HI-2019-01 (post-M265 BS03+RS04+Splitter01) Fiber Bending Experiment Results.
file: \data\2019\HI-2019-01\doc\HI-2019-01_Results(MF,rev1).pptx (rev: 29Jan2019,MF)

03-Jan-2019, after pot-M265 cals, BS03+RS04+Splitter01 were moved from tent to rm.124 at Pier35.
09 to 18-Jan-2019, 8 days of FO bending experiments = Exp. #01 to 46.

Fore-optics used were LuBot head + 20.5 ft of 600µm Fiber Optic w/ hydraulic hose from M264.
The collector head + FO were coupled to specs at Trk06 during first 4 days, and Trk09 last 4 days.
During MOBY265 deployment, Trk06 was LuTop, Trk09 was LuMid. Trk06 had a differently shaped BS spectral response than Trk09 – during M265 and during HI-2019-01. Light source during HI-2019-01 was NIST OL455-18U with PhotoDiode Monitor (no TEC on this PD mon).

Our intention was to test sensitivity to FO bending. We calibrated post-M265 BS/RS responsivities, but they did not compare well with in-water responses boot-strapped from MOS data (?). We also wanted to check the effect of tight FO coils seen in the TOP-200 commercial instrument Carol had at NIST in Dec-2018. And, during our 19-Dec-2018 telecon with Tasshi Dennis from NIST it was suggested that we could not expect to maintain stable calibrations before vs after bending fiber optics.

Stephanie's data processing + log sheets + photos are available under "H19-01-BS03/RS04" at
http://data.moby.mlml.calstate.edu/mobyrefresh/timeseries/characterizations/inital_testing/intial_html.html

Summary of findings:

Net signals decreased when a loop was added to the FO between the specs and the Lu head.
Net signal loss increased with decreasing diameter of a loop added to the FO.

Net signals returned to straight-FO levels after FO loops were removed (most of the time).

The lowest sensitivity to adding a FO loop was seen when there was a pair of tight (2.5 inch diameter = permanent) FO loops near the specs plus a tight 90° bend near the Lu head. A tight 360° loop near the Lu head was just as effective as a tight 90° bend near the Lu head.

Listing of Experiments performed during HI-2019-01:

Day	Exp#	Description
1 10Jan	1	straight FO to **Track#06**
	2,3,4	remove & replace Lu head on stand at sphere output port
2 11Jan	5	straight FO
	6,7	add 24in dia, 90° bend at head, then straight FO
	8,9	add 24in dia, 90° bend at head, then straight FO
3 12Jan	10	straight FO
	11	add 1x ~19in dia loop between specs & head
	12	2x ~18in dia loops between specs & head
	13,14	back to 1x ~19in dia loop, then straight FO
4 13Jan	15	straight FO
#A	16	coil FO onto 14in dia plastic FO spool near specs (~4x loops)
	17	straight FO
#B	18	1x 14in dia loop near specs
	19	add 1x 16in dia loop between specs & head
	20,21	remove 16in dia loop between specs & head, then straight FO
5 14Jan	22	straight FO to **Track#09**
#A	23,24	add 24in dia 90° bend at head, then back to straight FO
#B	25	add 1x 14in dia loop near specs
	26	add 1x 16in dia loop between specs & head
	27,28	remove 16in dia loop between specs & head, then straight FO
6 17Jan	29	straight FO
	30	1x 11in dia loop near specs
	31	add 1x 11in loop between specs & head
	32,33	remove 11in loop between specs & head, then straight FO
7 18Jan	34	straight FO
#A	35	**2x 2.5in dia loops** near specs = **TIGHT & PERMANENT**
	36	add 1x 11in dia loop between specs & head
	37	remove 11in dia loop between specs & head
#B	38	**1x 2.5in dia 90° bend** at head = **TIGHT**
	39	add 1x 11in dia loop between specs & head
	40	remove 11in dia loop between specs & head
8 19Jan	41	straight FO – includes 2x tight loops at specs & tight bend at head
#A	42	add 1x 11in dia loop between specs & head
	43	remove 11in dia loop between specs & head
#B	44	make 2.5in 90° bend into **1x 2.5in loop** at head = **TIGHT & PERMANENT**
	45	add 1x 11in dia loop between specs & head
	46	remove 11in dia loop between specs & head

Figure 1 shows fiber optic bend radius specifications from Ocean Optics, found at:
https://oceanoptics.com/product-category/bend-radius-and-mechanical/

Note: for 600 µm core size UV/VIS fiber - which we are using with MOBY refresh - long term bend radius (LTBR) = 24 cm = 48 cm diameter or ~19 in dia., and **short term bend radius (STBR) = 12 cm = 24 cm diameter, or ~9.5 in dia.**, for "how tightly the fiber can be bent without being prone to microscopic fractures".

Bend Radius & Mechanical

Optical fiber works by guiding light down the fiber core due to variations in index of refraction between the core and cladding. A flexible buffer material in one or more layers is then applied to improve flexibility and protect the glass core/cladding. Even with this additional coating, there are still limits on how tightly the fiber can be bent without being prone to microscopic fractures that can lead to breaks.

- LTBR (long term bend radius): Observe as a minimum radius allowed for storage conditions.
- STBR (short term bend radius): Observe as a minimum radius allowed during use and handling.

Mechanical Specifications: VIS/NIR, UV/VIS, SR fibers

Band	Fiber Core Size	Fiber Types	Cladding Thickness	Buffer Material	Buffer Thickness	Maximum OD	Operating Temperature	LTBR	STBR
	50 ± 5 µm	VIS/NIR, UV/VIS	35 ± 0.5 µm	polyimide	17 ± 5 µm	155 µm	-65 to 300 °C	4 cm	2 cm
	100 ± 3 µm	VIS/NIR, UV/VIS	12 ± 5 µm	polyimide	17 ± 3 µm	155 µm	-65 to 300 °C	4 cm	2 cm
	200 ± 4 µm	VIS/NIR, UV/VIS, SR	10 ± 4 µm	polyimide	10 ± 5 µm	243 µm	-65 to 300 °C	8 cm	4 cm
	300 ± 6 µm	SR	15 ± 7 µm	polyimide	20 ± 10 µm	380 µm	-65 to 300 °C	12 cm	6 cm
	400 ± 8 µm	VIS/NIR, UV/VIS, SR	20 ± 3 µm	polyimide	20 ± 7 µm	487 µm	-65 to 300 °C	16 cm	8 cm
	500 ± 10 µm	VIS/NIR, UV/VIS	25 ± 3 µm	polyimide	20 ± 10 µm	600 µm	-65 to 300 °C	20 cm	10 cm
	600 ± 10 µm	VIS/NIR, UV/VIS, SR	30 ± 3 µm	polyimide	25 ± 10 µm	720 µm	-65 to 300 °C	24 cm	12 cm
	1000 ± 3 µm	VIS/NIR	50 ± 3 µm	acrylate	50 ± 40 µm	1120 µm	-50 to 85 °C	30 cm	15 cm
	1000 ± 20 µm	UV/VIS	25 ± 3 µm	acrylate	50 ± 40 µm	1065 µm	-50 to 85 °C	30 cm	15 cm

- VIS/NIR is multimode step index fiber with a low OH fused silica core and glass cladding (400 – 2100 nm)
- UV/VIS is multimode step index fiber with a high OH fused silica core and glass cladding (300 – 1100 nm)
- SR is multimode step index fiber with a high OH fused silica core and glass cladding (200 – 1100 nm)

Figure 1, Fiber optic bend radius specifications from Ocean Optics

Figure 2 photos show the TOP-200 commercial instrument at NIST. The 90° bend is at the collector-head end of the (1 mm ?) fiber optic, and the encased (assumed) loop(s) are at the instrument end of the FO.

