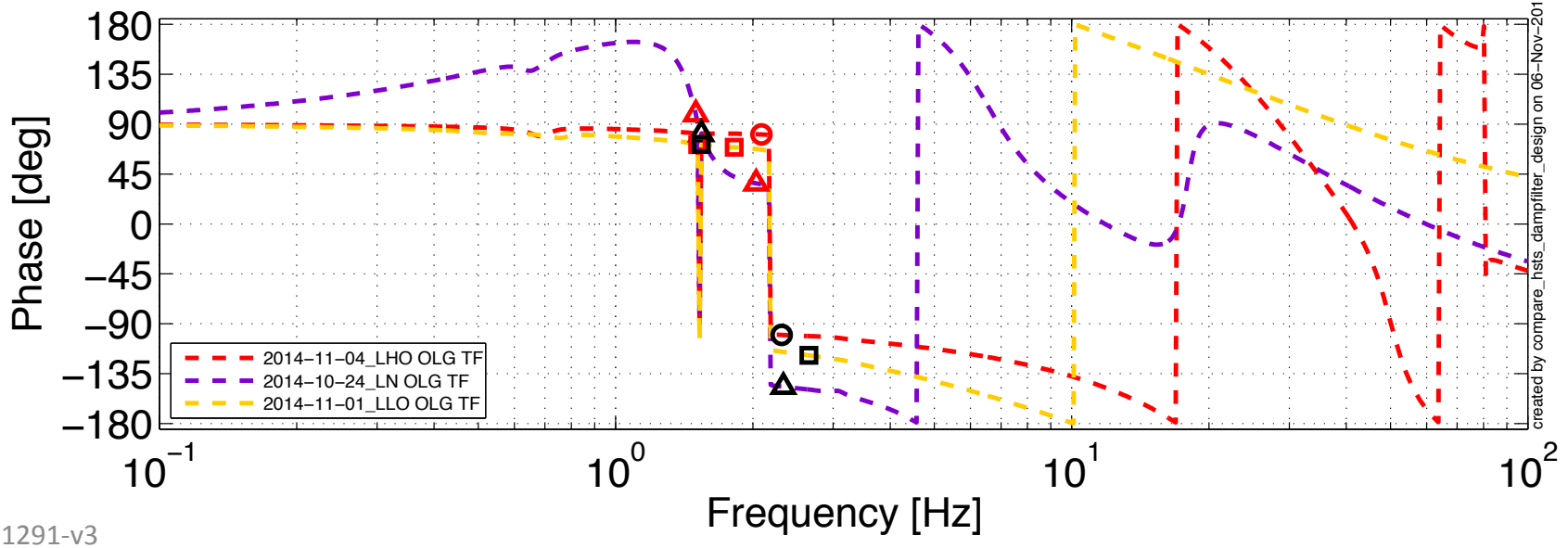

New FOM!
Damped Impulse Response, DOF: R
M1 Impulse
M3 Displacement [rad]
R (2014–11–04_LHO)
R (2014–10–24_LN)
R (2014–11–01_LLO)
Roll is just terrible – no stage is well damped at 1.5 [Hz]
M2 Impulse
M3 Displacement [rad]
And again, highest 40 [Hz] mode gets kicked
M3 Impulse
M3 Displacement [rad]
Time [s]
created by compare_hsts_dampfilter_design on 06-Oct-2014 , J. Kissel

