Overview of Stanford's SWG work

Brian Lantz, Sept 5, 2018

G1801749, Maastricht LVC meeting

Most of the work was done by others

Wind protection fence at LHO End-X

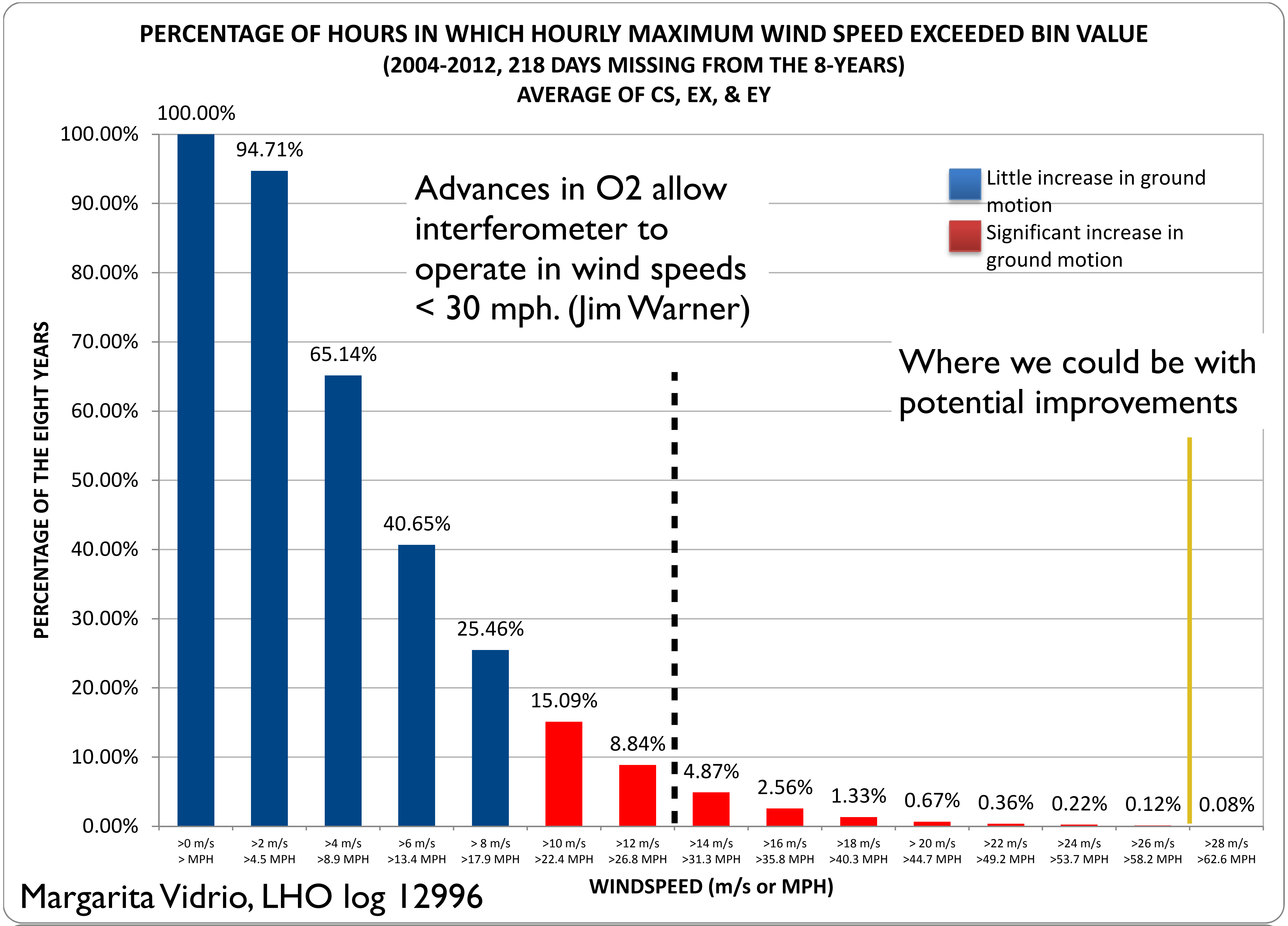
Improved cooldown technique for Voyager

Wind Fence Modeling

Elyssa Hofgard, Dane Stocks, Shi Tuck, Ian Gomez, Brian Lantz
Hugh Radkins, Jim Warner, Bubba Gateley, Jeff Kissel,
Giacomo Lamberti, Prof. Catherine Gorle

- Wind at LHO is a problem
- Problem is worst in the small buildings
- We think that a protective barrier can help.
- End-X is partially protected by the local terrain.
- People are (or at least should be) suspicious of Computational Fluid Dynamics (CFD) modeling
- We are preparing to build a 'test-at-scale' at End-X.
- (my) Goal is to
  - protect End-X before O3 and
  - understand fences more accurately so we can
  - build a taller fence at End-Y before O4.
- Fence complements the BRS

Wind statistics for LHO

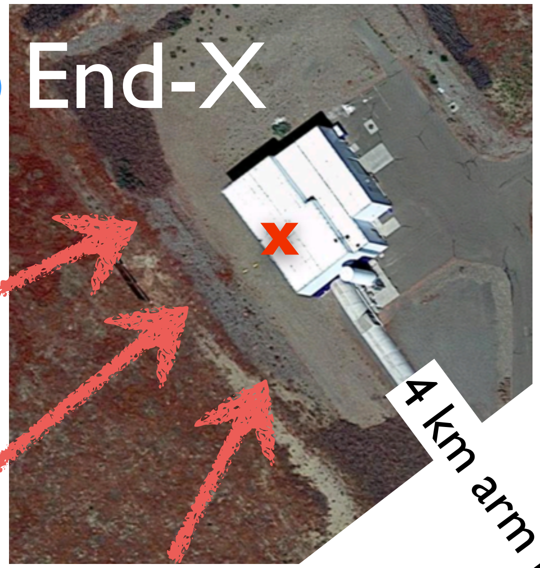


histogram drops rapidly with wind speed, 0.08% = 7 hours/year

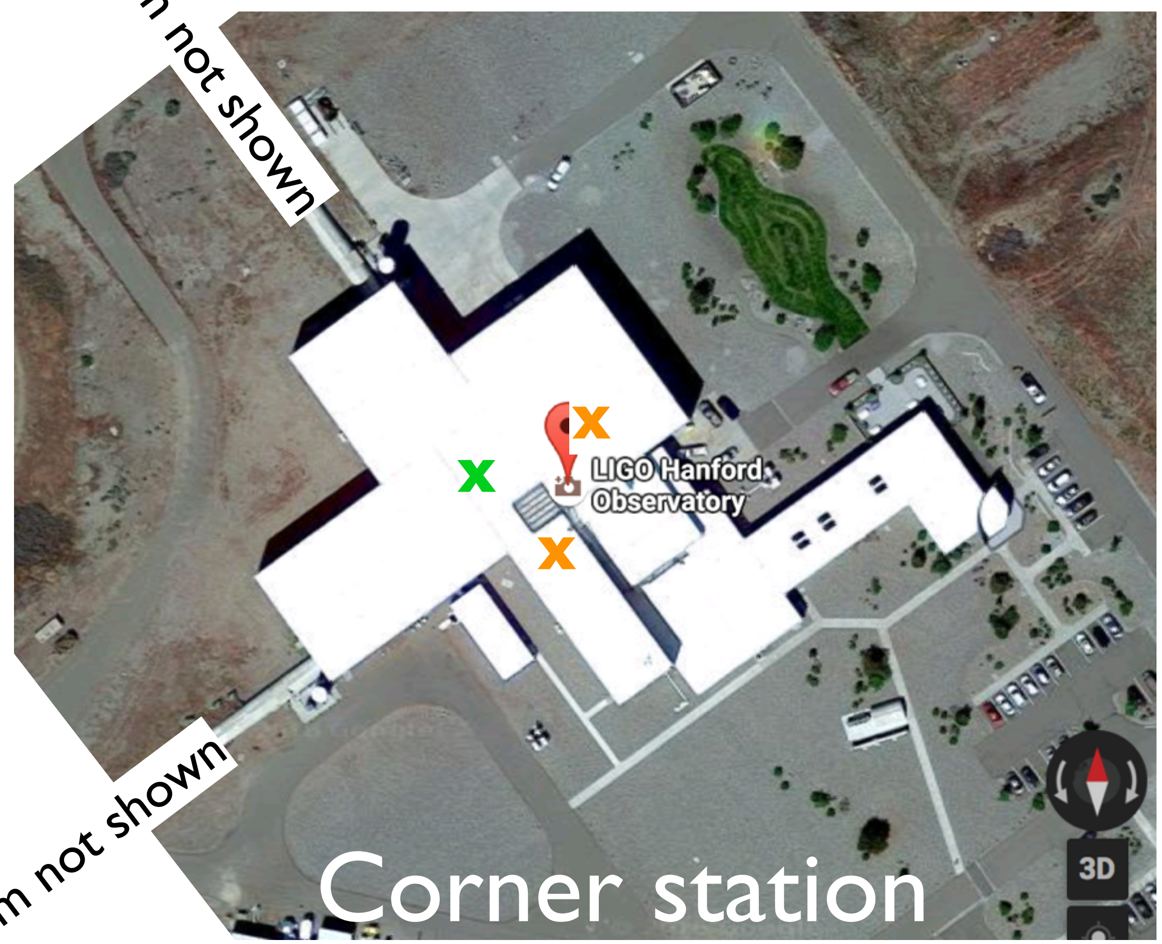
More wind statistics

- Strong winds are mostly from the southwest
- STS-2s in end stations (x) see ~10x more wind tilt than sensor in middle of corner station(x)