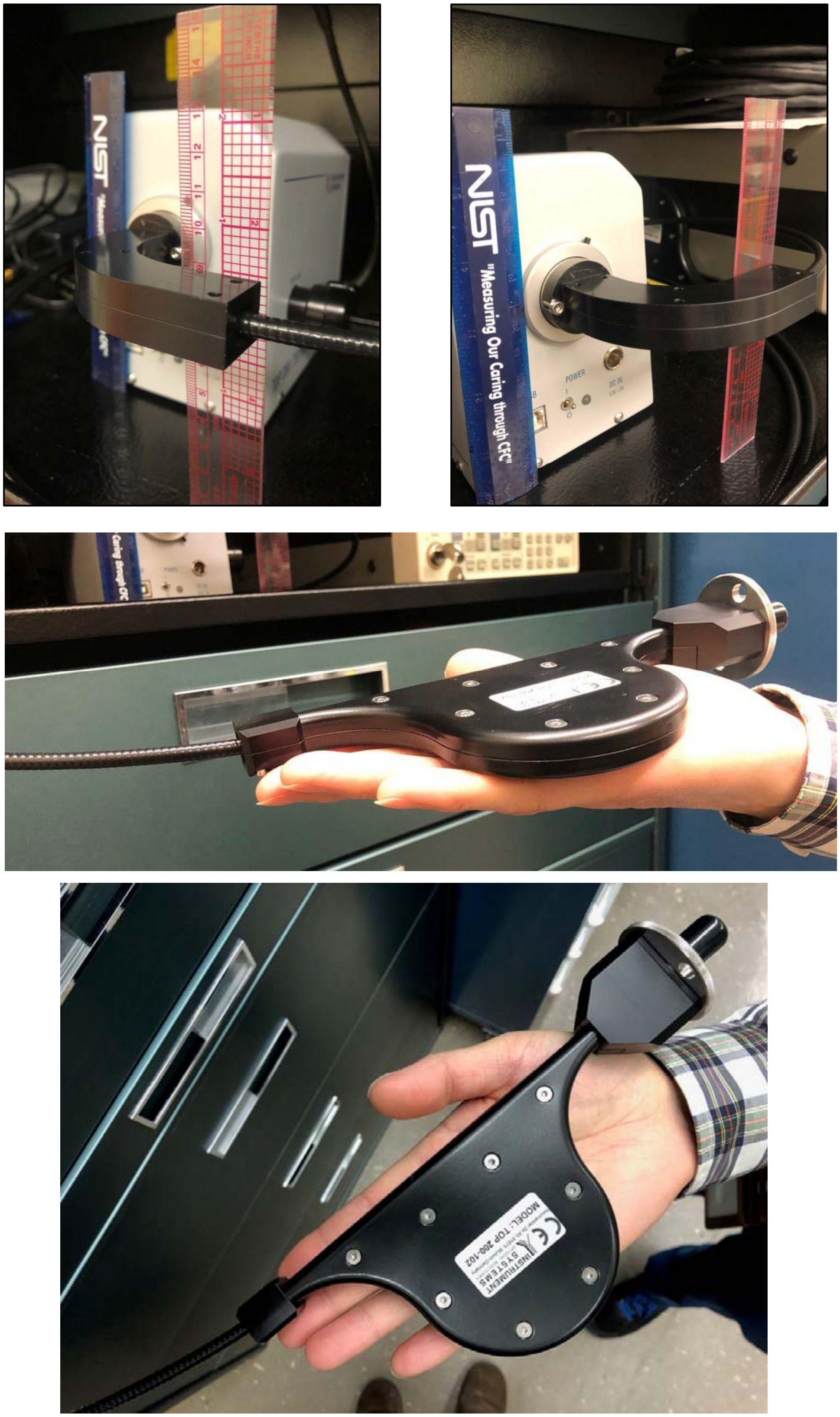
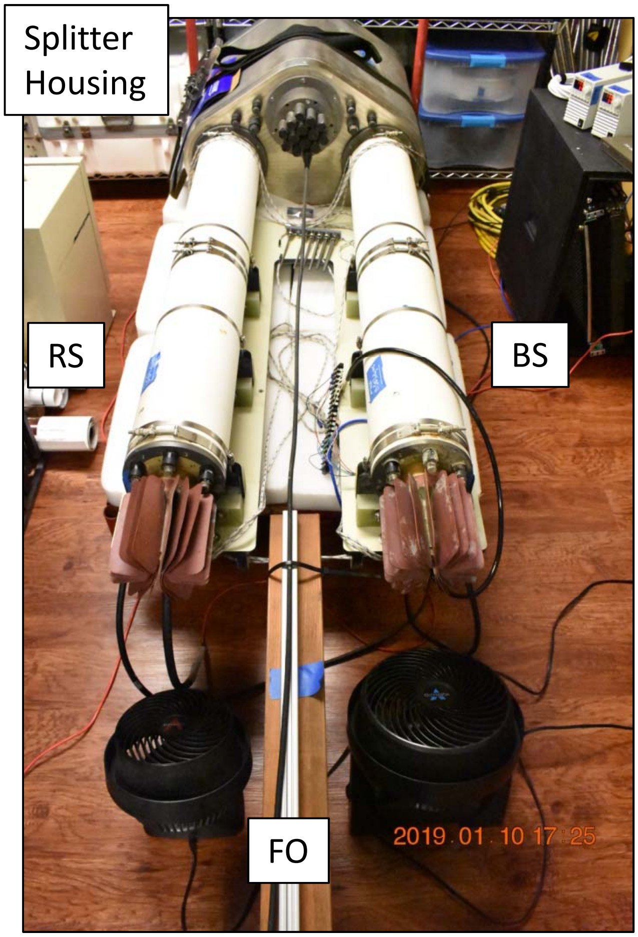


Figure 2, TOP-200 Fiber Optic at NIST

Figure 2 photos show the equipment setup in room124 at Pier35, UHMC Hawaii.



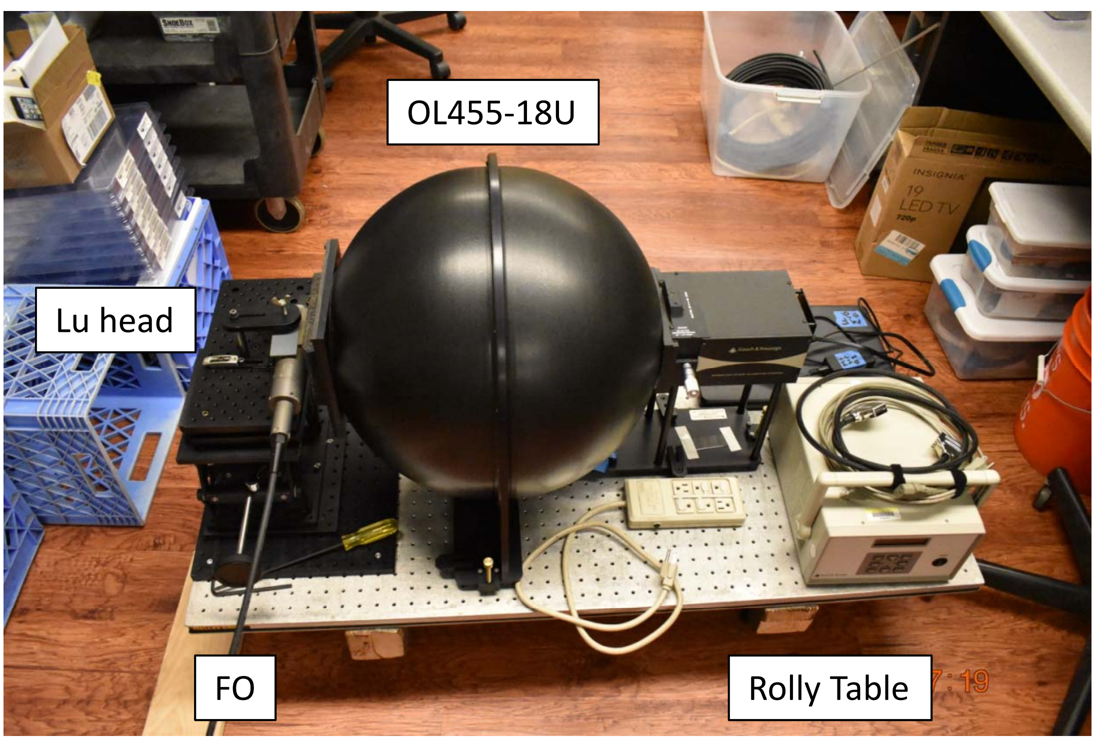
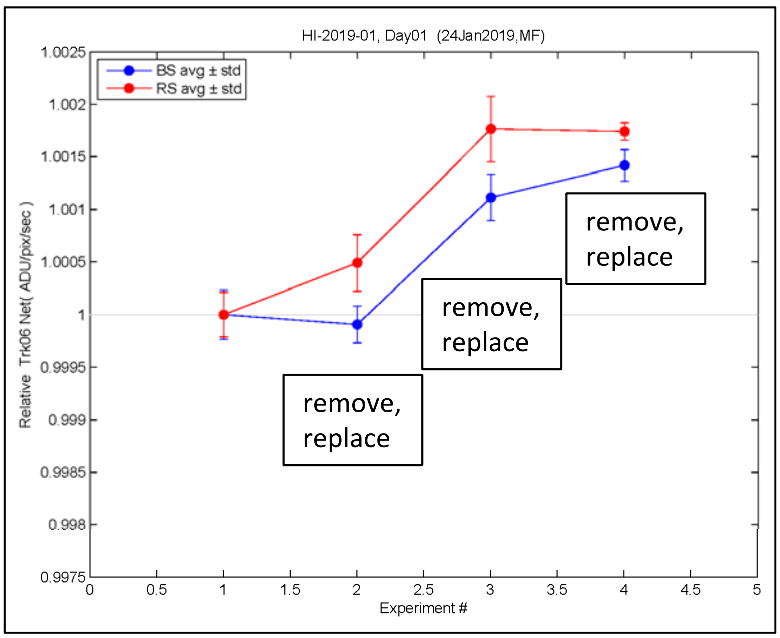


Figure 3, HI-2019-01 instrument setup.

Day01 checked the stability of the Lu head mount at the integrating sphere source.

Remove Lu head

Replace Lu head



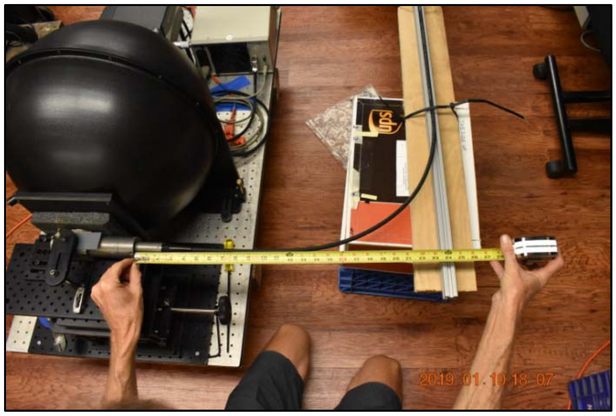
Blue = BS03 data, Red = RS04 data. Net Signal data were average of 11 spectral pixels centered at pixel 512. Symbols: mean of N=4 scan sets; errorbars: ± stDev of N=4 scan sets; then normalized to first mean shown. Data were not corrected for sphere PD monitor drift.

Over the ~45 min of these 4x experiments the PD output decreased ~0.3%. The Y-axis scale of this figure is ± 0.25%. The upward drift of net signal over time was seen during most experiment days. The Blue and Red specs response roughly tracked each-other.