Damping Loop Design Comparison
HSTS R

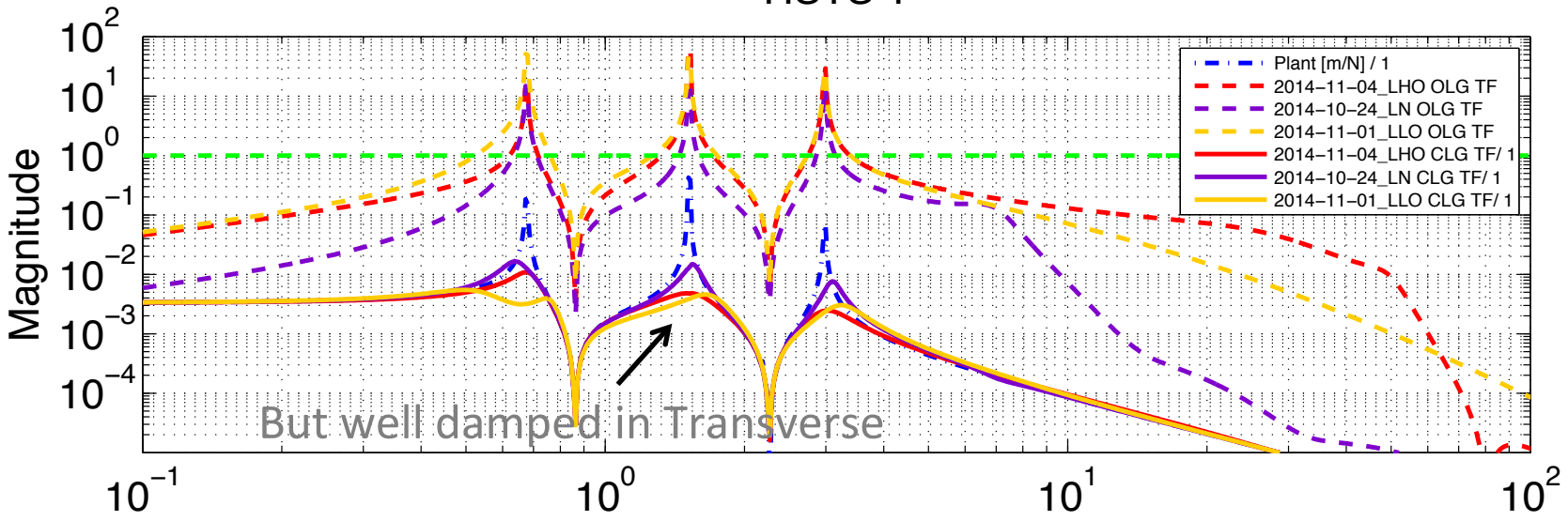


is a “transverse” mode…

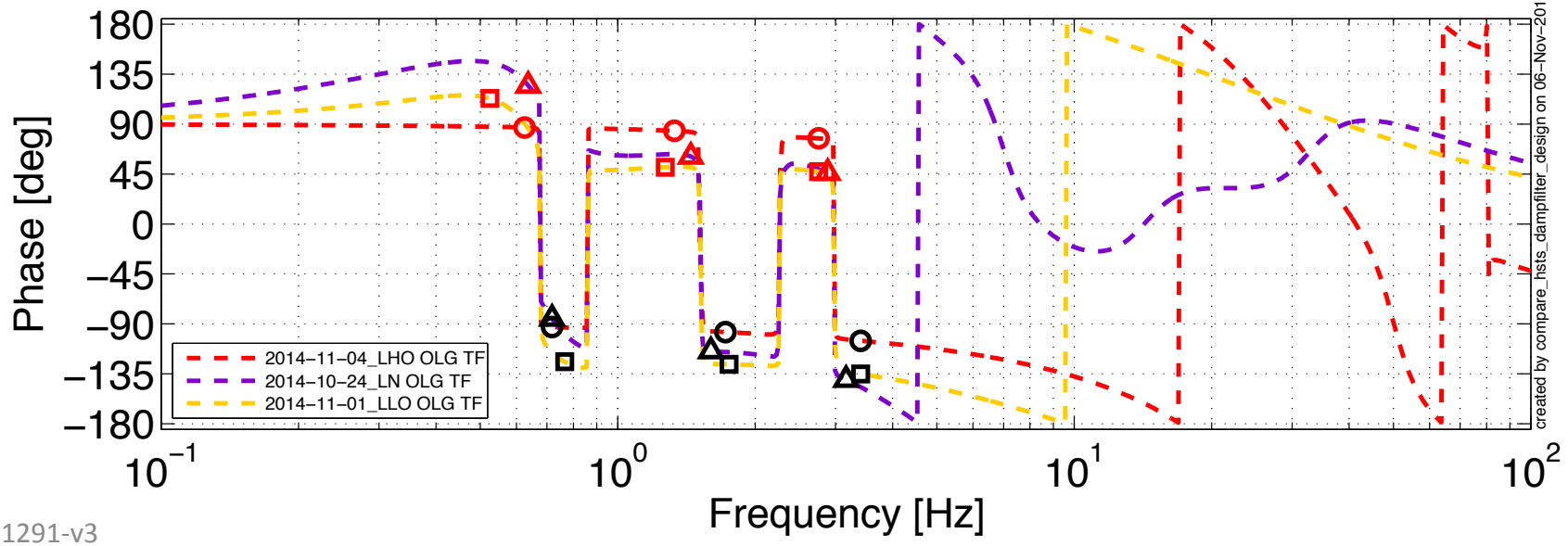
First LUGF [o,^,s] : [LHO, LN, LLO] : [99.3, 81.1, 109] [deg]
Last UUGF [o,^,s] : [LHO, LN, LLO] : [80, 33.2, 61.5] [deg]



Damping Loop Design Comparison
HSTS T



First LUGF [o,^,s] : [LHO, LN, LLO] : [93.1, 55.3, 66.9] [deg]
Last UUGF [o,^,s] : [LHO, LN, LLO] : [74.8, 39.7, 44.9] [deg]



What have we learned?

- Each design has its pros and cons
- As expected, Low-noise design is low noise, Low-Q design (i.e. LLO) reduces Q for Longitudinal but …
- Just changing the overall gain is not the answer, nor is paying attention to only Longitudinal
- Lots of stuff doesn't change with design
  - Pitch global TFs
  - Pitch impulse response
  - Exciting of highest Vertical and Roll modes
  - Roll impulse response
- L (and Y) global transfer functions are more complex for Low-Q, and drastically change depending on design

Remember: there are no optical levers on these SUS

Conclusions

- I haven't looked yet, but I'm sure the situation will be the same for other SUS types (and the worst for QUADs)
- If you want UGFs between 0.5 to 10 [Hz], it's going to be hard, and will take careful, patient design
- Changing damping loop design will impact those global control designs (including L2P and L2Y decoupling filters)
- Perhaps we consider switching between designs (i.e. having both on hand, and change the configuration based on IFO needs)?
- **Should LHO take the global control / decoupling redesign schedule hit and import LLO's filters?**
- In the limit of infinite time – can we explore a design that optimizes impulse response at the lowest stage from each stage and simplifies global control TFs and gets the 10-20 [Hz] noise OK?
- Do we seriously start considering modal damping? Sure they're good at noise, but how about these other FOMs?

Suggestions welcome.