dominant high-wind direction



4 km arm not shown

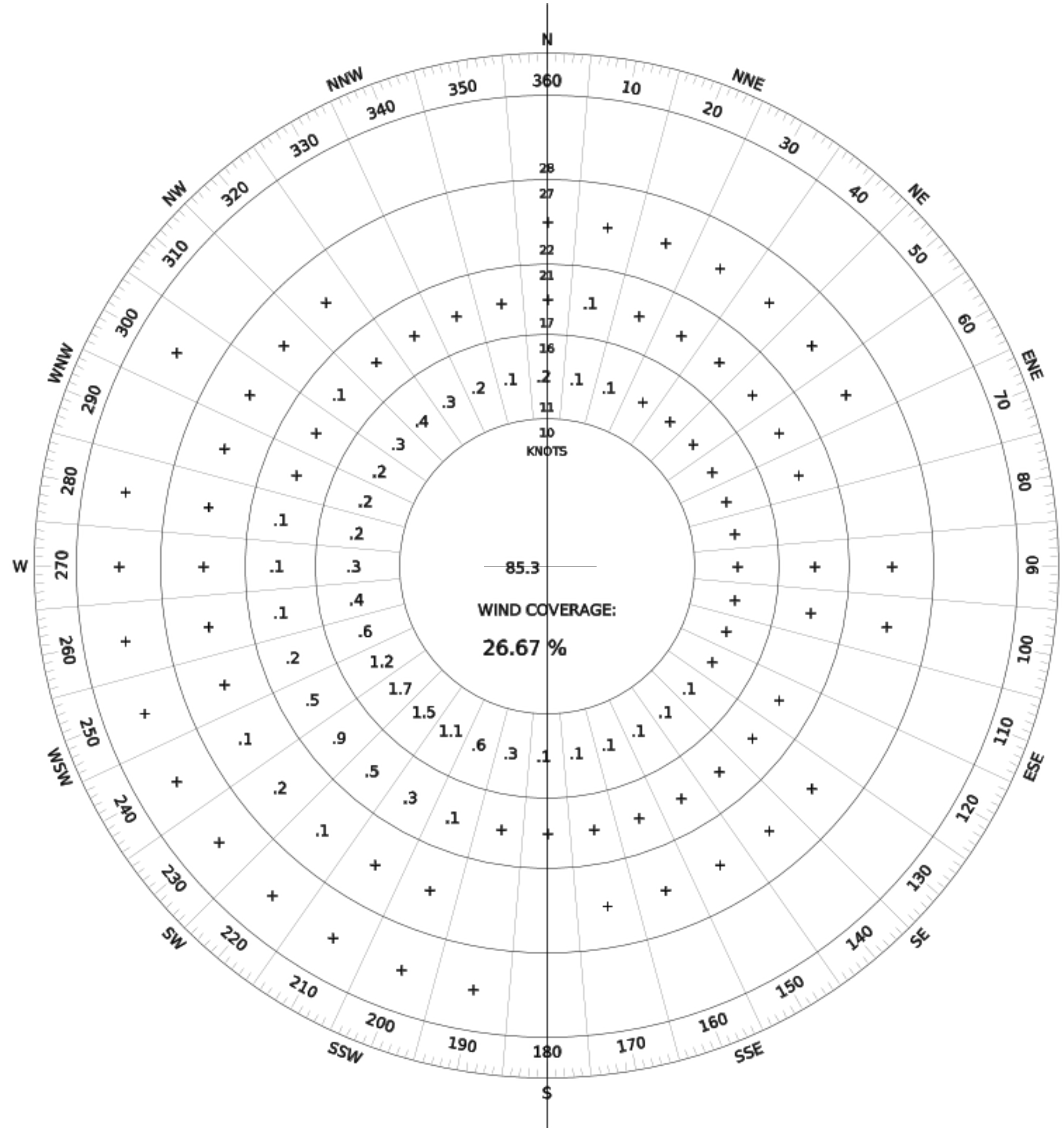


sensor locations are approximate

4 km arm not shown

Imagery by Google Maps

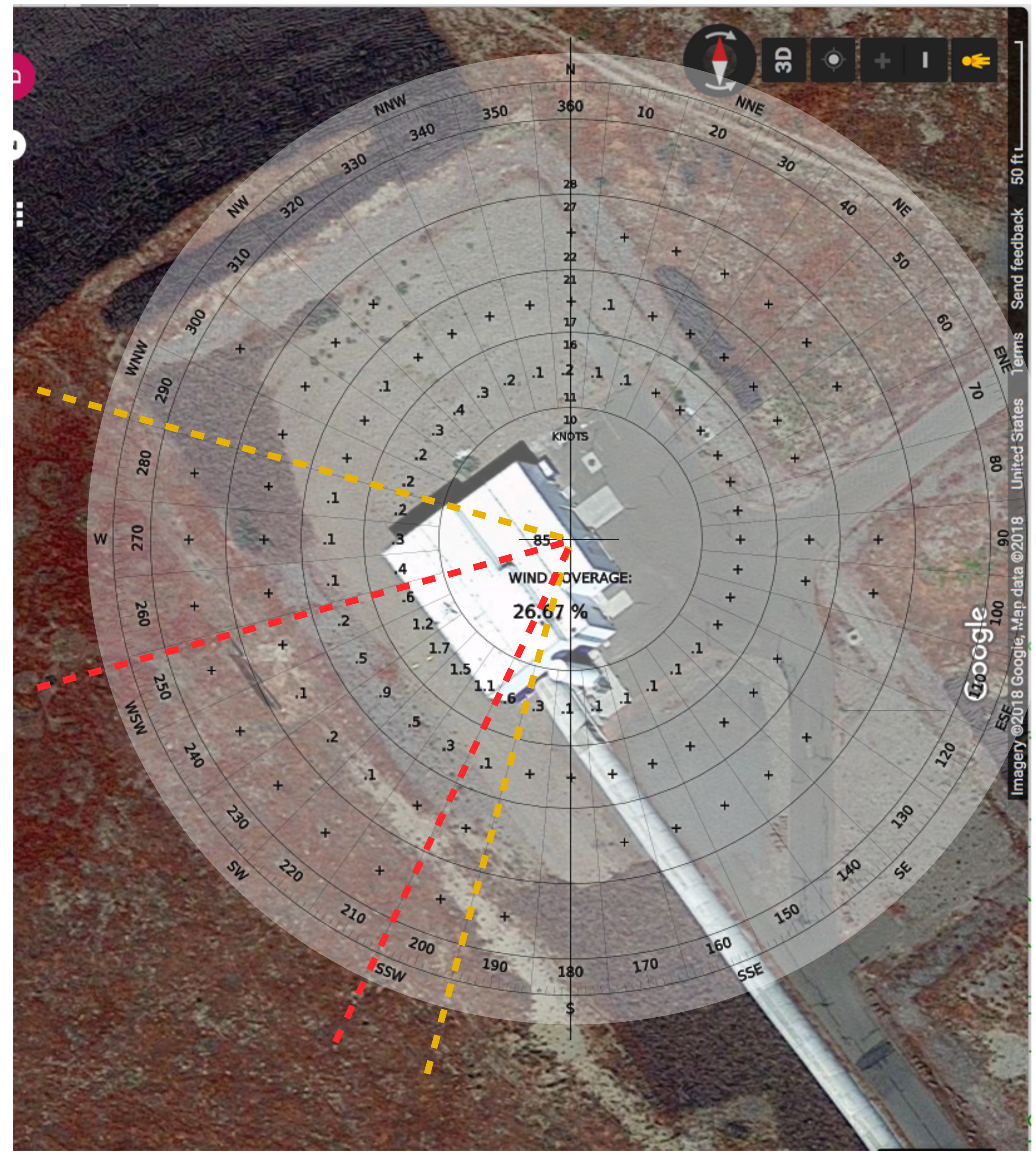
Google image of LHO EndX, Test fence is visible, Test fence is ~85 ft from the building. Top of the test fence is about 5 feet below the top of the building.



Wind rose from Pasco airport, 10 years of data. Most of the high wind comes from the SW, i.e. up the Y arm toward the corner station

even more statistics

superimpose the wind rose on the building and pick directions to include directions near SW where wind is 17-21 knots at least 0.1% of the time. Misses some of the high wind but gets most of it.



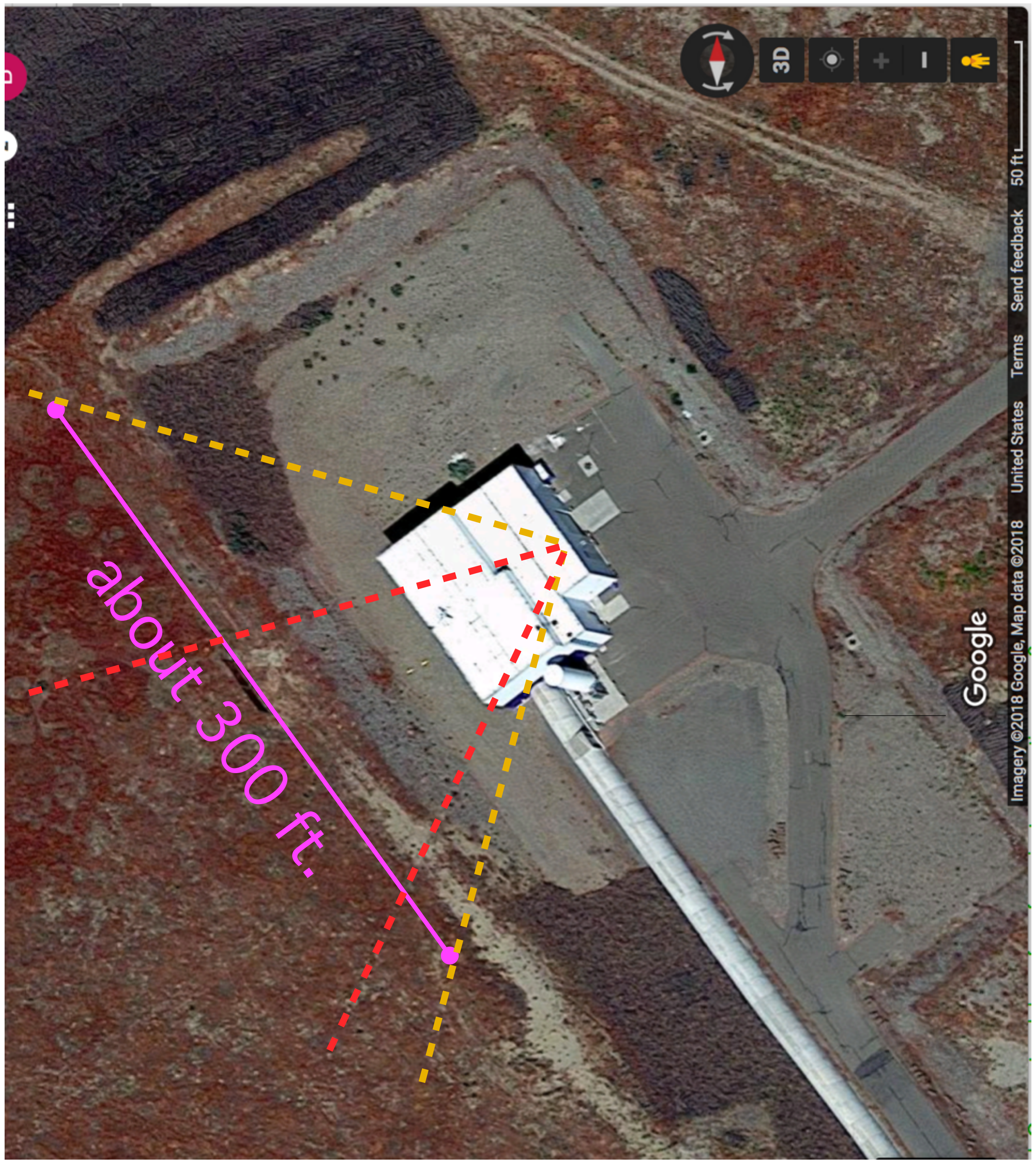
At the airport -
When the wind is > 20 mph, it comes from red direction 75% of the time.

When it is > 25 mph, it comes from red direction 80% of the time. When

For speeds > 30 mph, direction outside of yellow area was 4 hours in 10 years.

Choosing fence size

To get good protection you need ~200-300 ft of fence.
Ground cut makes a curve difficult.
~15-22 posts on 15’ spacing

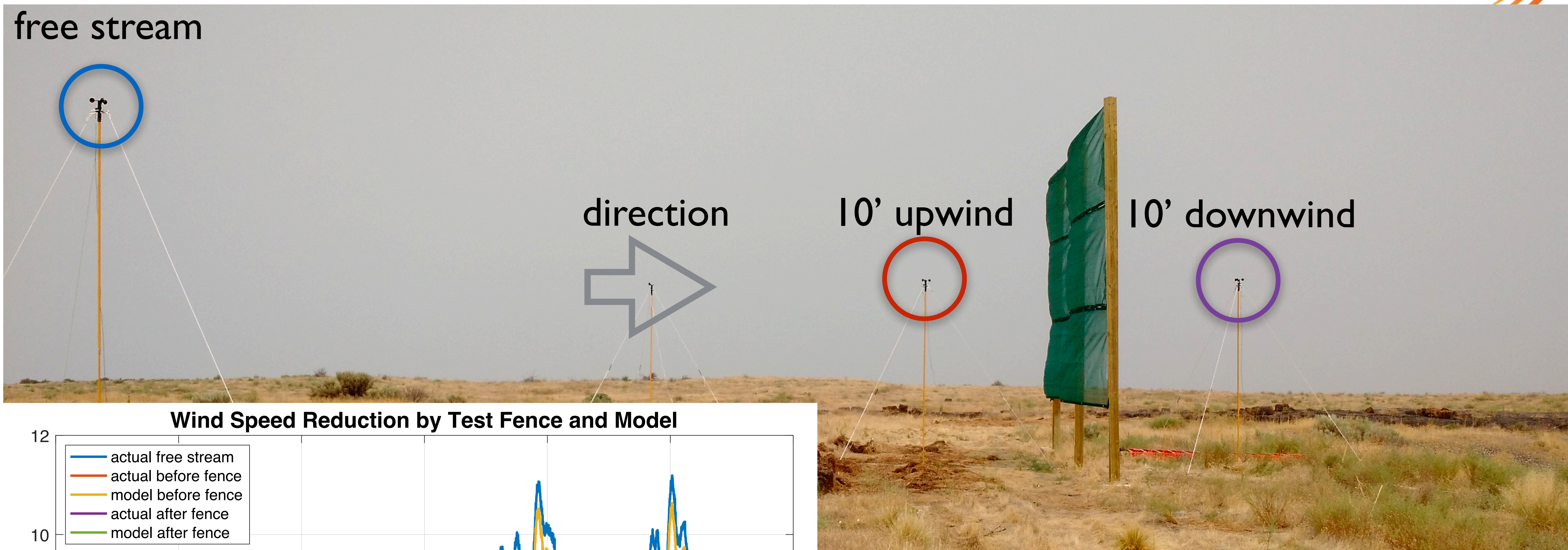


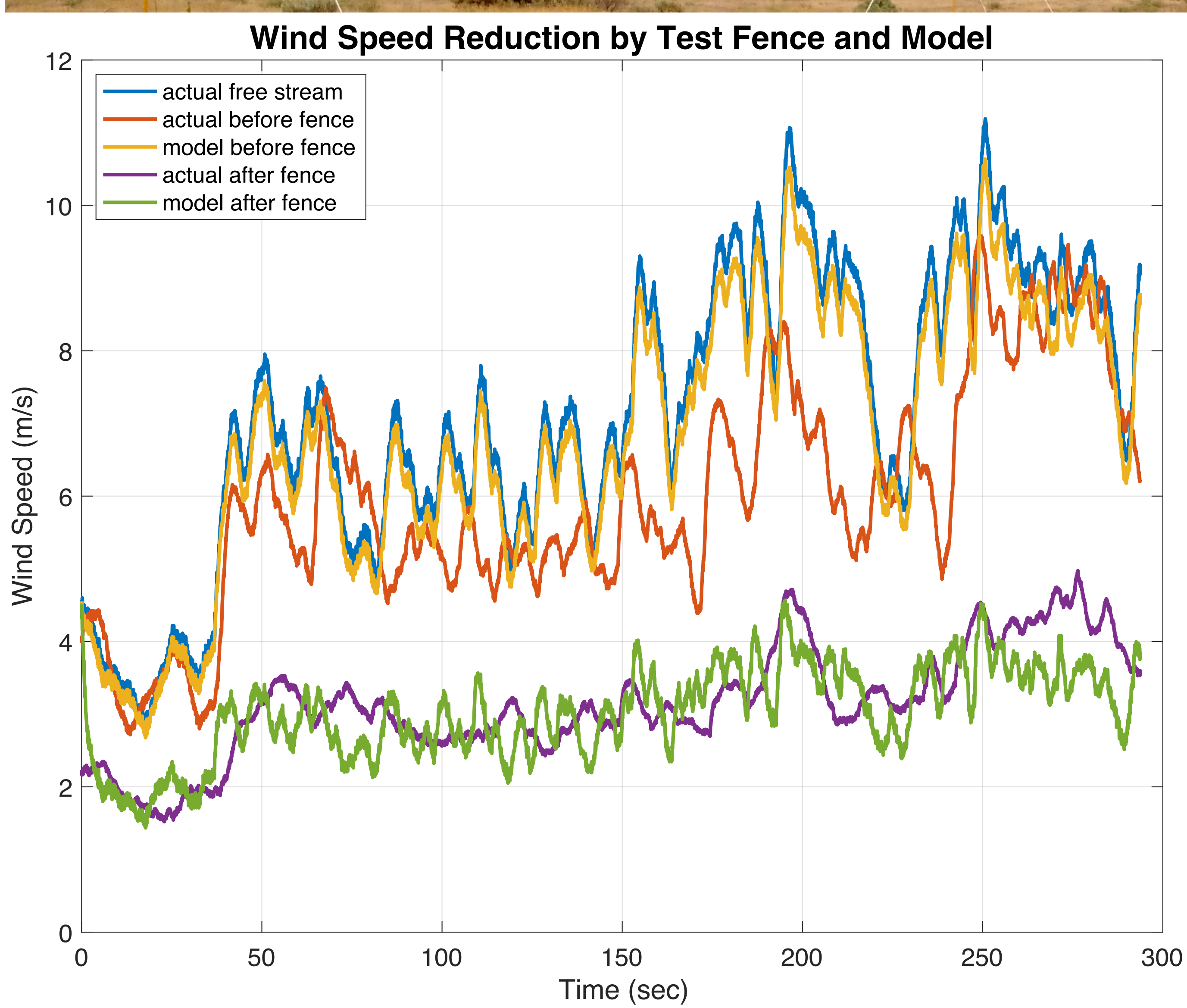
Test Fence vs. CFD

Test fence is 30 feet wide, with 50% blockage from 4' up to 20'.
3 anemometers, 1 direction sensor.
Wind not cooperating when this picture taken.

How does the CFD compare to reality?

Test Fence





Make a time-dependent wind model to match free-stream wind data.