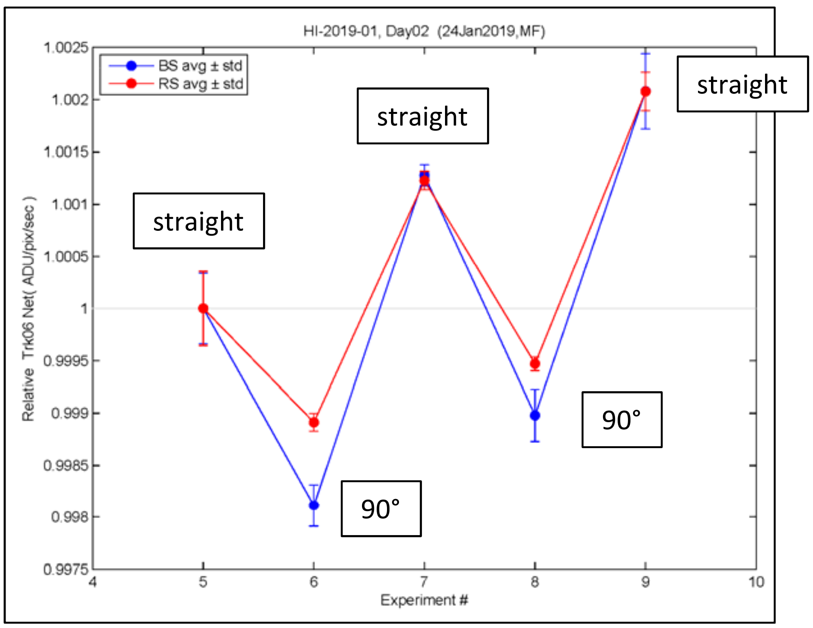
The Lu head + FO were coupled to Track#6 on the spectrographs for Day01 through Day04.

Figure 4, HI-2019-01 Day01 Results

Day02 added and removed (two times) a large-ish ~24 in dia. 90° bend near the Lu head.



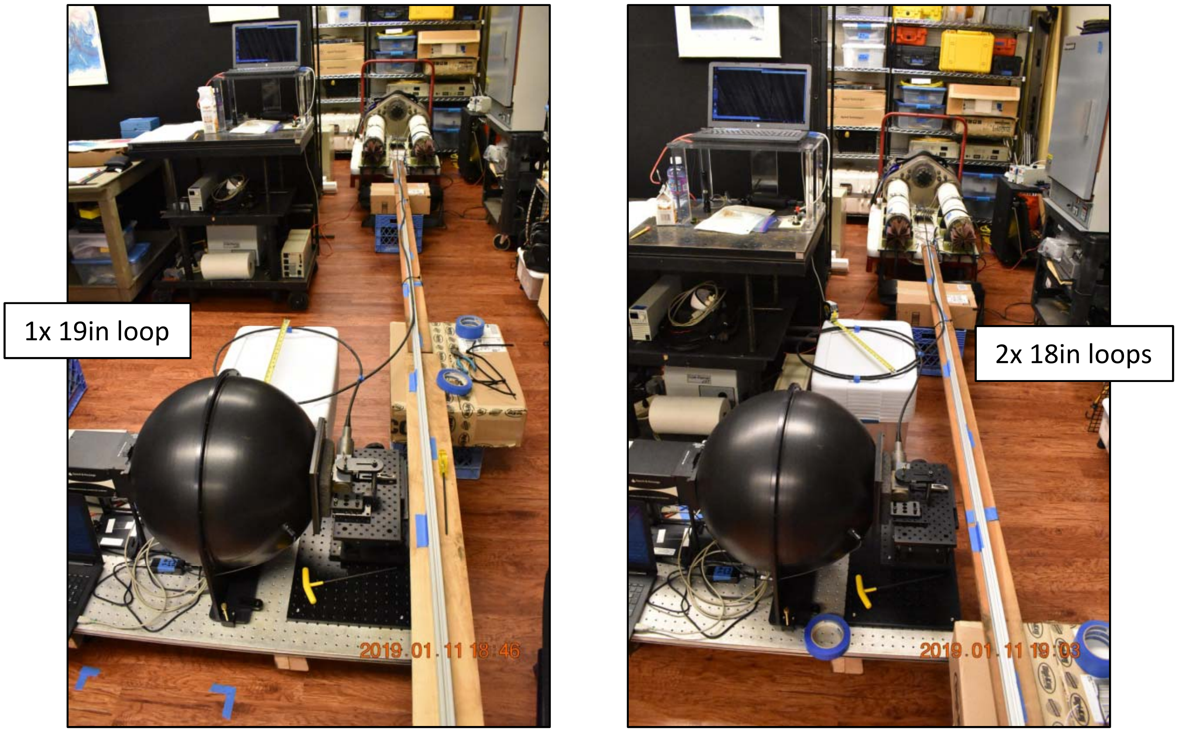
24 in dia 90° bend in FO near Lu head

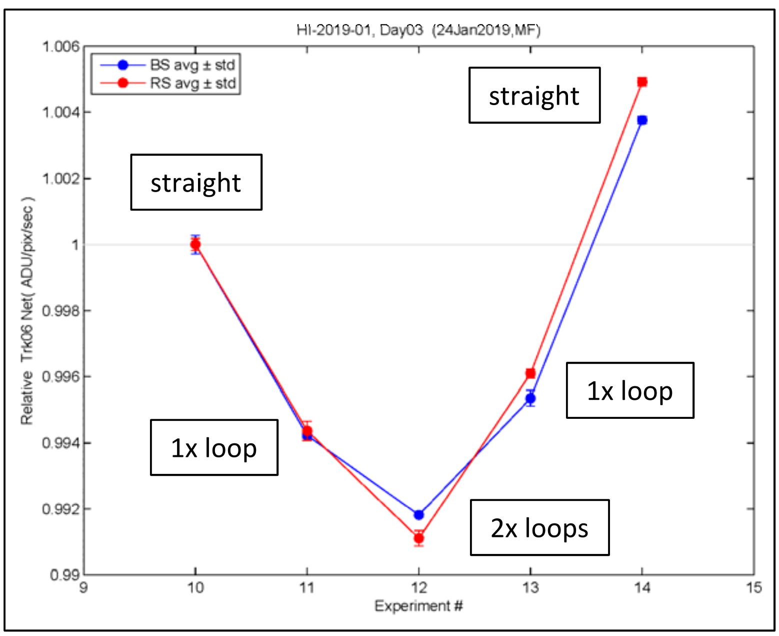


The Y-axis scale of this figure is also ± 0.25%. Adding a soft 90° bend decreased the net signal, but only by ~0.15%. Net signal level via straight FO ~returned after removing the 90° bend (with a 0.25% signal drift over ~1 hr run time). The BS looked more sensitive than RS to a 90° bend.

Figure 5, HI-2019-01 Day02 Results

Day03 looked at the effect of adding large ~18 in dia loops between the specs and head.

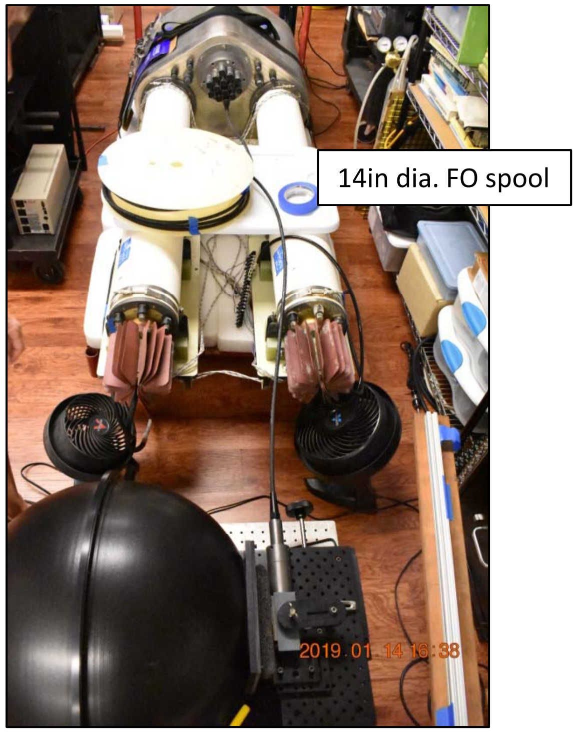


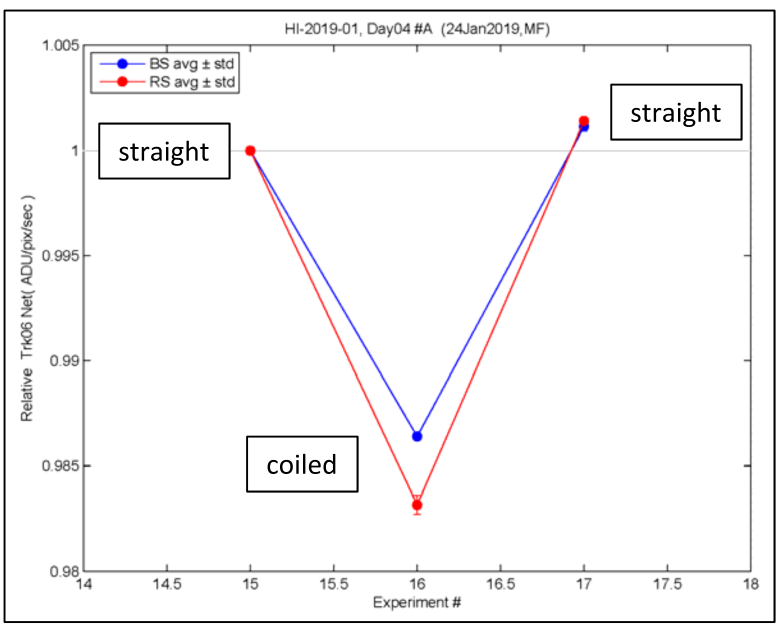


Adding one large loop decreased Net Signals ~0.6%, adding another loop decreased signals another 0.3%. Removing the 2nd loop returned signals to 1x loop level, and removing both loops returned signal to starting straight-FO level (plus 0.4% signal drift over ~1 hr run time). BS & RS signal changes were of similar magnitude.