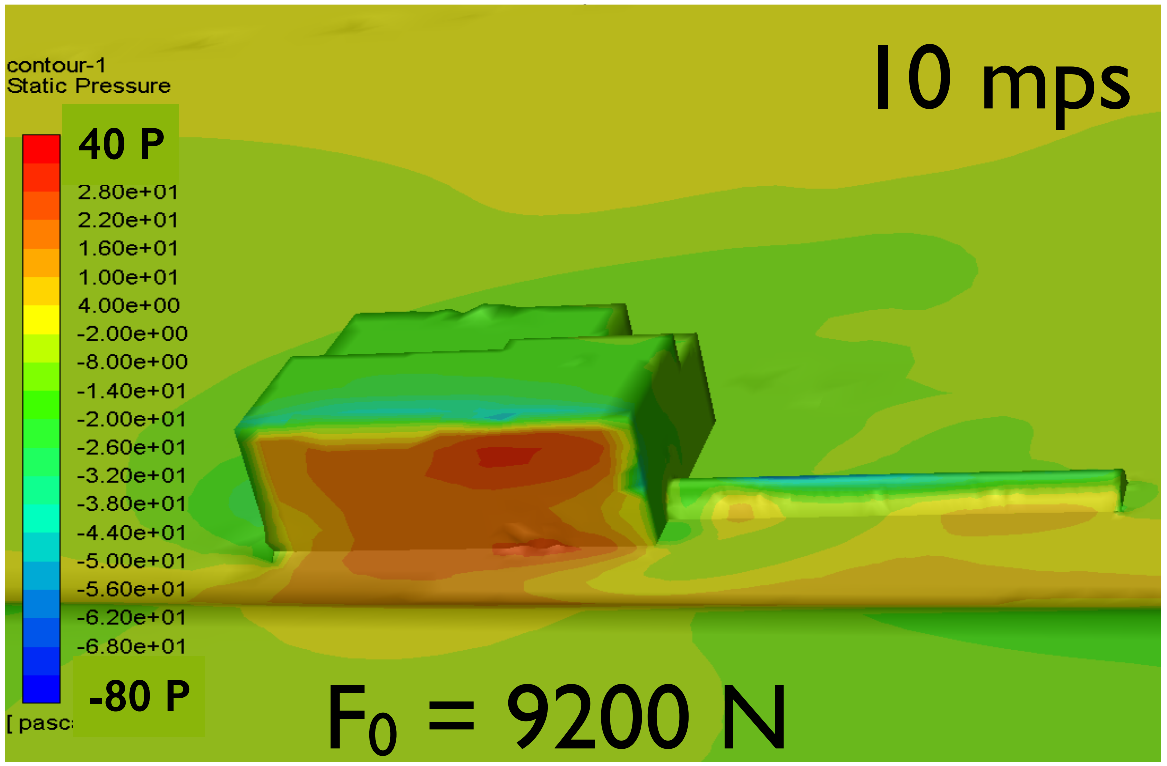
Wind data upwind of fence slower, not well correlated to free-stream. (expected)

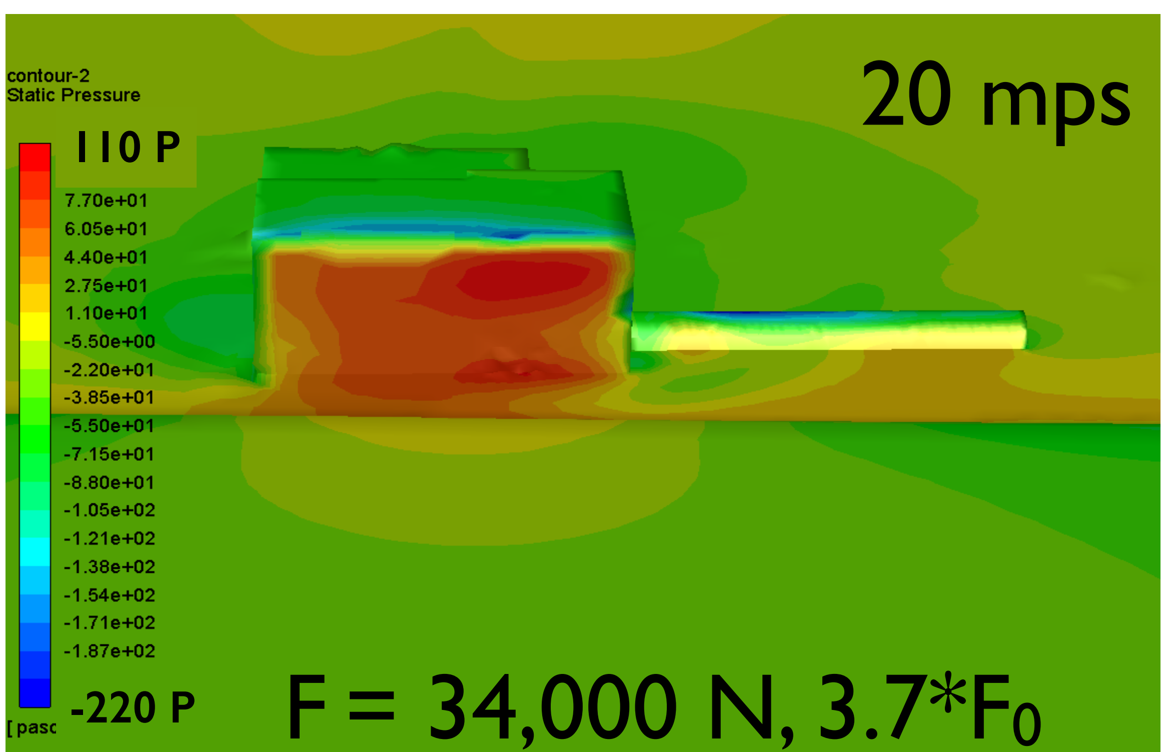
avg. Model downwind close to avg. Data downwind. great!

Data downwind is more stable than others.

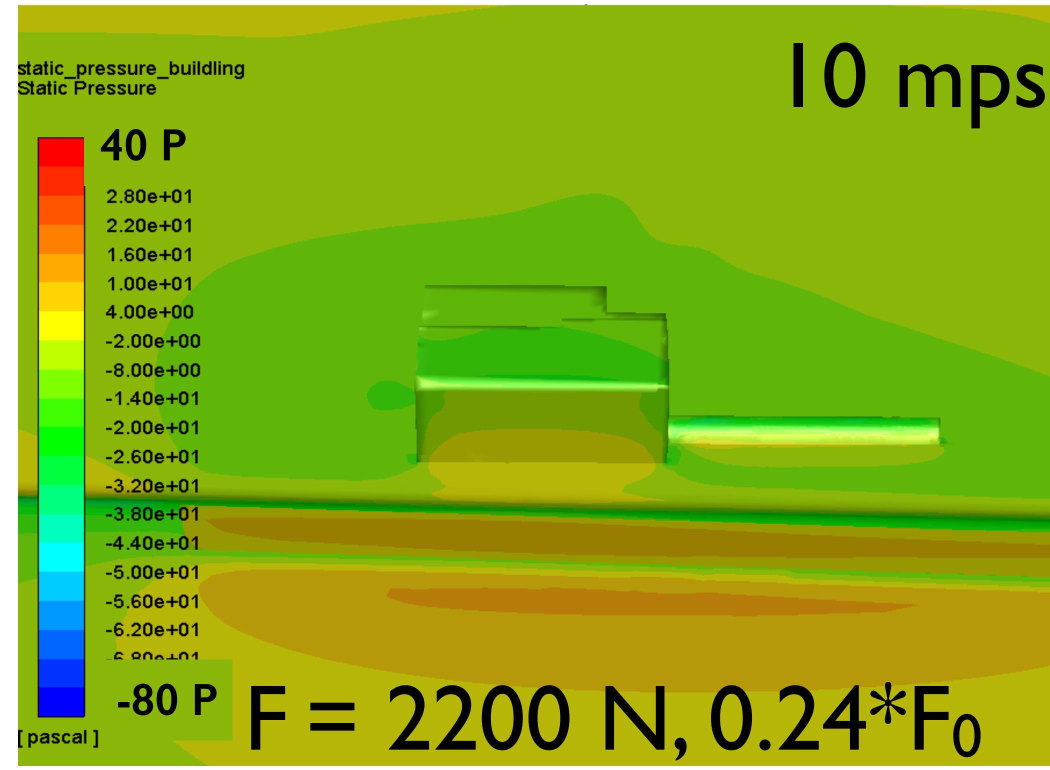
Model of Fence and End-X

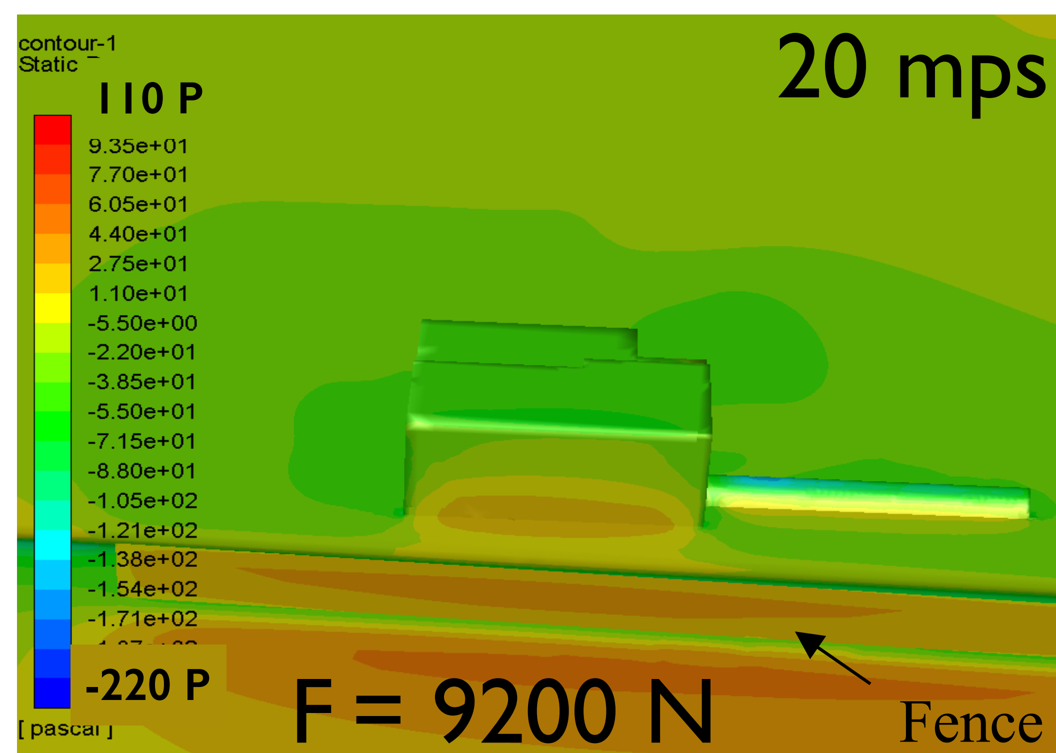
No Fence

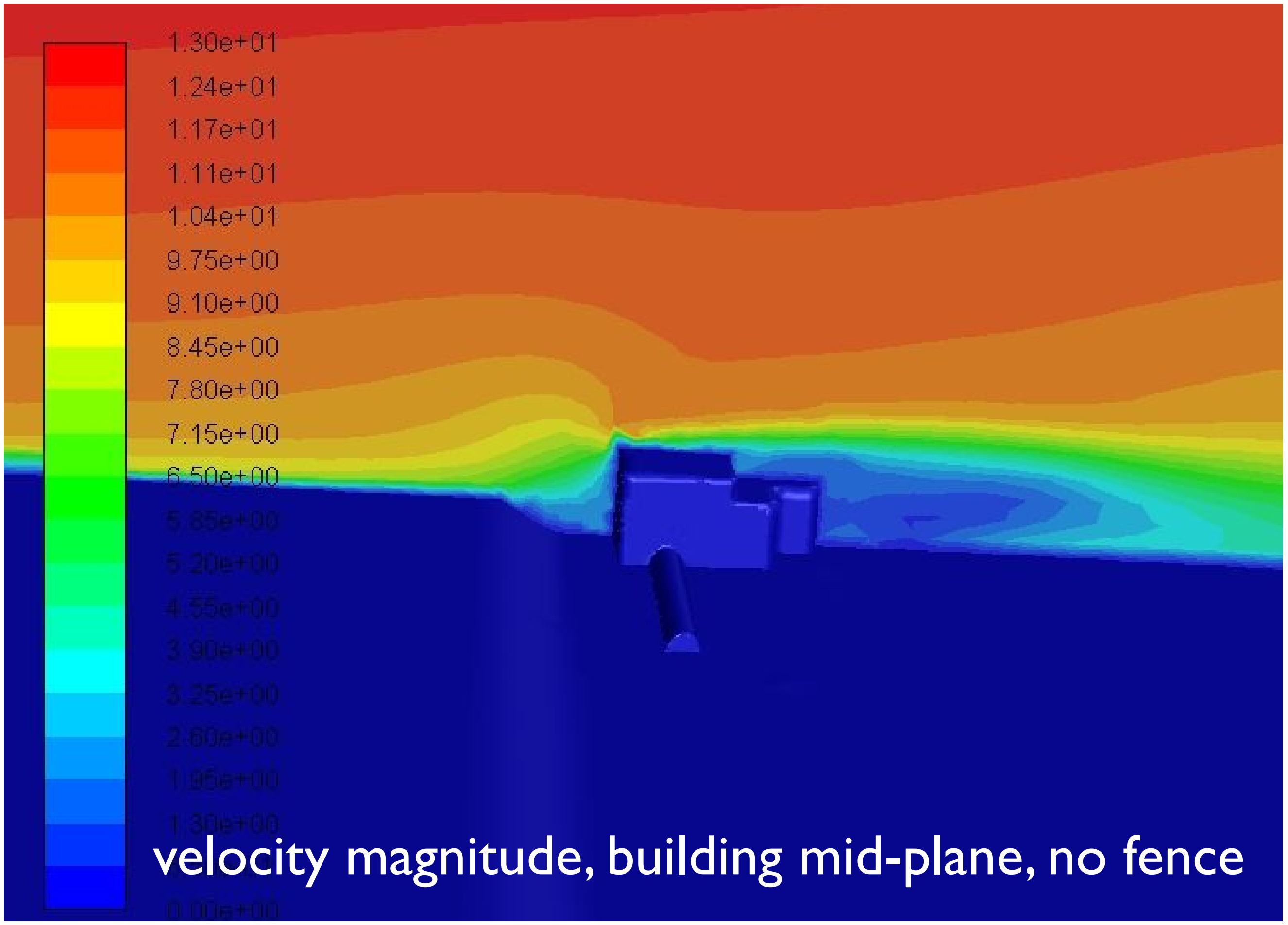


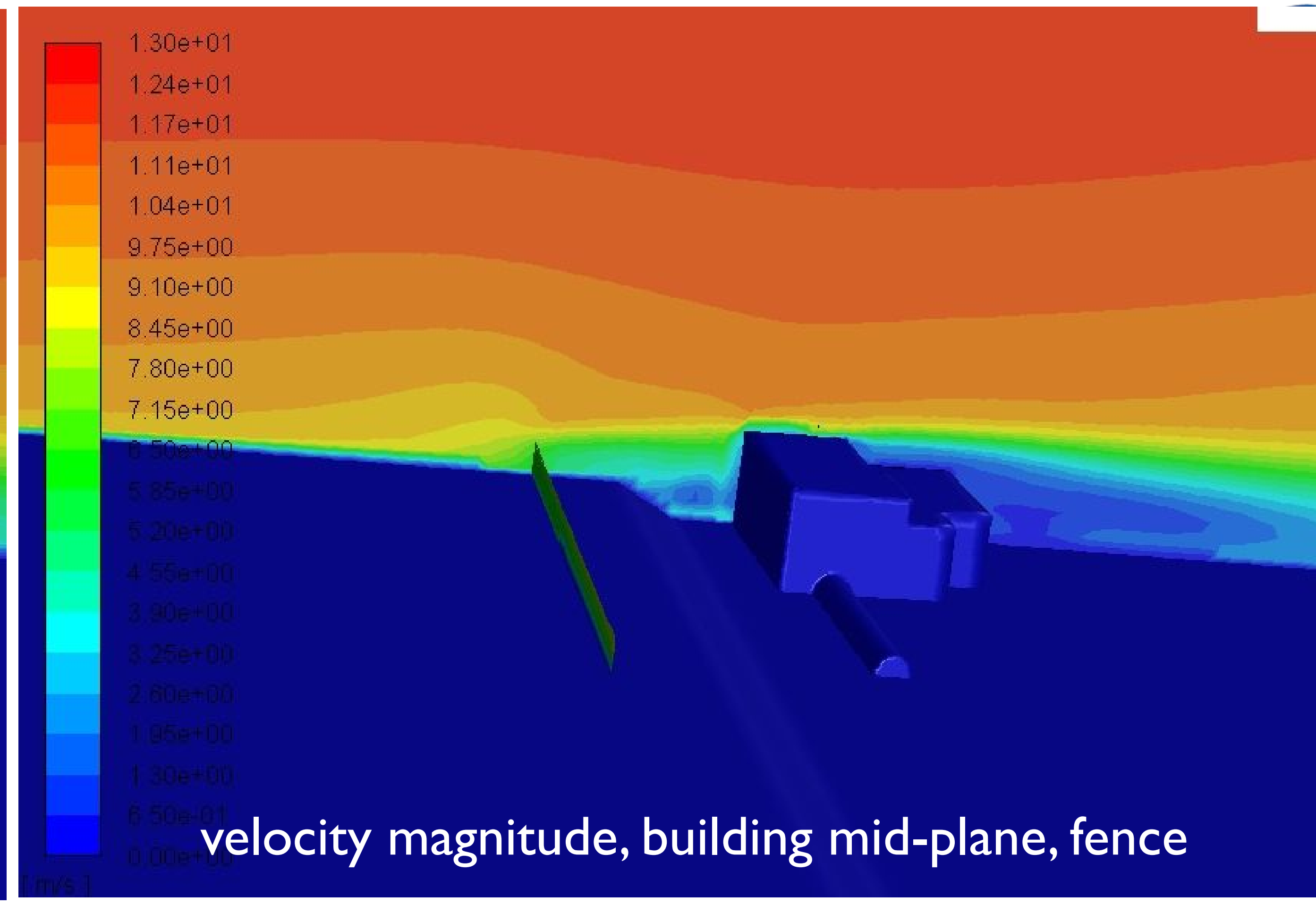


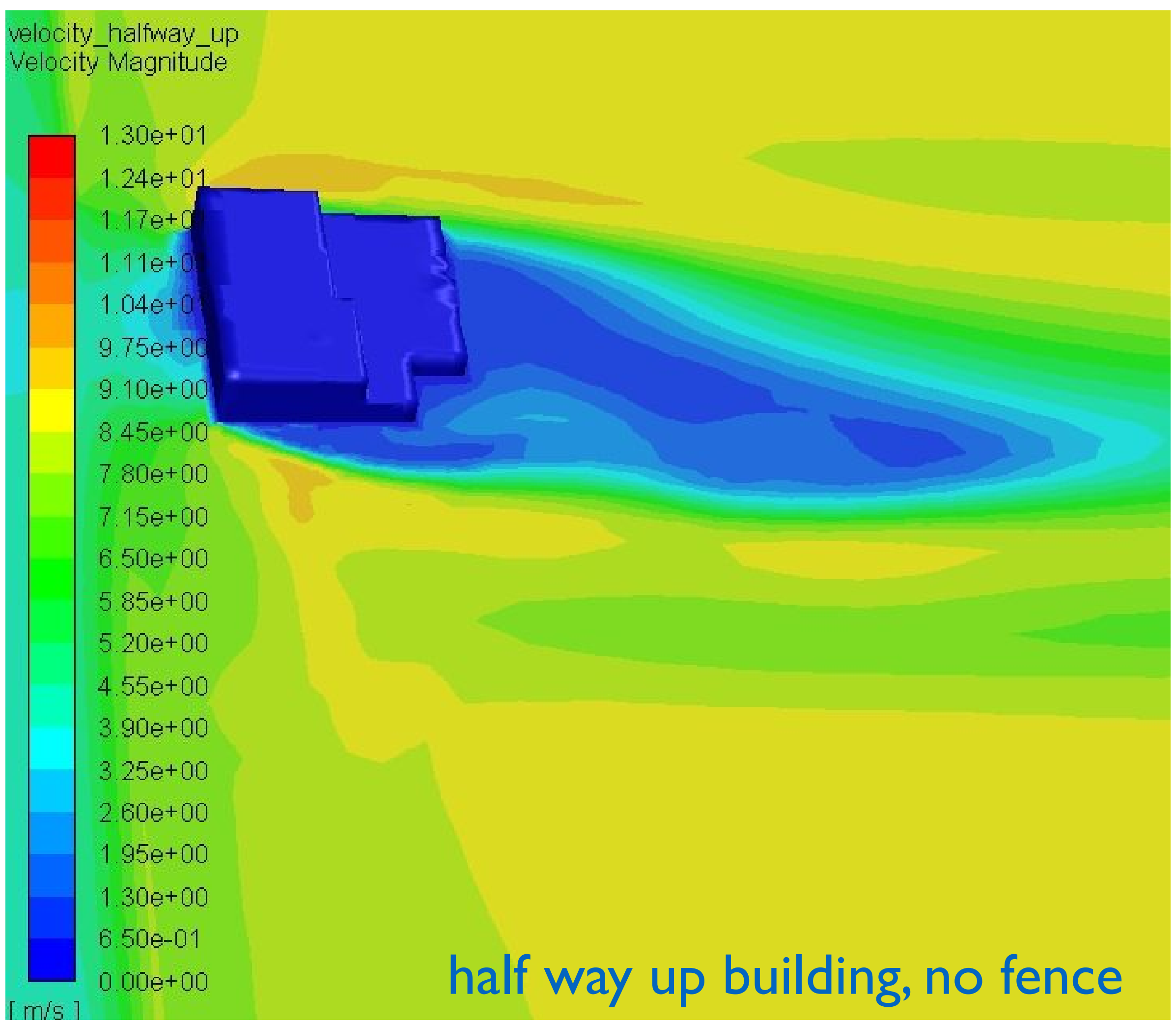
Fence

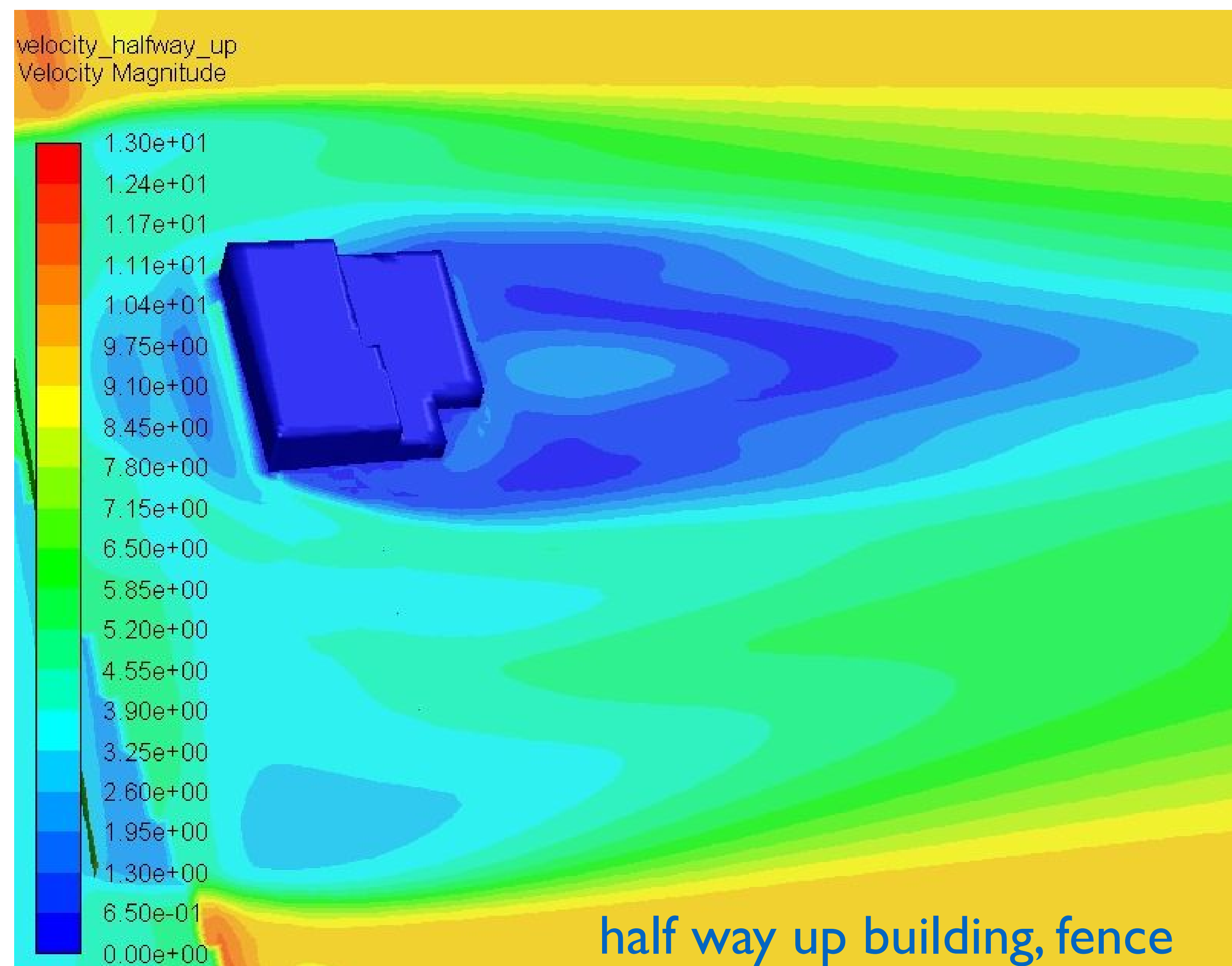





1.30e+01
1.24e+01
1.17e+01
1.11e+01
1.04e+01
9.75e+00
9.10e+00
8.45e+00
7.80e+00
7.15e+00
6.50e+00
velocity magnitude, building mid-plane, no fence


1.30e+01
1.24e+01
1.17e+01
1.11e+01
1.04e+01
9.75e+00
9.10e+00
8.45e+00
7.80e+00
7.15e+00
velocity magnitude, building mid-plane, fence


velocity_halfway_up
Velocity Magnitude
1.30e+01
1.24e+01
7.80e+00
7.15e+00
6.50e+00
5.85e+00
5.20e+00
4.55e+00
3.90e+00
3.25e+00
2.60e+00
1.95e+00
1.30e+00
6.50e-01
0.00e+00
[m/s]
half way up building, no fence


velocity_halfway_up
Velocity Magnitude
1.30e+01
1.24e+01
1.17e+01
1.11e+01
1.04e+01
9.75e+00
9.10e+00
8.45e+00
7.80e+00
7.15e+00
6.50e+00
5.85e+00
5.20e+00
4.55e+00
3.90e+00
3.25e+00
2.60e+00
1.95e+00
1.30e+00
6.50e-01
0.00e+00
half way up building, fence

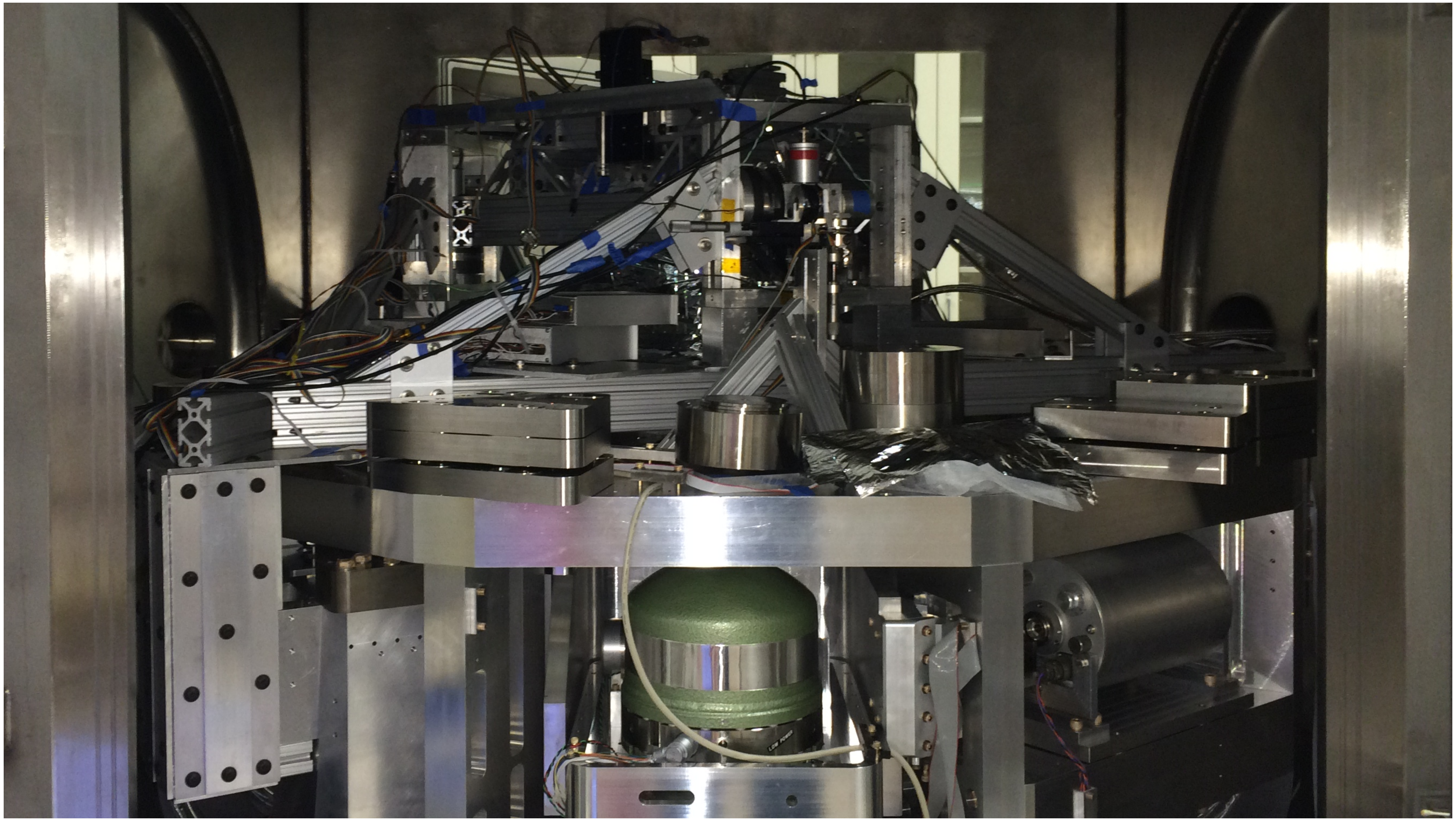
Status

- Parameters used to model the fence seem reasonable
- Fence model predicts 50% effective wind speed reduction
- Collecting data from free stream sensor to compare slab tilt, (analysis has started)
- Hopefully, next meeting we'll have good results from the EX fence, and you'll hear about it during the commissioning talk.