Figure 6, HI-2019-01 Day03 Results

We next looked at tighter FO loops. **<u>Day04 part #A;</u>** a 14 in dia. plastic FO spool was used to coil the whole FO. A spooled FO is how we envisioned handling the fore-optics with instrument off of a buoy.

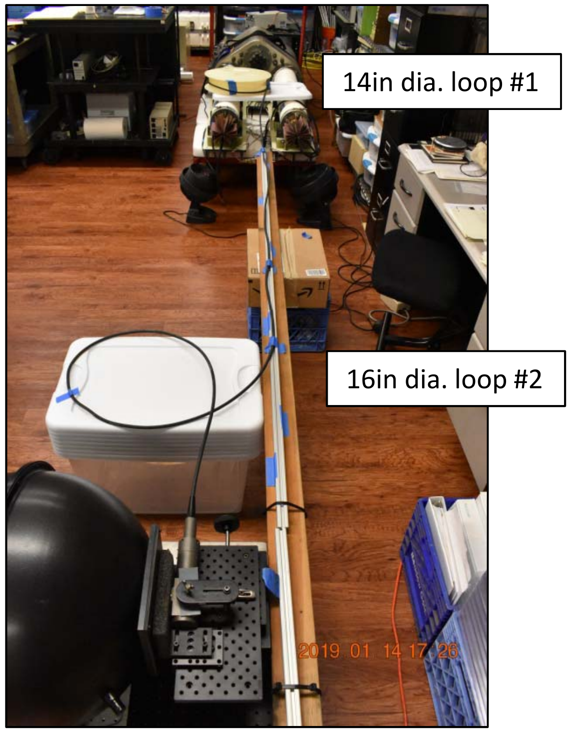


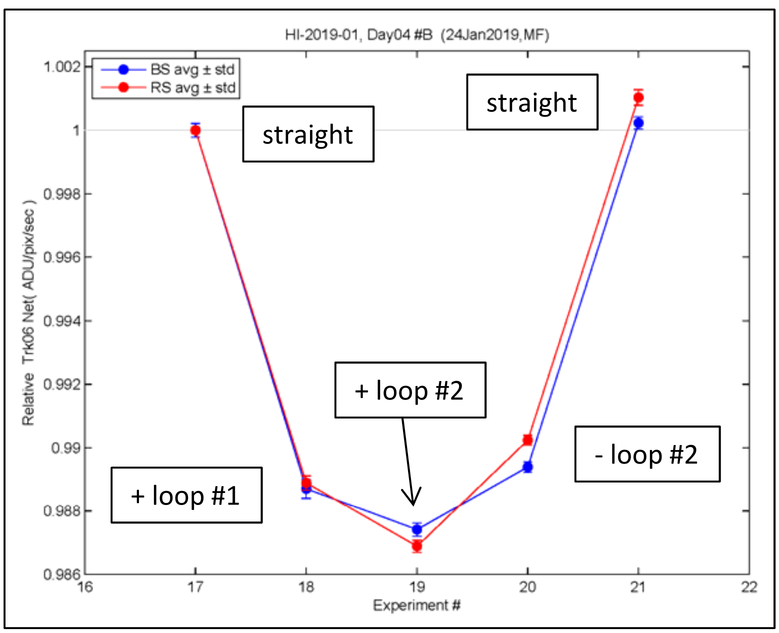


Coiling the FO on the spool decreased net signal ~1.5%, and uncoiling the FO returned signal to starting/straight level. Here, the RS seemed more sensitive to the coiled FO than did the BS.

Figure 7, HI-2019-01 Day04 part #A Results

<u>Day04 part #B</u> inserted 1x 14 in dia. loop near the specs, then added a 2nd 16 in dia. loop between the specs and head - to test if a loop near the specs decreased sensitivity to additional bending.

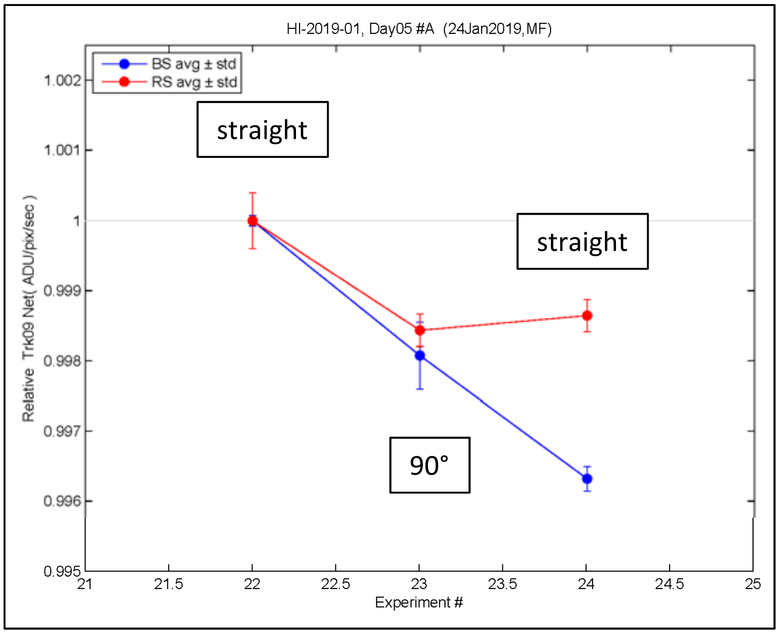




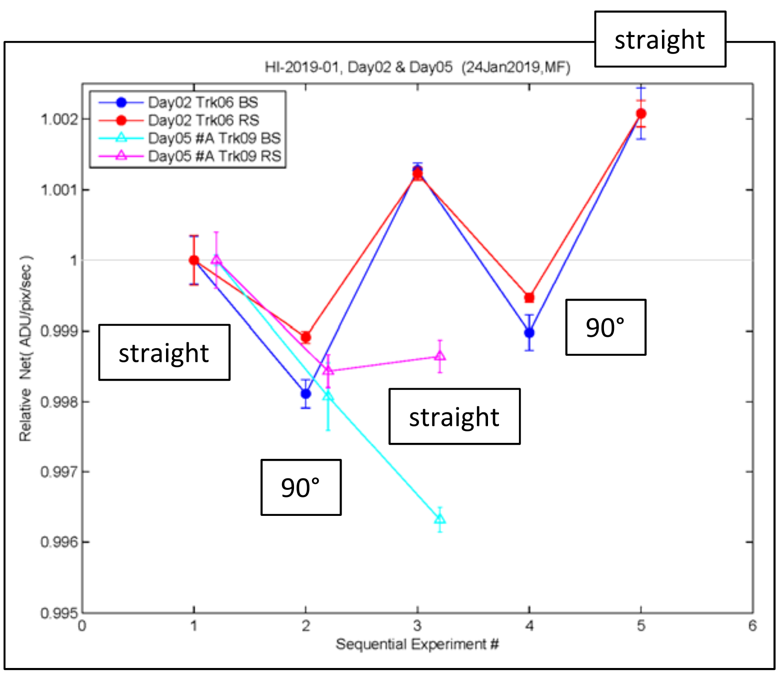
Adding 1x 14in loop near specs decreased net signals ~1.1% vs straight FO (i.e. slightly less loss than 4x loops in Day4 part #A). Adding loop #2 reduced signals another 0.17% - significantly less than loop #1's affect. Again, removing the loops returned signal levels. BS & RS responses were similar.

Figure 8, HI-2019-01 Day04 part #B Results

On Day05 the FO was moved from Trk06 to Trk09. **Day05 part #A** repeated the broad 24in dia. 90° bend near the Lu head – this time on Trk09.



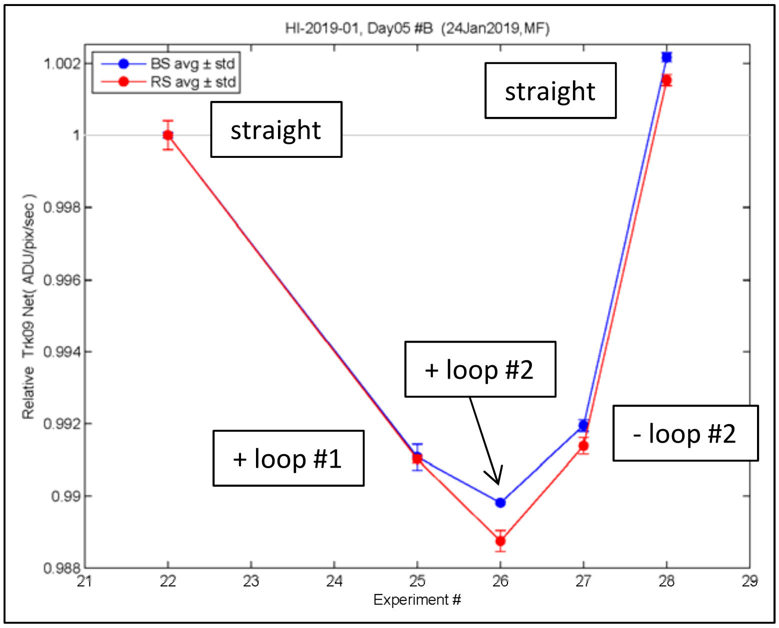
This was the only sequence where removing a large FO bend did not return straight signal levels… **An explanation for this has not yet been found…**