Cryogenics

<u>People who have helped with the update</u>

Edgard Bonilla, Jaimi Salone, Carissa Cirelli, Veronica Guerrero, Odylio Aguiar, Brett Shapiro, Brian Lantz

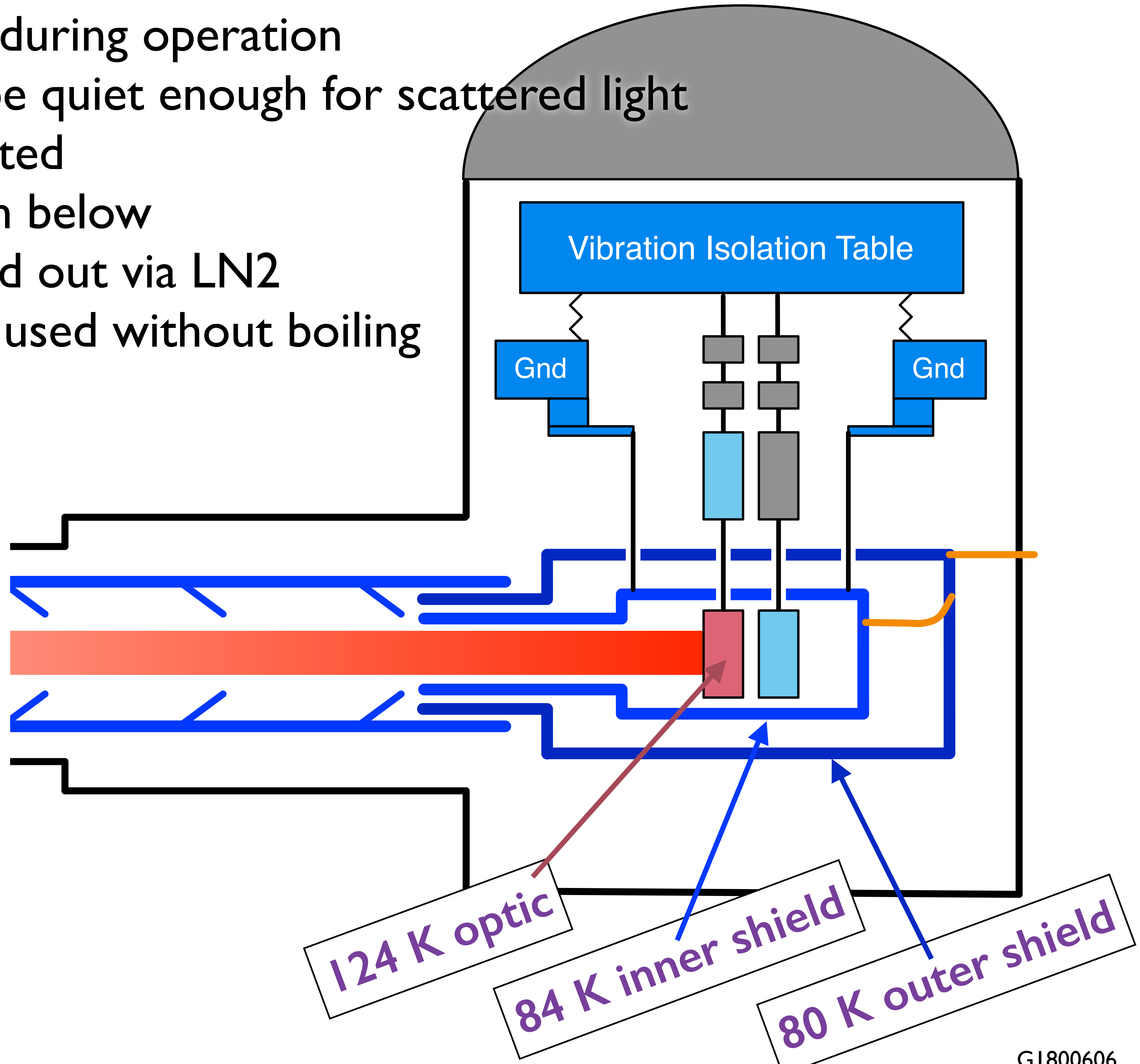


We've reduced the cooling time of our 1 kg silicon 'optic' from 10:47 to 3:08 by using dilute nitrogen gas to improve the thermal conductivity.

Voyager technology

Cool mirror radiatively during operation
Inner shield need only be quiet enough for scattered light
Stanford has demonstrated

1. temperatures shown below
2. heat flow from shield out via LN2
3. LN2 at 63 K can be used without boiling



G1800606

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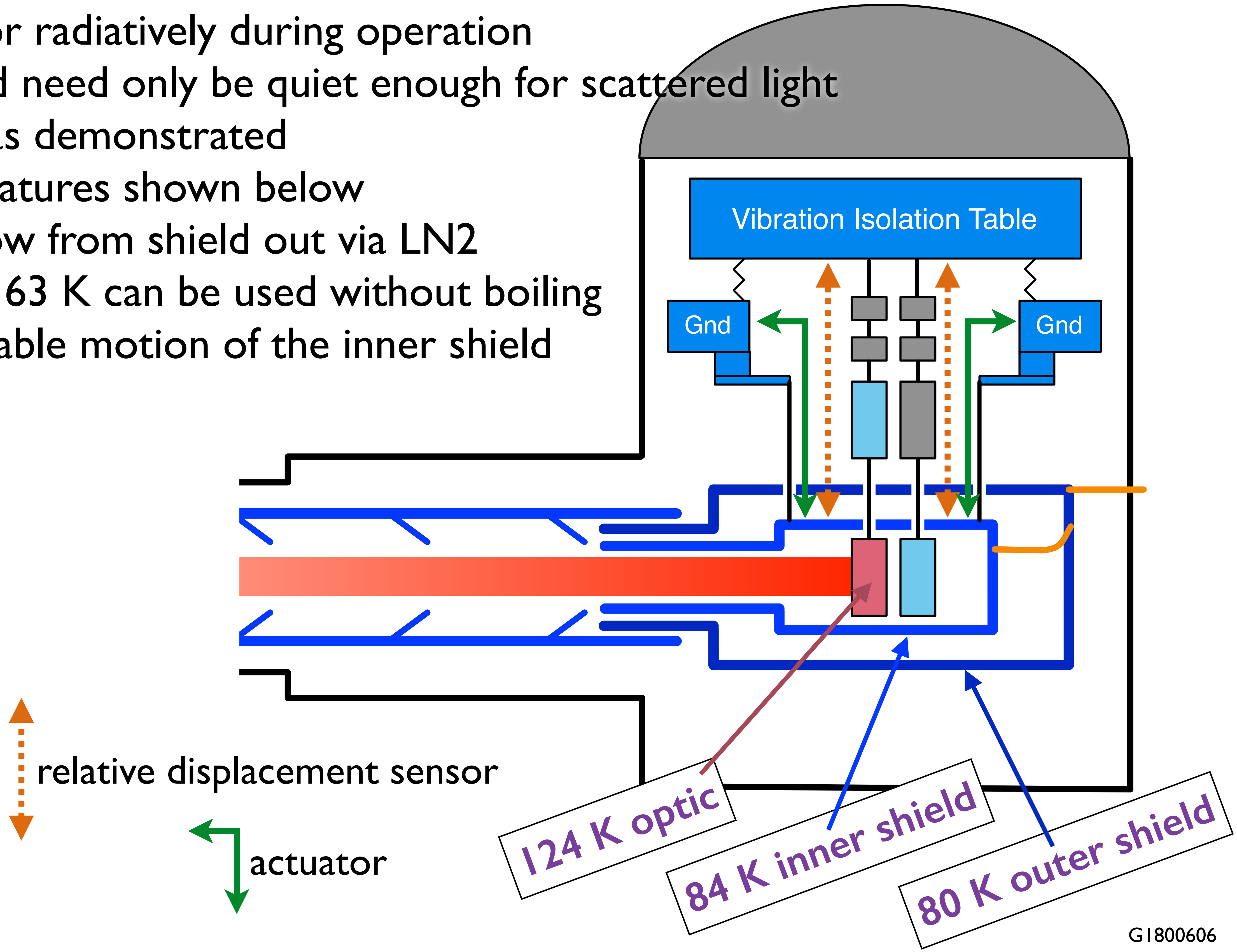

G1800606

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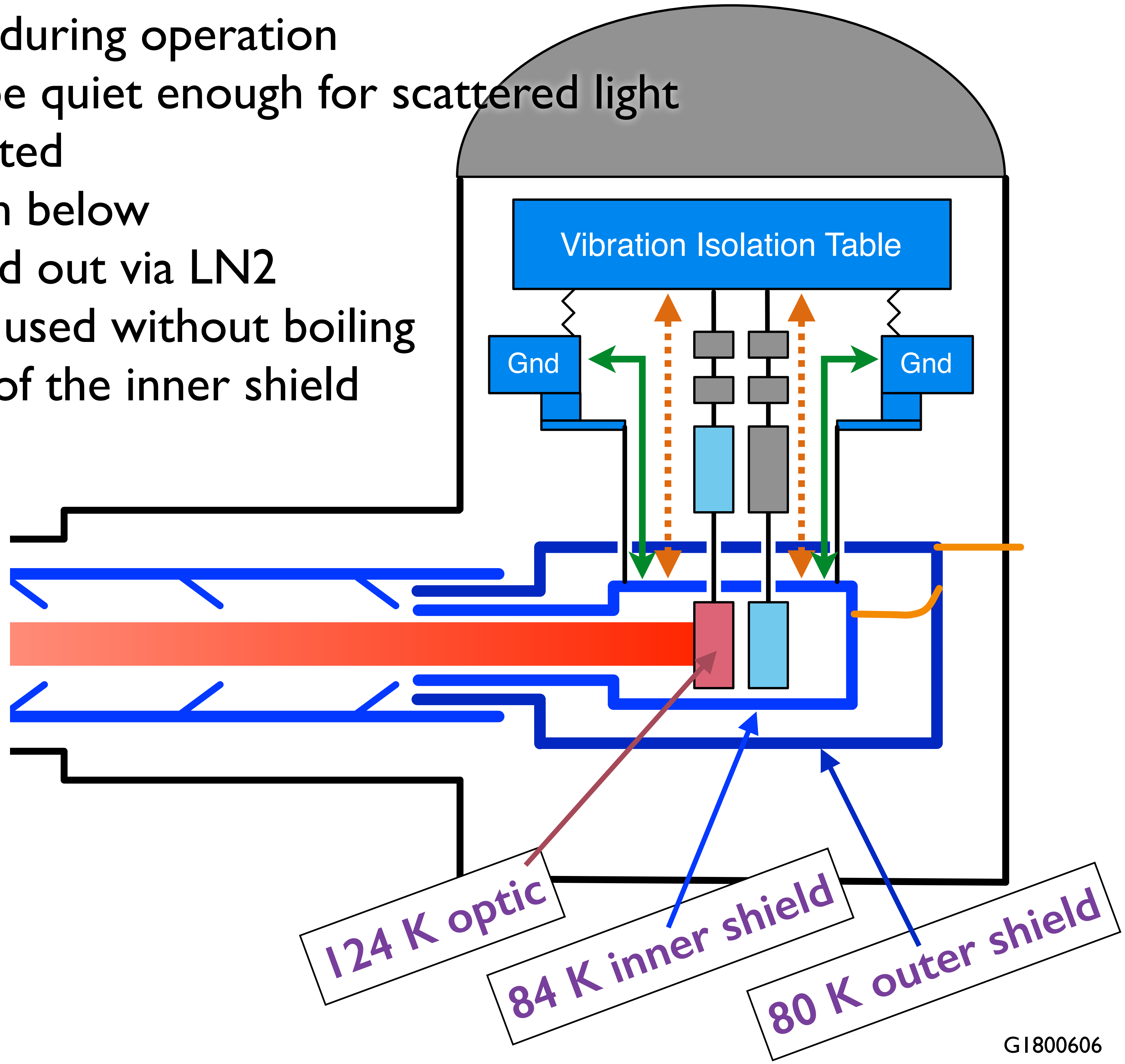
Next
- Improved cooldown with exchange gas