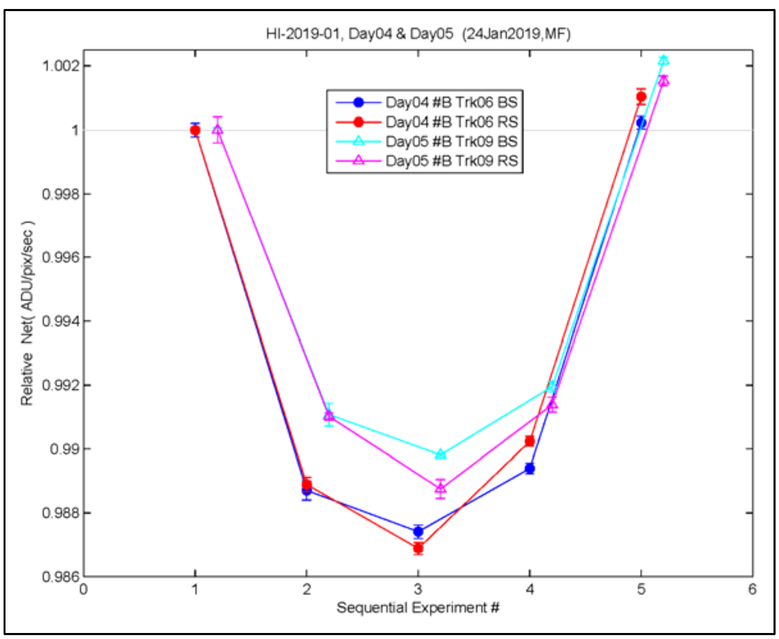
Above over-plots Trk06 & Trk09 90° bend results – Trk09 are open symbols. Signal decrease for the 90° bends are of similar magnitude. BS signal seem more sensitive than RS to a 90° bend.

Figure 9, HI-2019-01 Day05 part #A Results

Day05 part #B via Trk09 repeated Day04 part #B via Trk06 experiments.



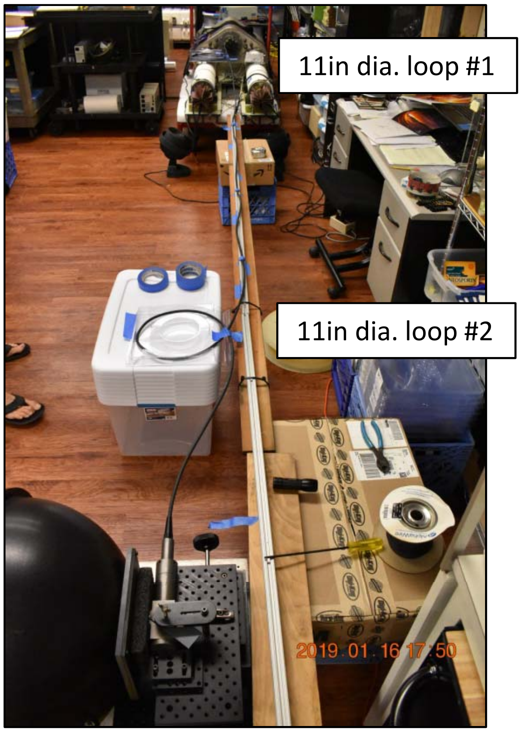
Since the return-to-straight-FO Exp#24 (see Fig.8 Top = Day05 #A, above) did not return starting signal, the starting signal from Exp#22 was used above for normalization.



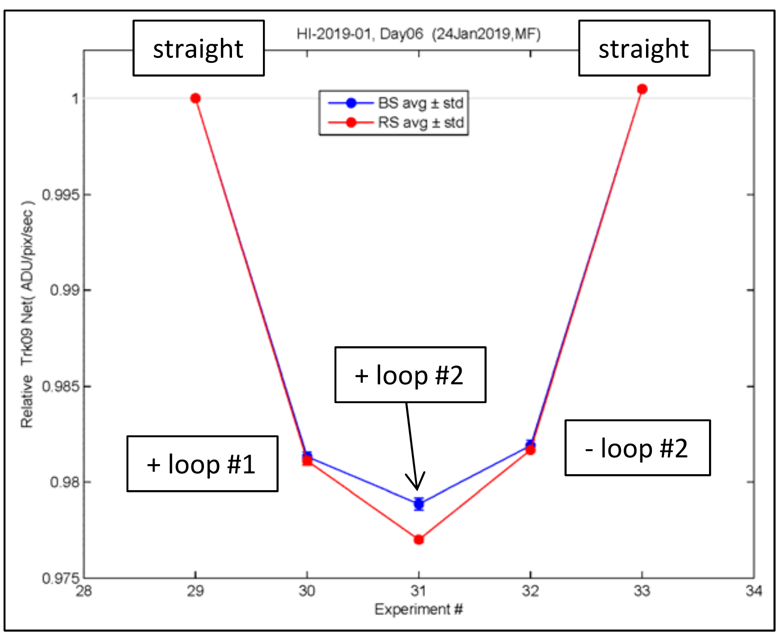
Above overplots Trk06 & Trk09 2-loop results – Trk09 are open symbols. Signal decrease for the Trk09 loops are of smaller magnitude than for Trk06.

Figure 10, HI-2019-01 Day05 part #B Results

Day06 tightened the loops to 11in dia. – determined by an Ocean Optics FO shipping box form.



11 in dia. Ocean Optics FO shipping box (modified).

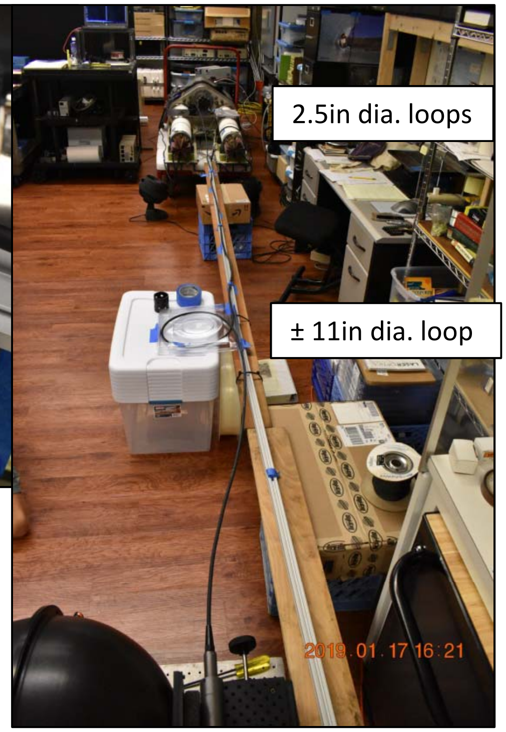


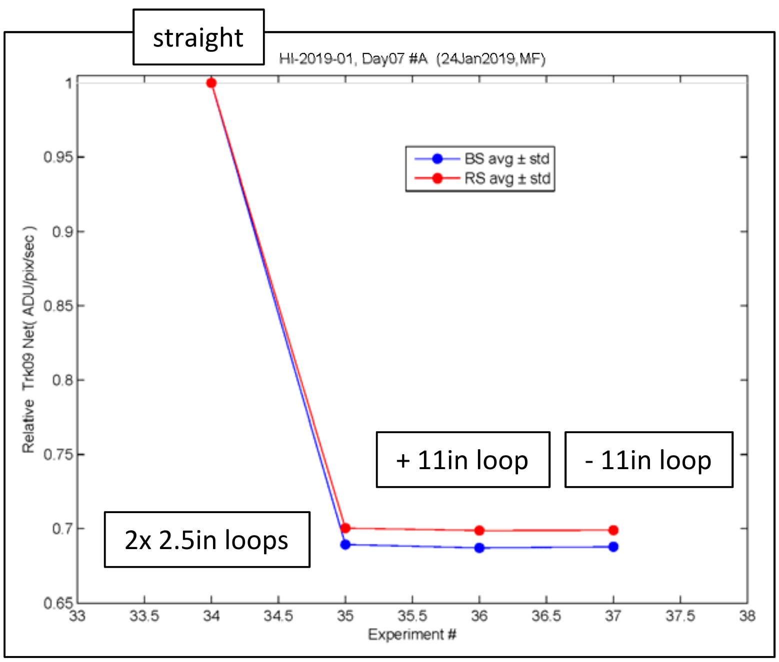
Adding an 11in loop near specs decreased net signals ~1.9% = more signal loss than larger loops. Adding 2nd 11in loop reduced signals another 0.23% at BS & 0.42% at RS- also more signal drop than larger 2nd loops. Ex. compare this with Fig.7 for Day04#B 14in loop near specs. RS seemed more sensitive to the 2nd loop than did the BS.

Figure 11, HI-2019-01 Day06 Results

<u>Day07 part #A</u> tested adding 2x 2.5 in dia. **tight & permanent** loops near specs.

2x 2.5 in dia. **permanent** FO loops near specs.