G1800606

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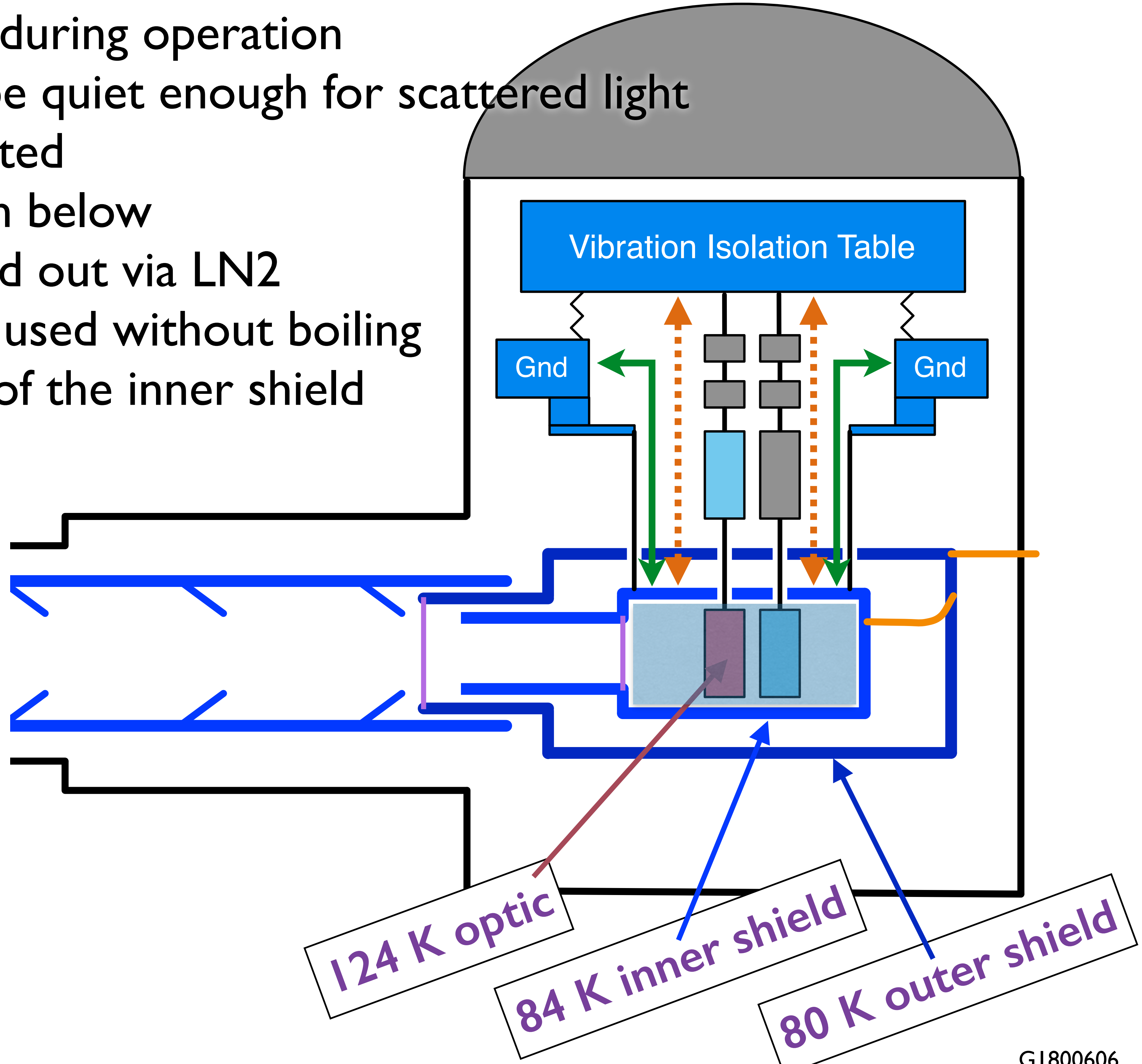
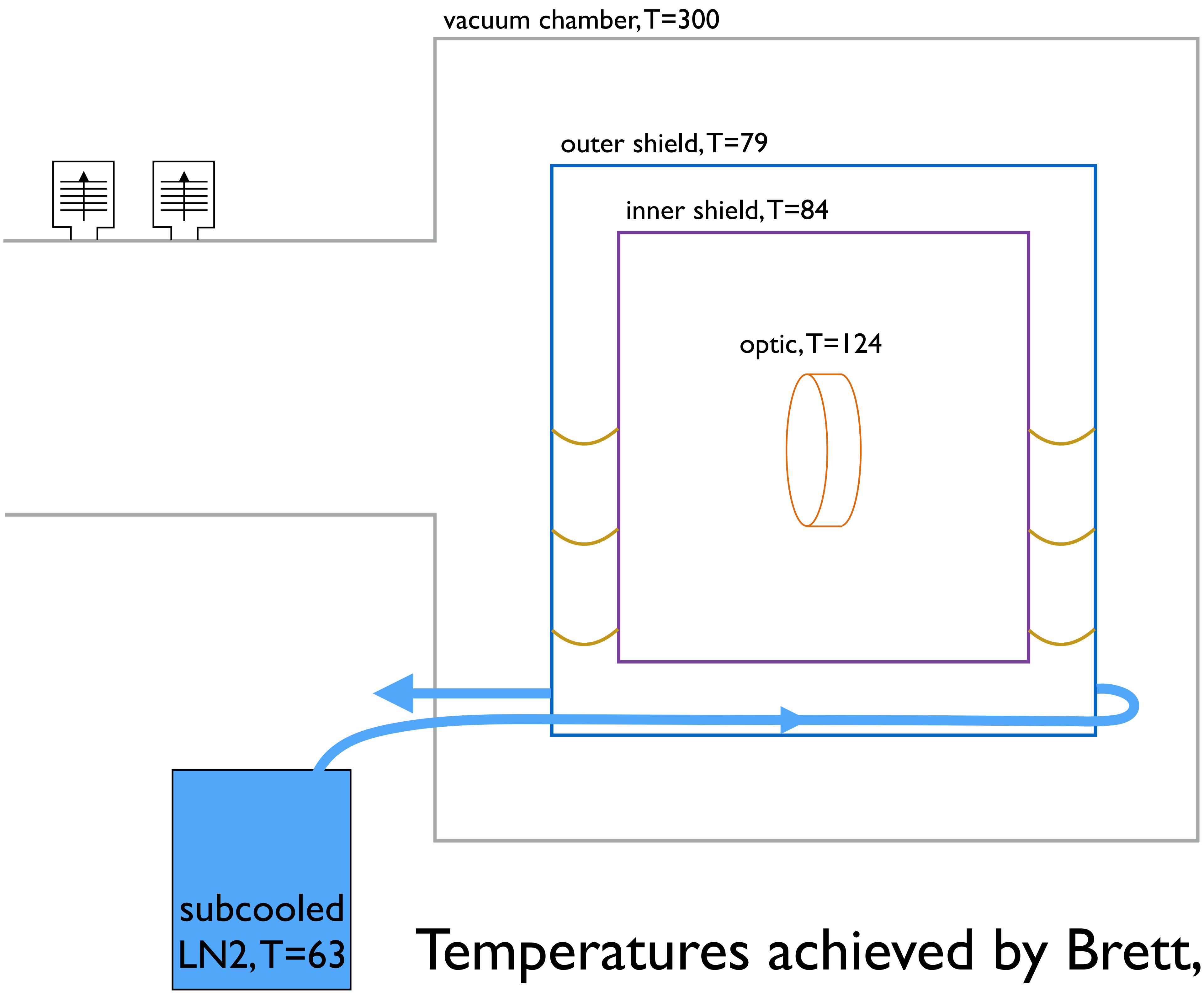


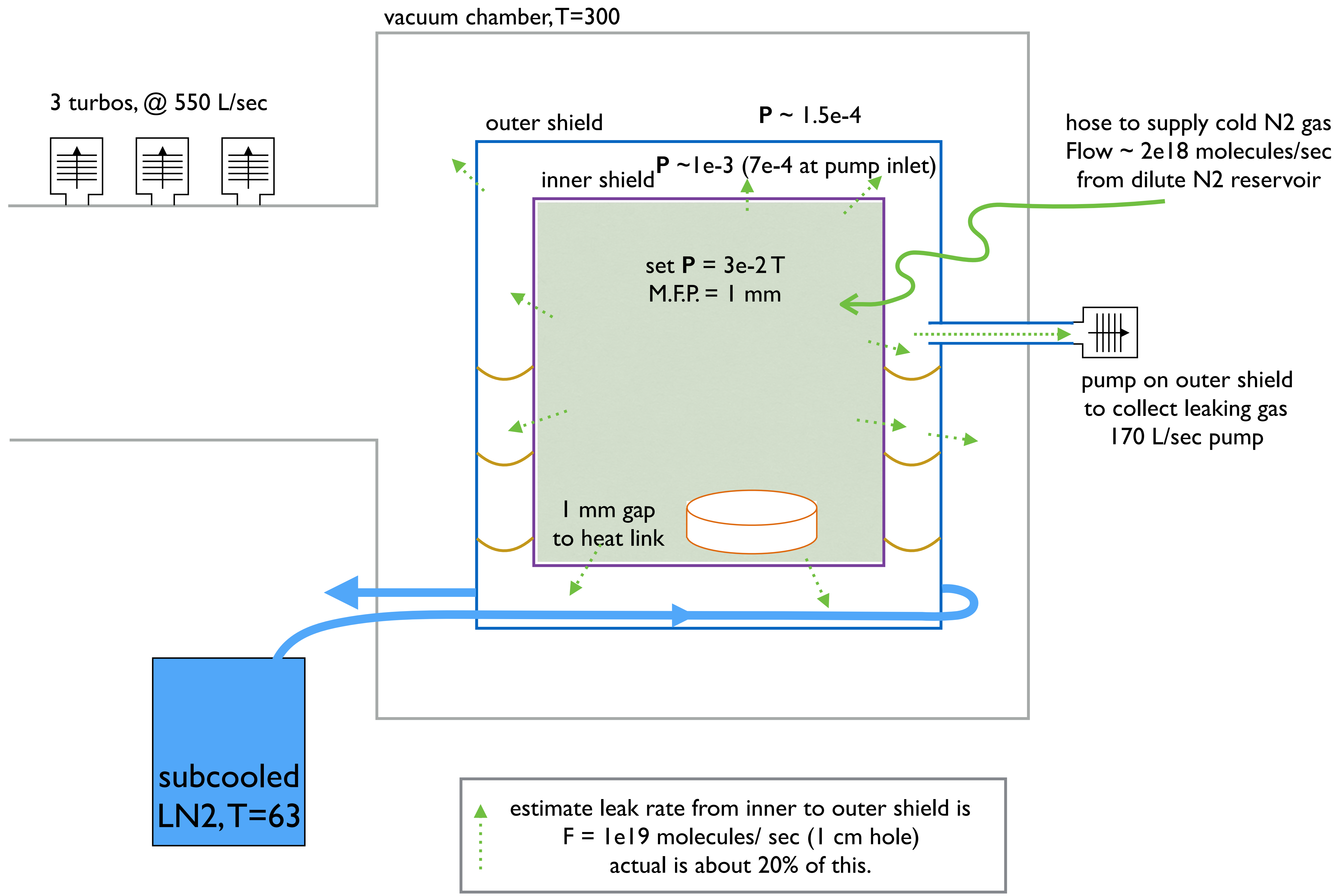
B. Lantz, Aug 14, 2018

Sketch for exchange gas discussion

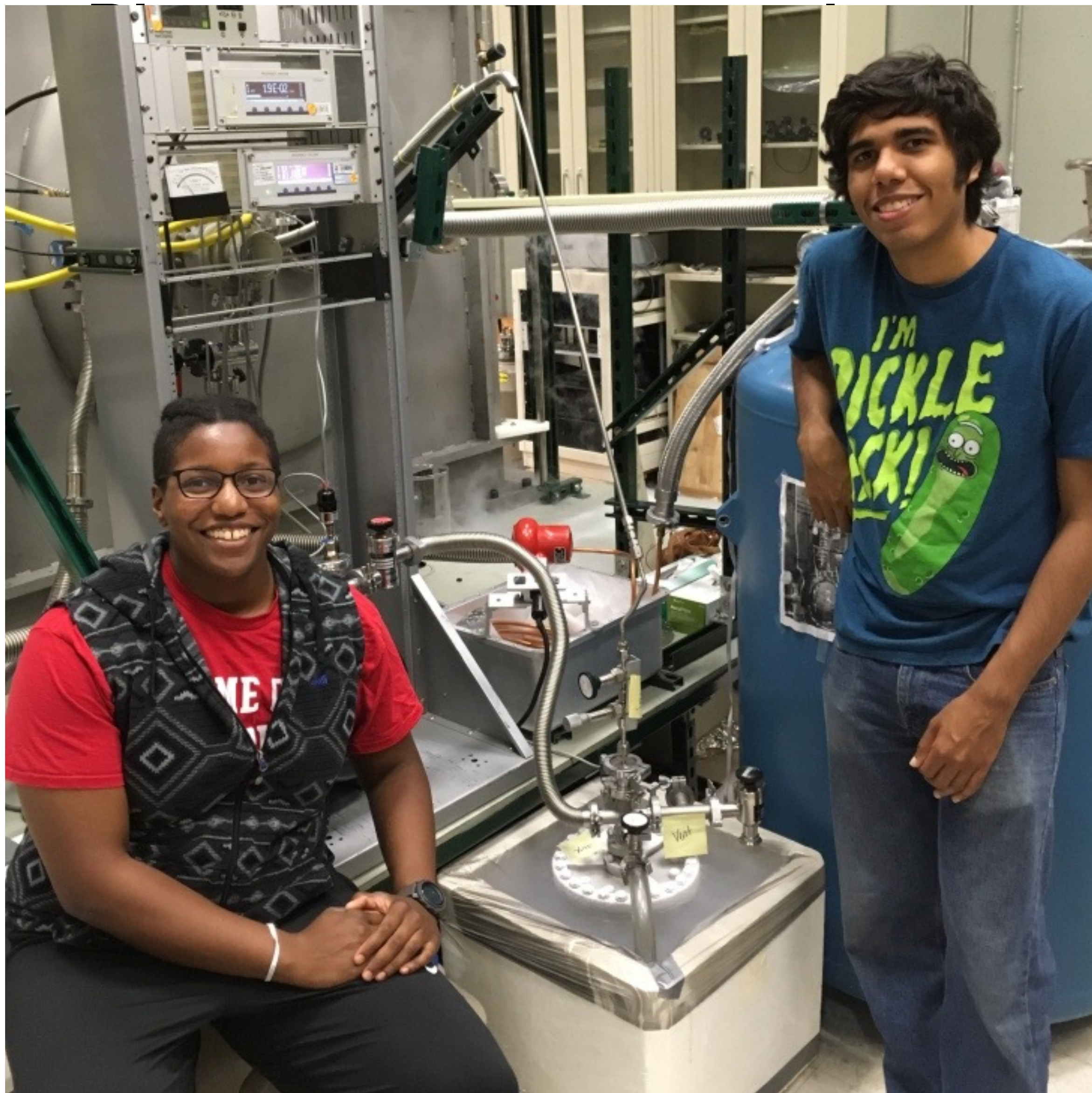


Temperatures achieved by Brett, Marcio, Edgard

Plan to increase cooling rate of optic (now 11 hours for ETF)



Jaimi, Edgard, and the dilute N2 reservoir



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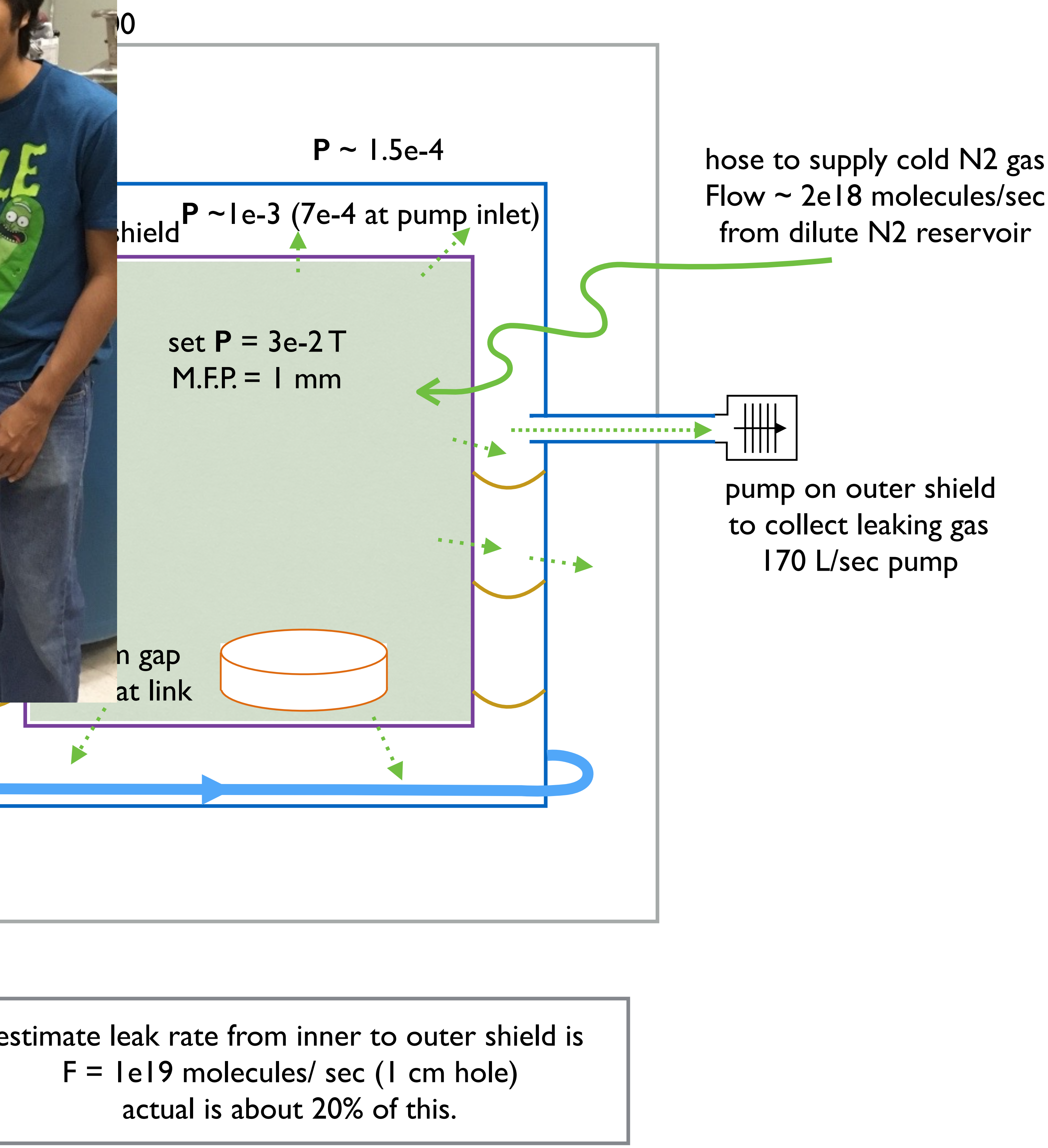
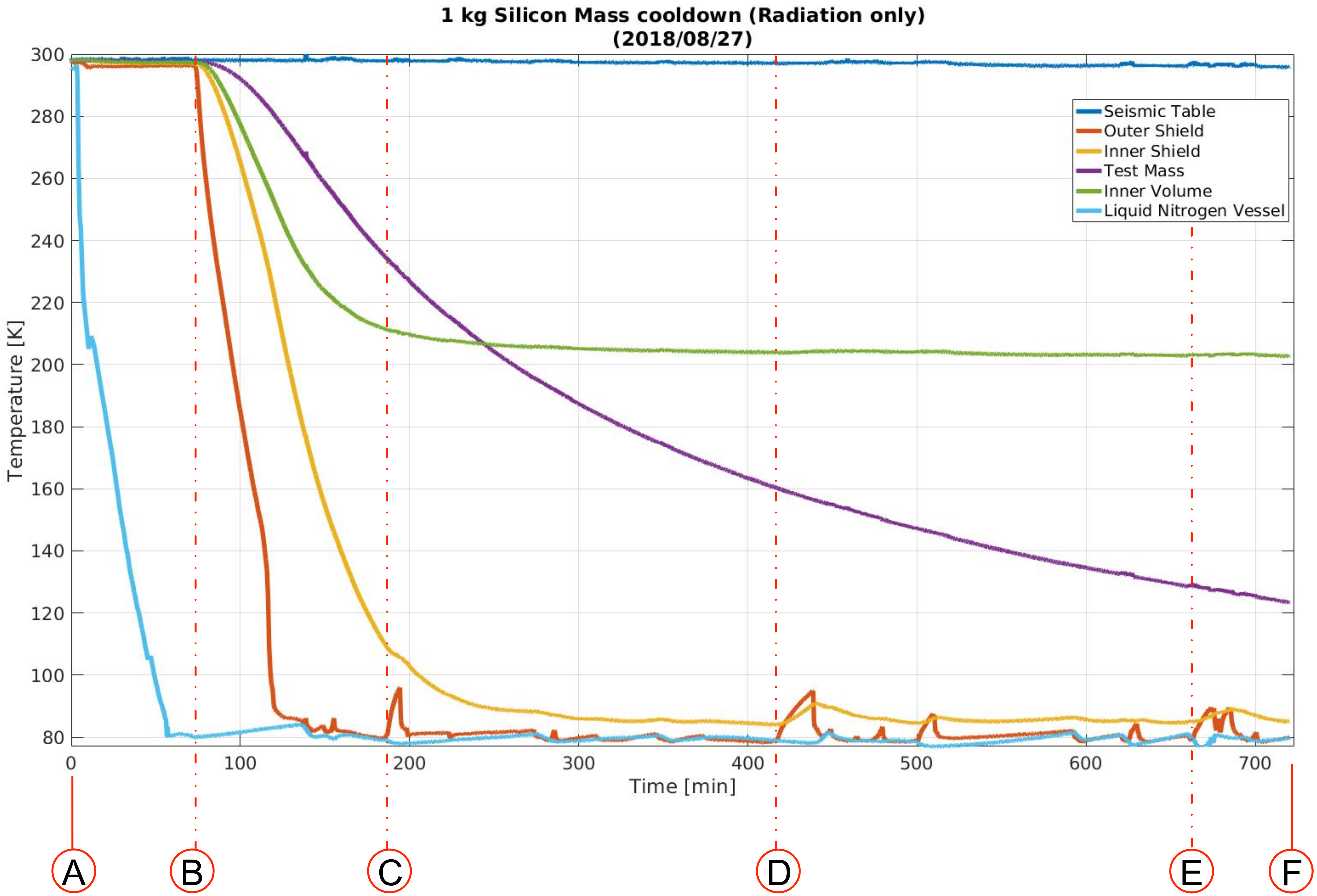


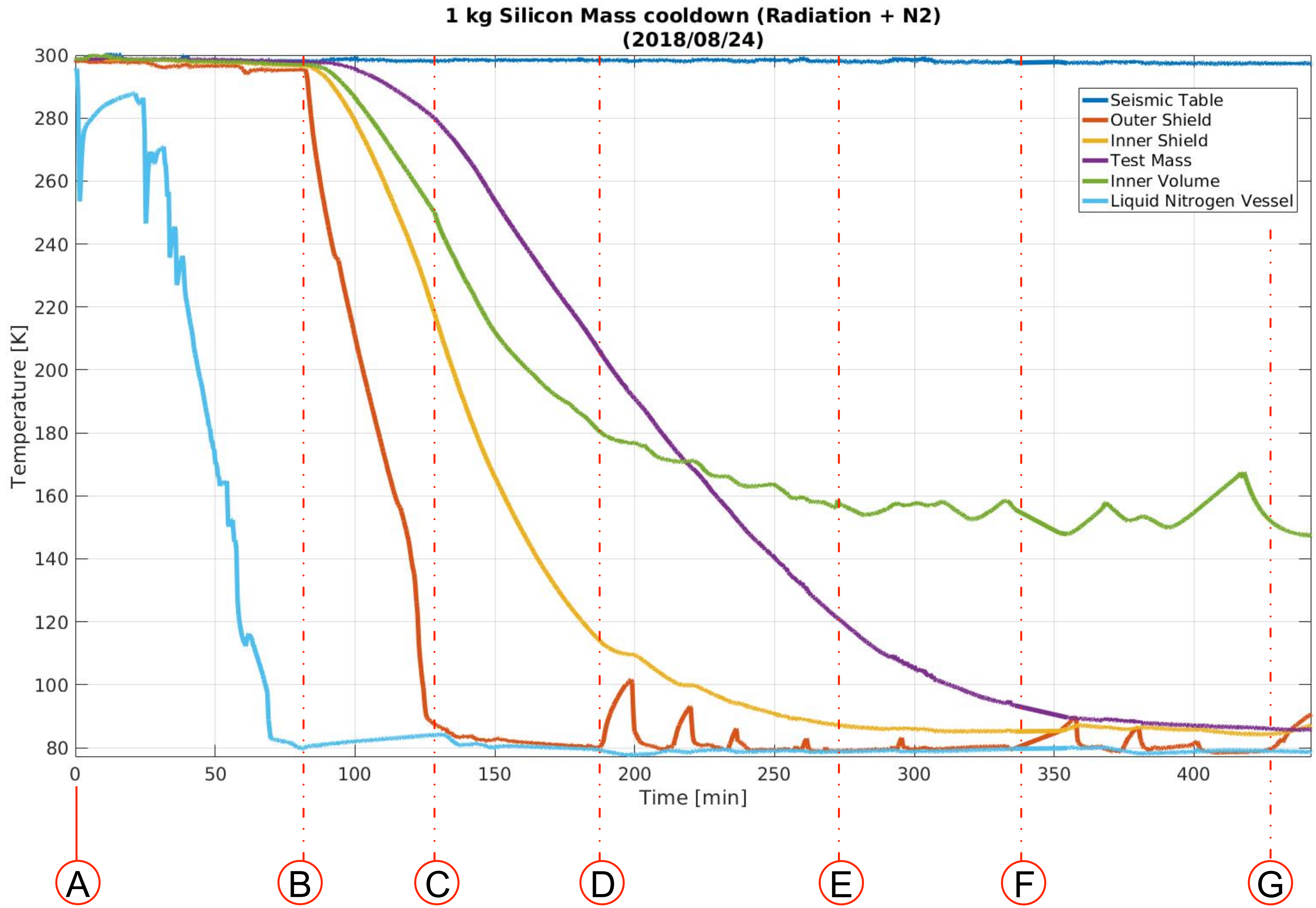
647 minutes to cool the 1 kg silicon w/ radiation



A: Start to fill LN2 vessel (0 min)
B: Start to flow LN2 on the shields (73 min)
C: Vessel is full, switching dewar (180 min)

D: Experiment unattended, finding new dewar (415 min)
E: LN2 vessel is empty (660 min)
F: Target Achieved (720 min)

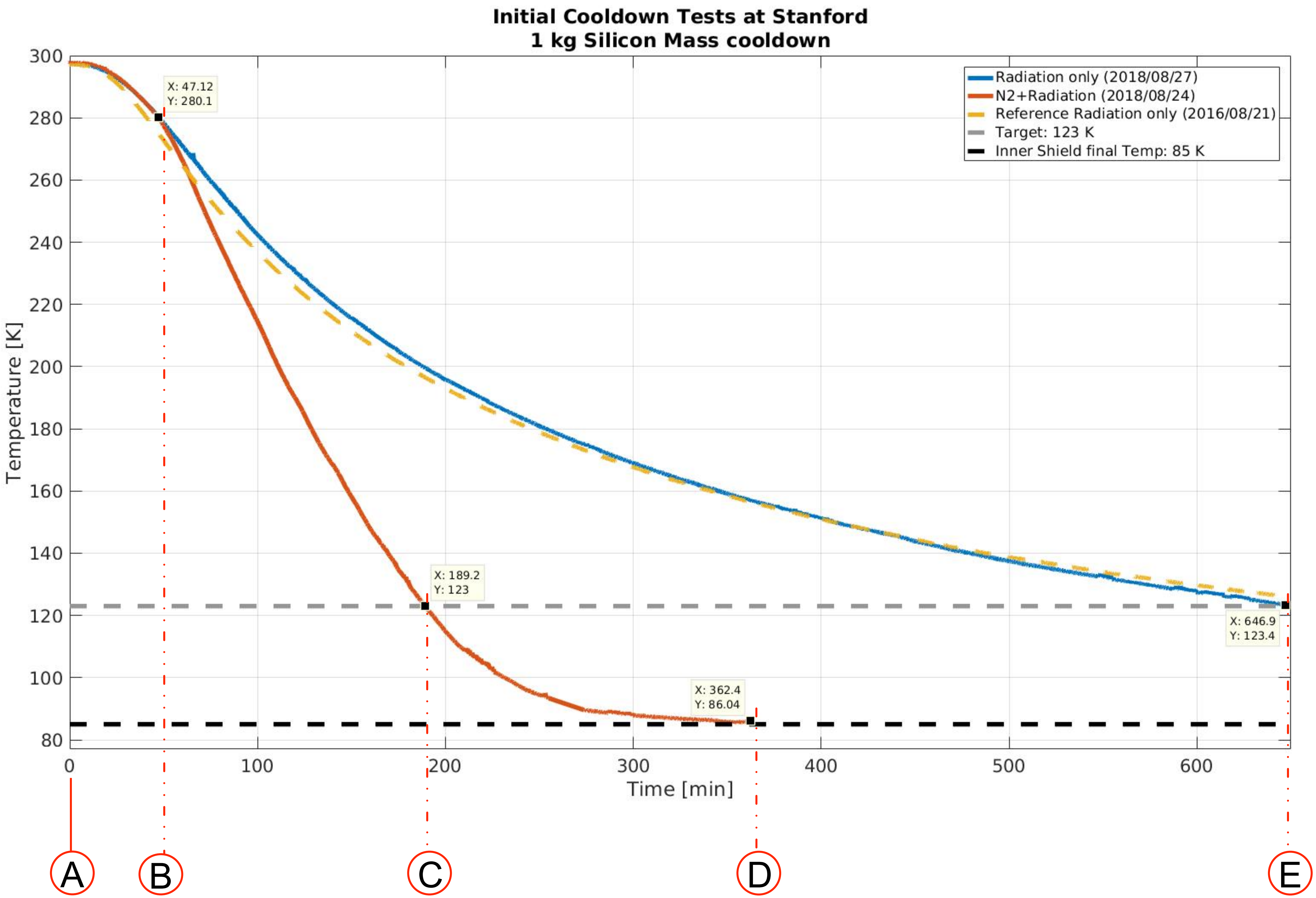
188 minutes to cool the 1 kg silicon w/ radiation



A: Start to fill LN2 vessel (0 min)
B: Start to flow LN2 on the shields (82 min)
C: Start gas injection (129 min)

D: Vessel is full, switching dewar (180 min)
E: Target Achieved (270 min)
F: False Stop (335 min)
G: T~86 K, True Stop (425 min)

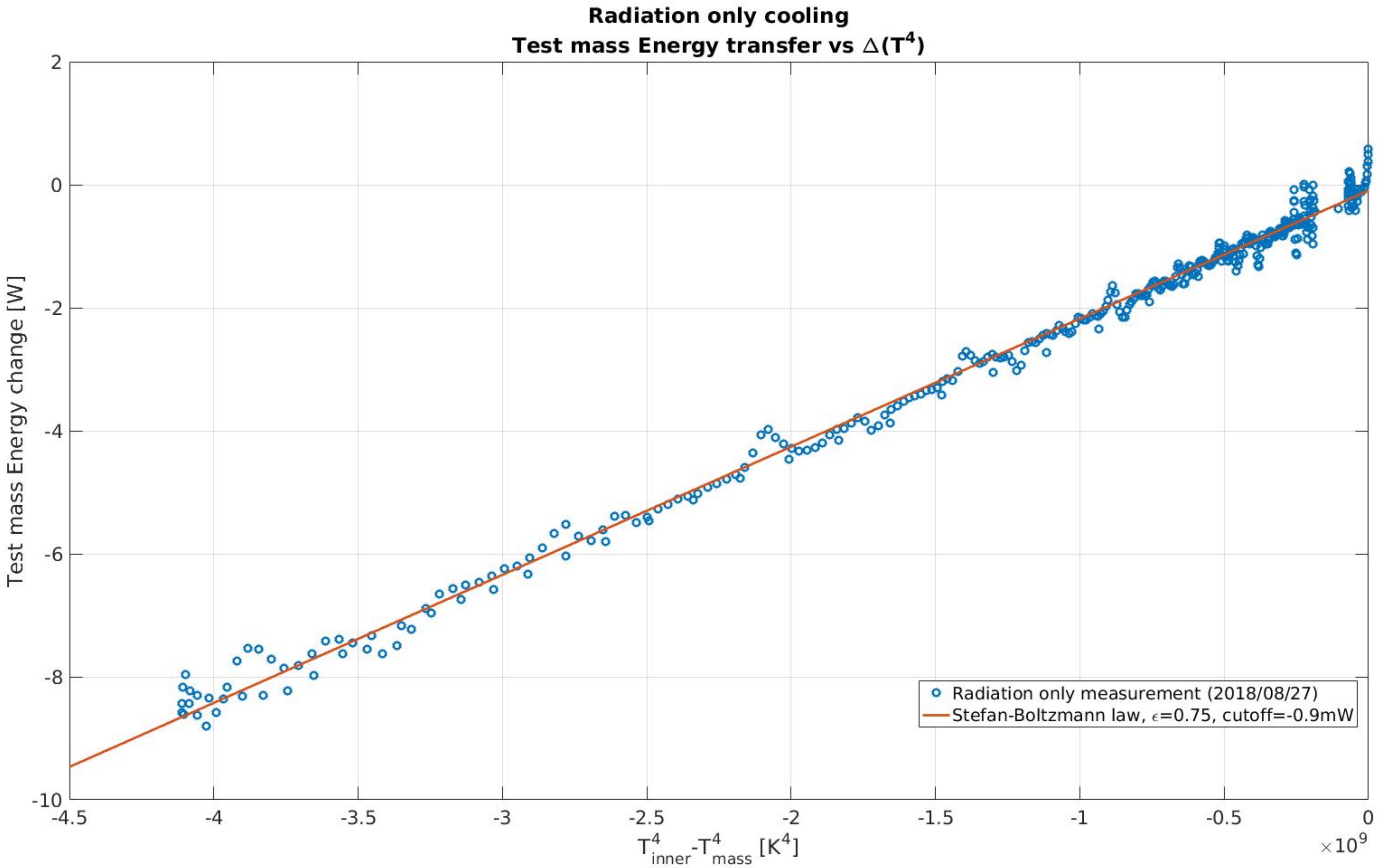
Cooldown comparison



A: Start to flow LN2 on the shields (0 min)
B: Start gas injection (47 min)
C: Gas + Radiation achieves target (189 min)