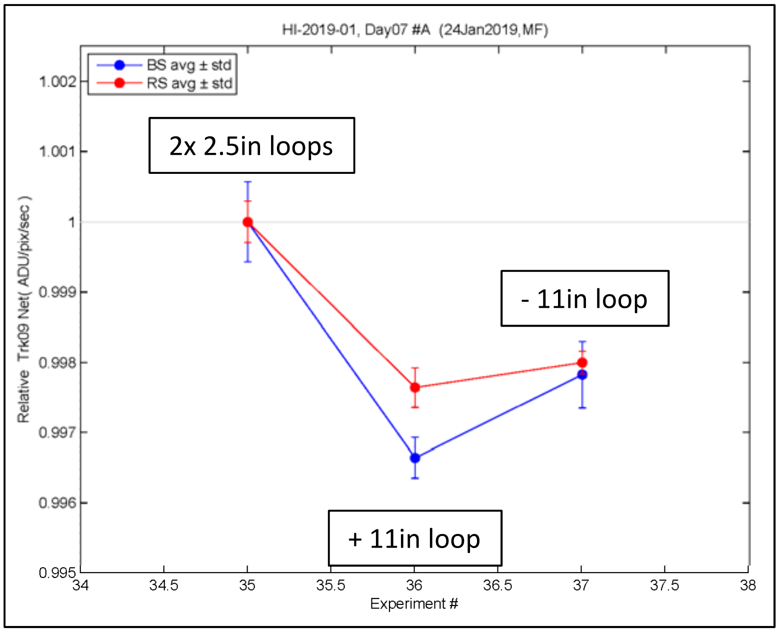




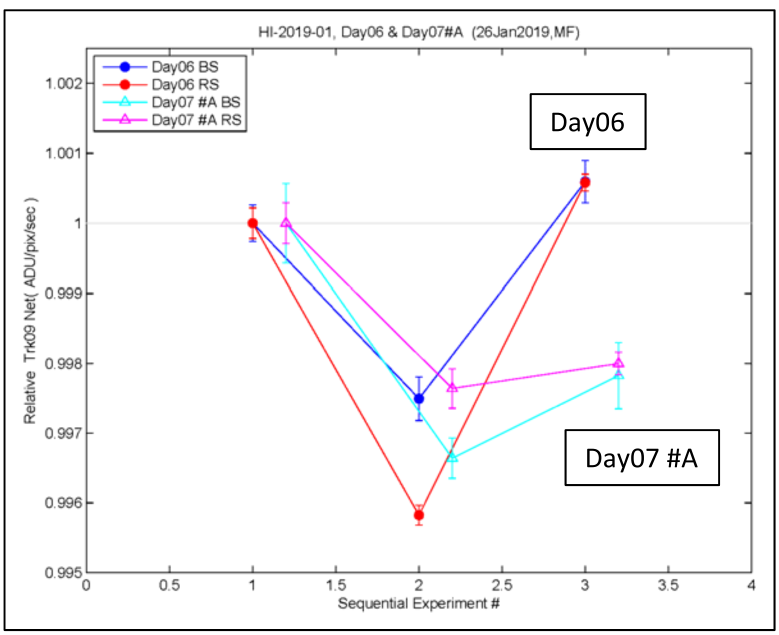
Adding 2x **tight & permanent** loops near the specs decreased the BS signal 31% and RS signal 30%. See next figure for zoomed-in plot showing effect of 11 in dia. loop between specs and Lu head.

Figure 12, HI-2019-01 Day07 part #A Results

<u>Day07 part #A cont.</u> = sensitivity after adding 2x 2.5 in dia. **tight & permanent** loops near specs.



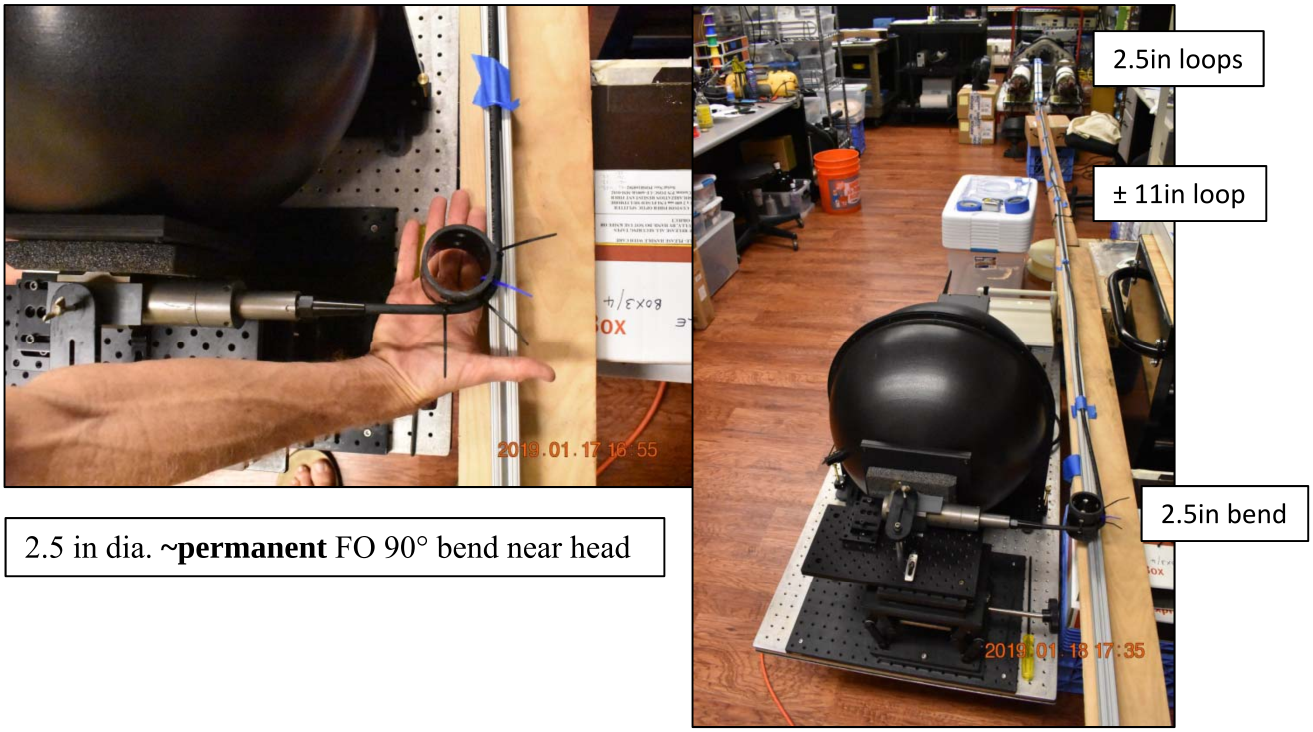
Above: adding an 11 in dia. loop - after inserting the 2x **tight & permanent** loops near the specs - decreased the signals ~0.35% at the BS and ~0.25% at the RS. Removing the 11in loop increased signals ~0.1%, but not to same levels as before 11in loop was added. Here, the BS looked more sensitive than the RS to adding the 11 in dia. loop between specs & head.

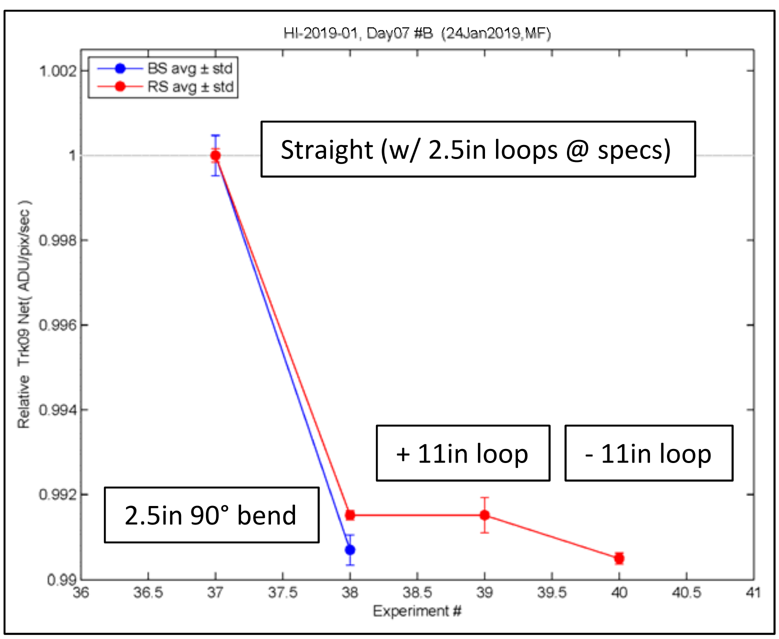


Above compares Day06 vs Day07#A = add & remove 11in dia. loop between specs & head – where Day06 also had 11in loop near specs, vs Day7#A also had 2x tight loops near specs.

Figure 13, HI-2019-01 Day07 part #A Results, cont.

<u>Day07 part #B</u> tested adding 2.5 in dia. 90° **tight & ~permanent** bend near head.

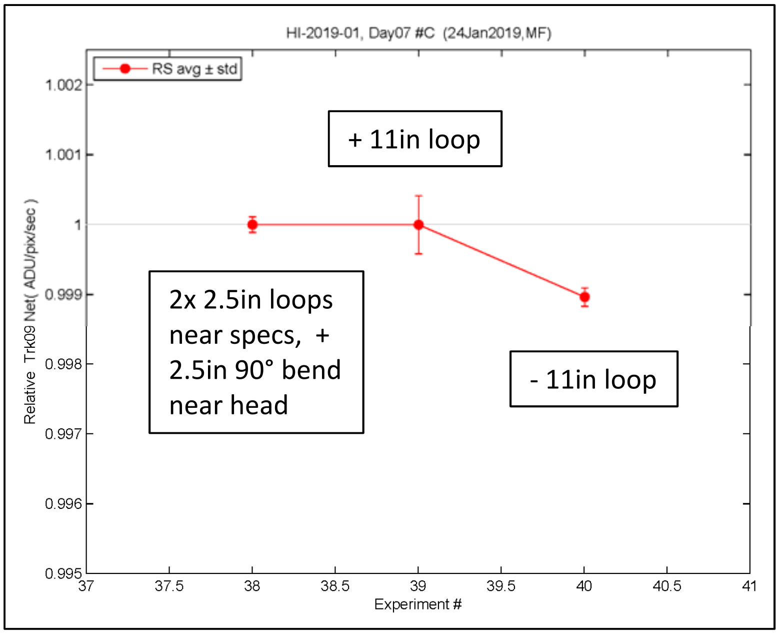




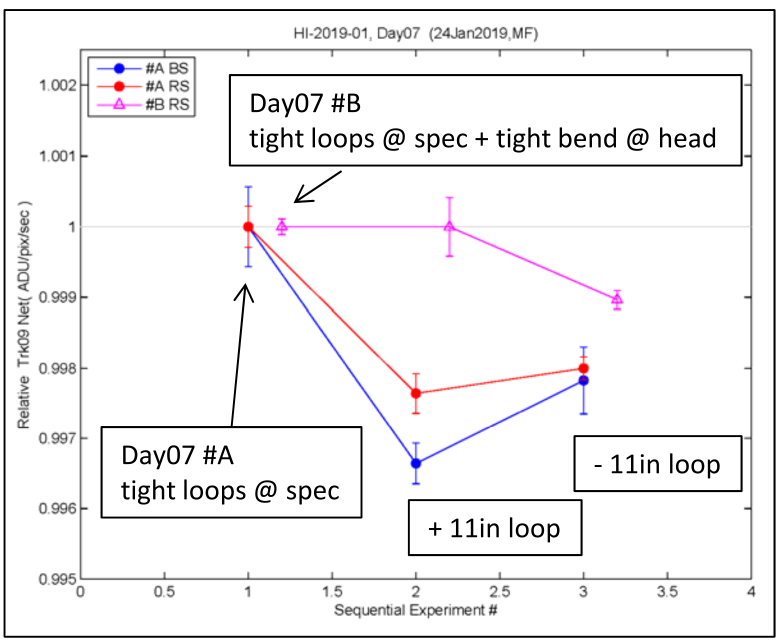
Adding a **tight & ~permanent** 90° bend in the FO near the head decreased the signals ~0.9%.
However, the BS camera overheated at this time – we only got RS data via add/removing 11in loop…
See next figure for zoomed-in plot showing effect on RS of 11 in dia. loop between specs and Lu head.

Figure 14, HI-2019-01 Day07 part #B Results

<u>Day07 part #B cont.</u> = sensitivity after adding 2.5 in dia. **tight & ~permanent** 90° bend near head.



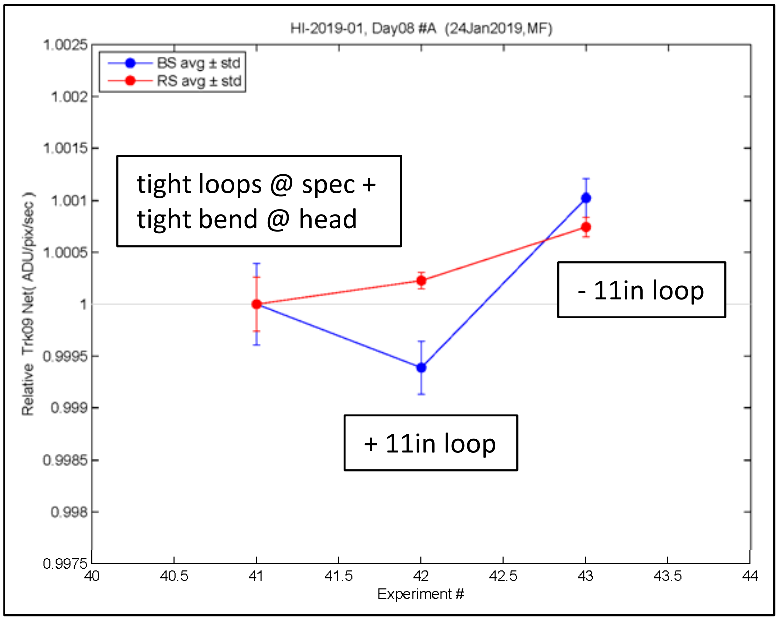
Above: adding an 11 in dia. loop - after inserting the 2x **tight & permanent** loops near the specs and inserting **tight & ~permanent** 90° bend near head – did not change the signal at the RS. Removing the 11in loop decreased the signal ~0.1%. BS data were missing here because the camera over-heated.



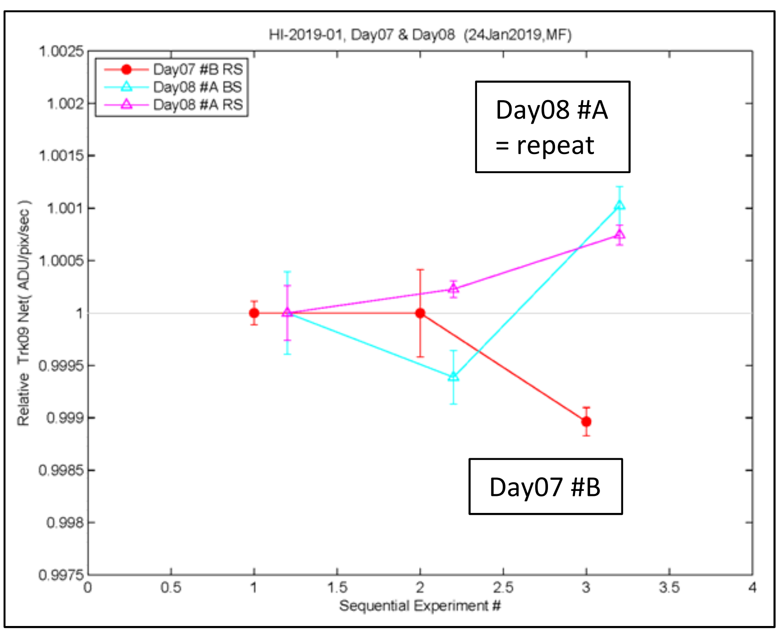
Above compares Day07 #A vs Day07 #B = add & remove 11in dia. loop between specs & head – where Day07 #A also had no tight bend @ head, vs Day7#B also had a tight bend @ head.

Figure 15, HI-2019-01 Day07 part #B Results, cont.

Day08 part #A = repeat Day07 #B with both BS & RS collecting data.



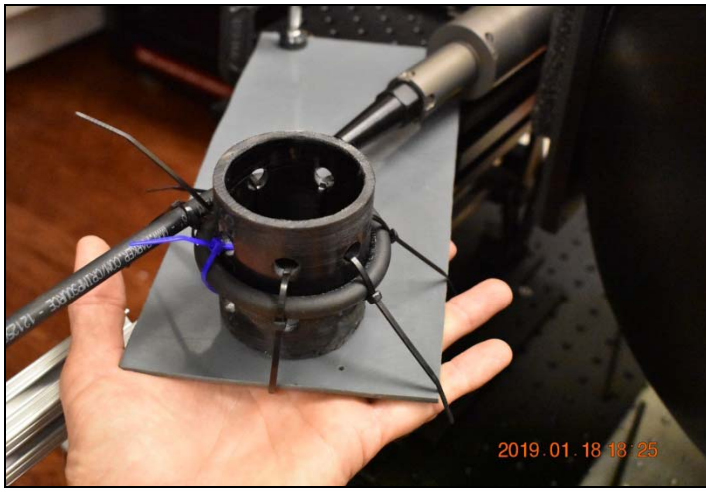
Above: adding an 11 in dia. loop - after inserting the 2x **tight & permanent** loops near specs and inserting **tight & ~permanent** 90° bend near head - decreased the signal 0.06% at the BS and increased signal 0.02% at the RS. Removing the 11in loop increased signals ~0.1% above level before 11in loop was added.



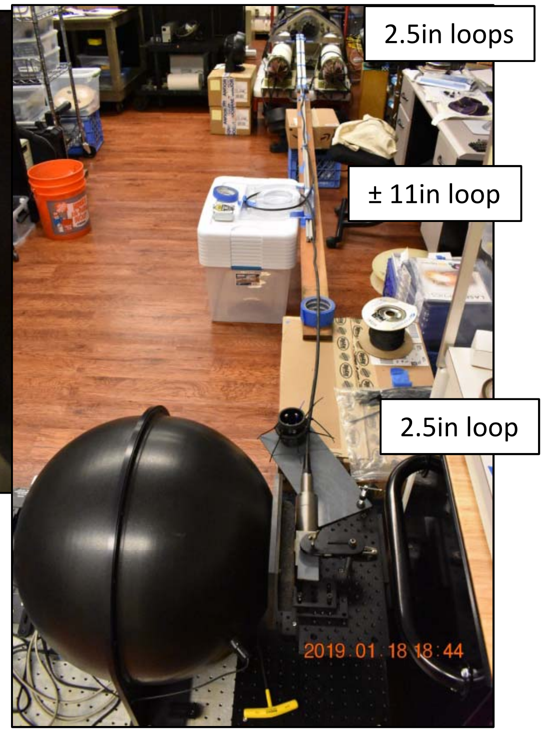
Above compares Day07 #B vs Day08#A = add & remove 11in dia. loop between specs & head – open symbols are Day08, both Days had 2x tight loops at specs + tight bend at head.

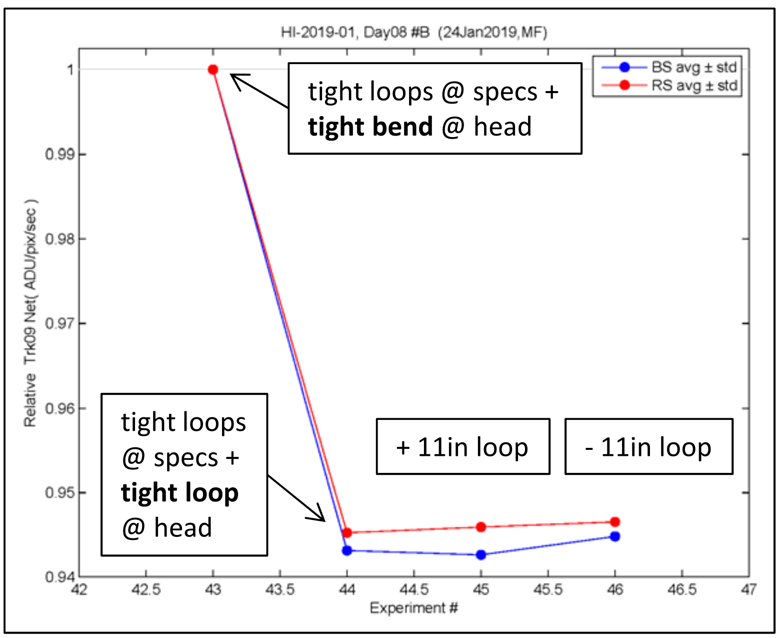
Figure 16, HI-2019-01 Day08 part #A Results

<u>Day08 part #B</u> replaced tight 90° bend with a **tight & permanent** 360° loop near head
…because a tight loop would be easier to tuck into a MOBY arm than a tight right-angle bend…



2.5 in dia. **permanent** FO loop near head

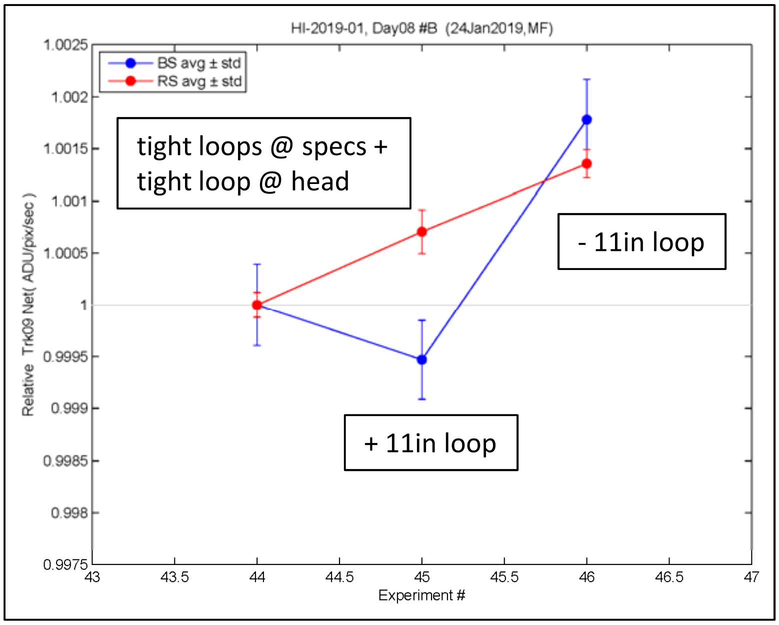




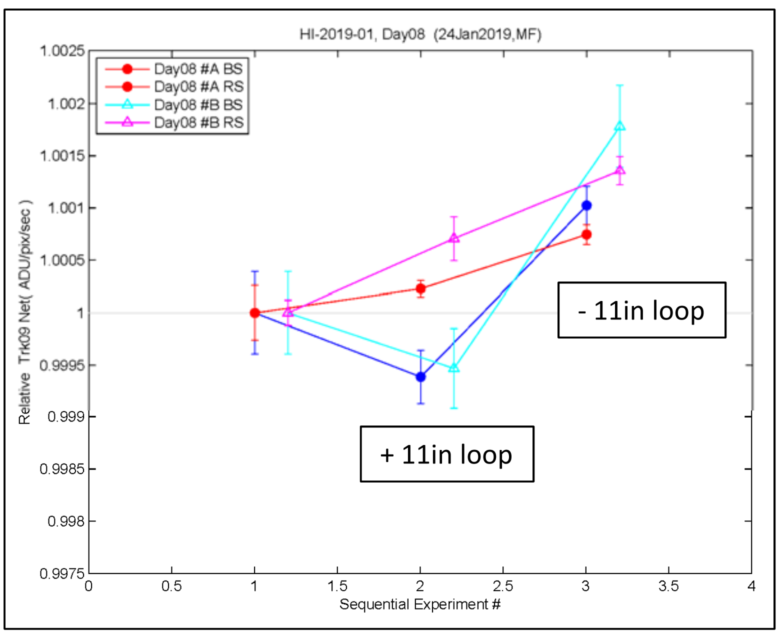
Making the tight 90° bend at head into a **tight & permanent** loop at head decreased the signals 5.7% at BS and 5.5% at RS. See next figure for zoomed-in plot showing effect of add/removing an 11 in dia. loop between specs and Lu head … with tight loops at specs and tight loop at head.

Figure 17, HI-2019-01 Day08 part #B Results

Day08 part #B = add/remove 11in dia. loop, with tight loops at specs & tight loop at head.

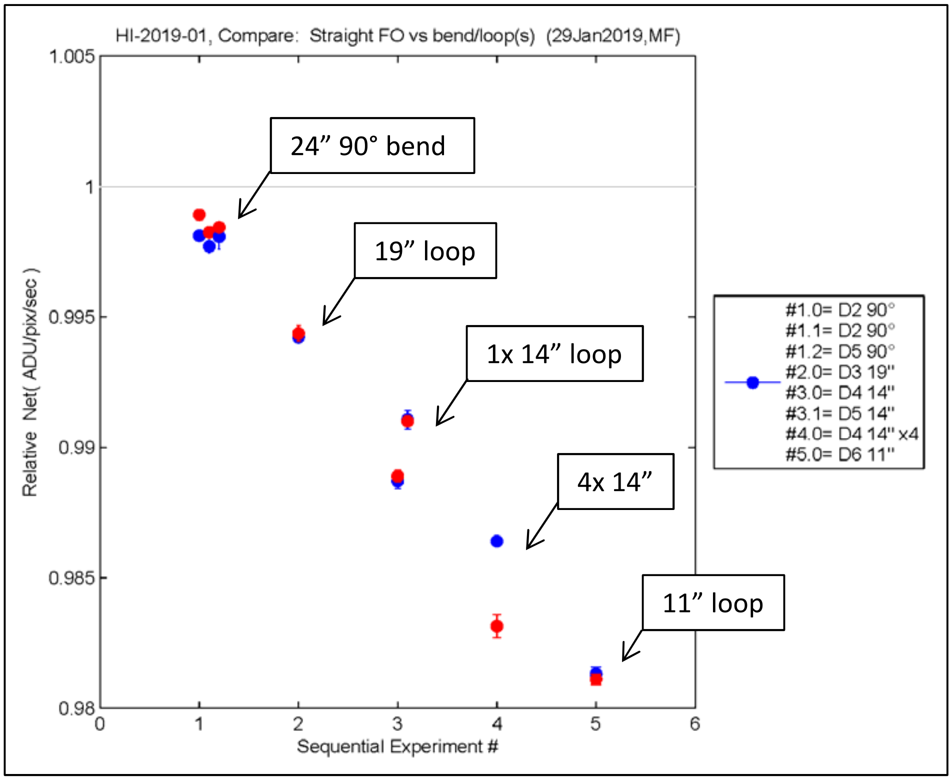


Above: adding an 11 in dia. loop - including the 2x **tight & permanent** loops near specs and **tight & permanent** loop near head - decreased the signal 0.05% at the BS and increased signal 0.07% at the RS. Removing the 11in loop increased signals ~0.15% above level before 11in loop was added.

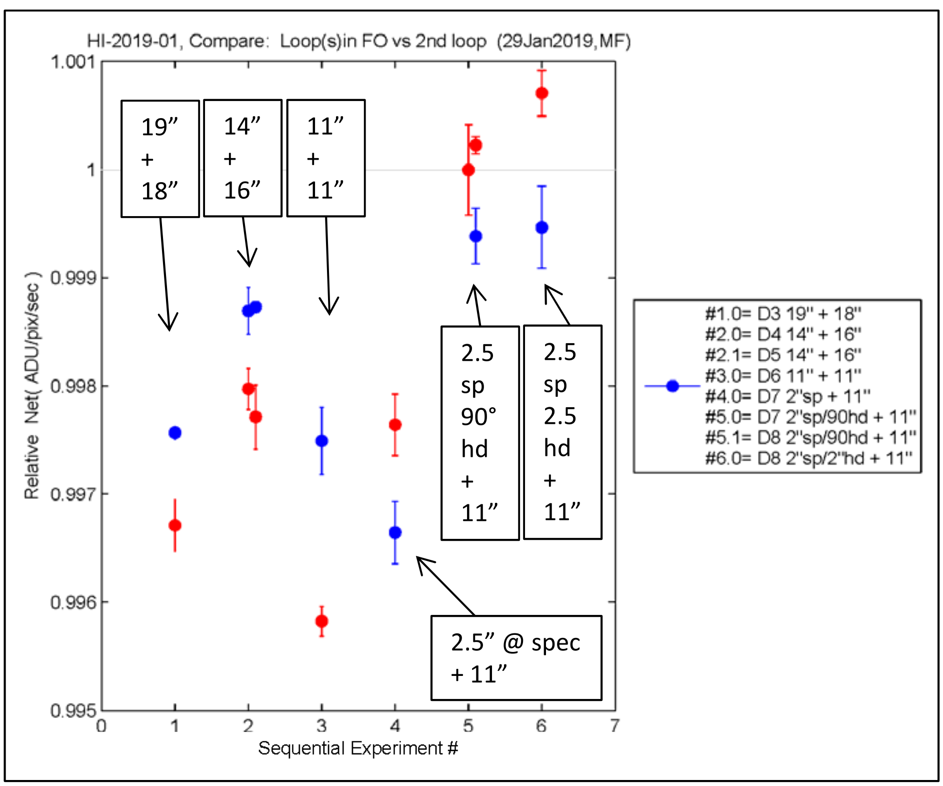


Above compares Day08 #A vs Day08 #B = add & remove 11in dia. loop between specs & head – where #A had tight bend at head and #B had tight loop at head. Similar results for both.

Figure 18, HI-2019-01 Day08 part #B Results, cont.



Above: all experiments, straight FO vs adding 1 (or more) FO bend or loop(s)



Above: all experiments, loop(s)/bend in FO vs adding 1 more FO loop

Figure 19, HI-2019-01 comparisons of results