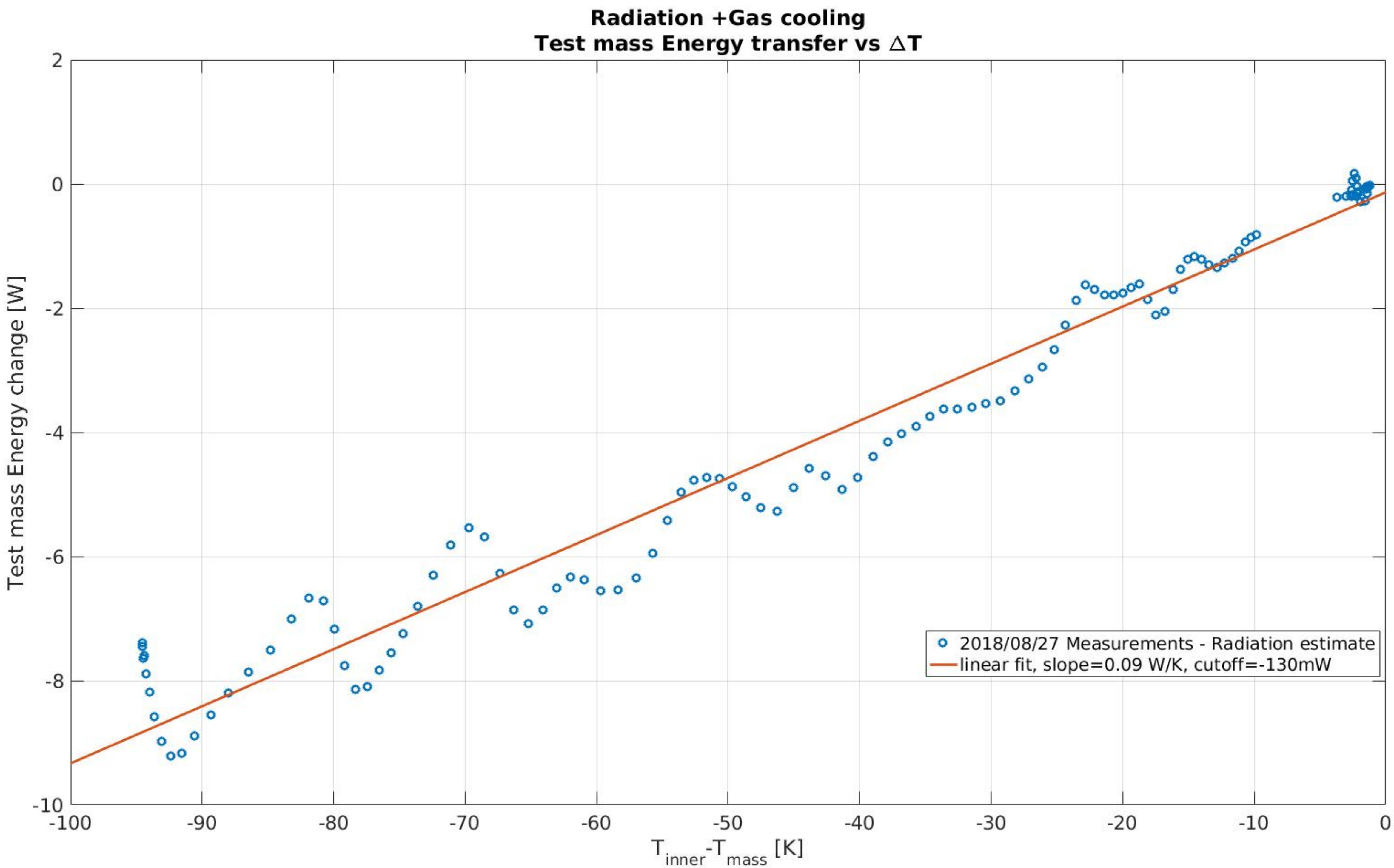
D: Gas+Radiation mass is at 86 K (362 min)
E: Radiation only mass achieves target (646 min)

Fit to radiative coupling



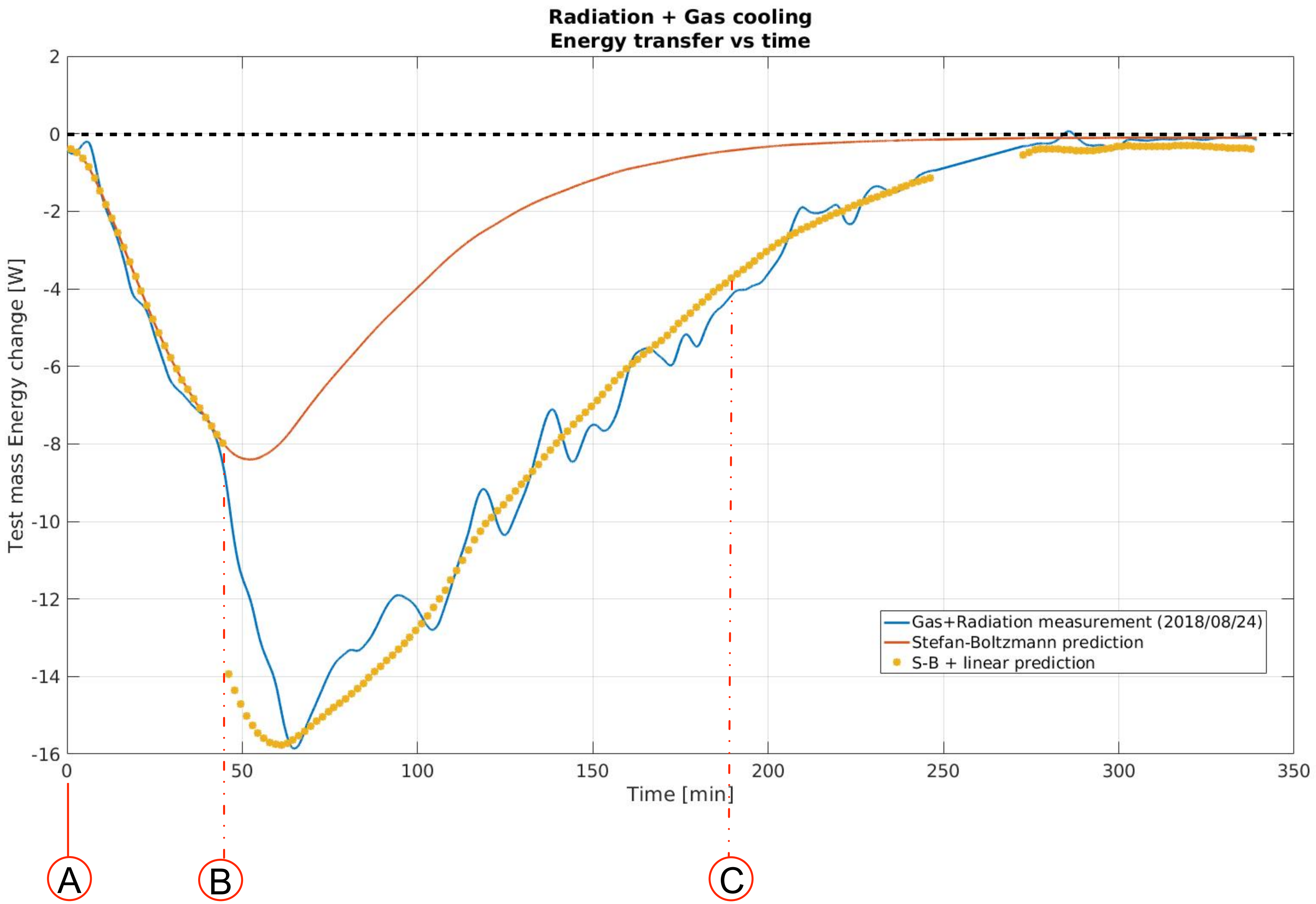
- We are confident that the main mechanism for the cooldown is radiative.
- The 0.75 emissivity is around the value expected, since the 1 kg Silicon mass is coated black everywhere but one face.
- The cutoff here is probably due to the contact with the inner shield through the glass beads.

Fit the gas data



- Preliminary fit. This does not include the pressure information and forces the dependence on the temperature difference.
- The data was treated by eliminating the radiative contribution to the heat transfer.

Heat transfer fits look good



A: Start to flow LN2 on the shields (0 min)
B: Start gas injection (47 min)
C: Target Achieved (189 min)

- The curve cannot be explained by radiative transfer only
- There is a sharp turn on the derivative after gas injection
- The discontinuity of the fit at B is due to the lack of pressure data

Edgard's remarks

- To generate the derivative I used a method called total variation (TV) estimation. I used it, because I wanted to keep sharp features like the one that appears after the gas injection.
- If we use the Free molecular flow model:
  - with the accommodation coefficient =1;
  - P = 3e-2 torr (It fluctuated around this value)
  - If we assume that the temperature of the gas is ~200K (read from sensor)
  - The area in question is a face of our little optic
- Predicted slope = 0.106 W/K
- 'measured' slope= 0.092 W/K (around 10% difference, preliminary)
- If anyone asks for Helium instead of N_2, it turns out that the accommodation coefficient is small enough that it is not worth it to use it in the free-molecular flow regime.

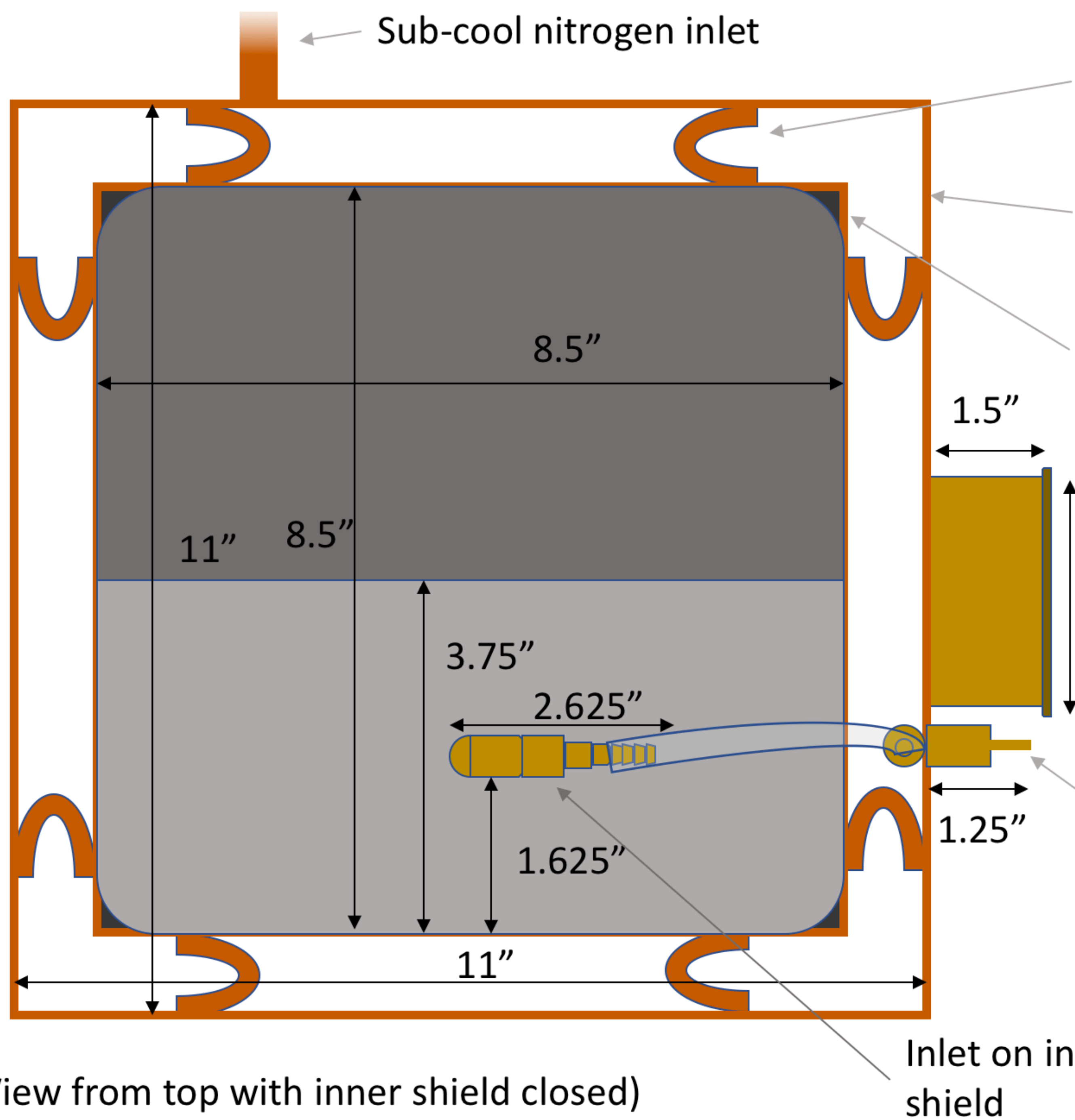
Concluding remarks

- We’ve demonstrated a number of critical pieces of technology
- There is much more to do
  (an optic on the bottom of a closed box is not an interferometer)
- Our next step is to run all the parts together
- Need to take a step back and think about choices
  - single pass nitrogen is good for simple tests,
  terrible for everything else.

space from optic to shield set by 3,
1 mm diameter glass beads

Plumbing and wiring

Shield Diagram

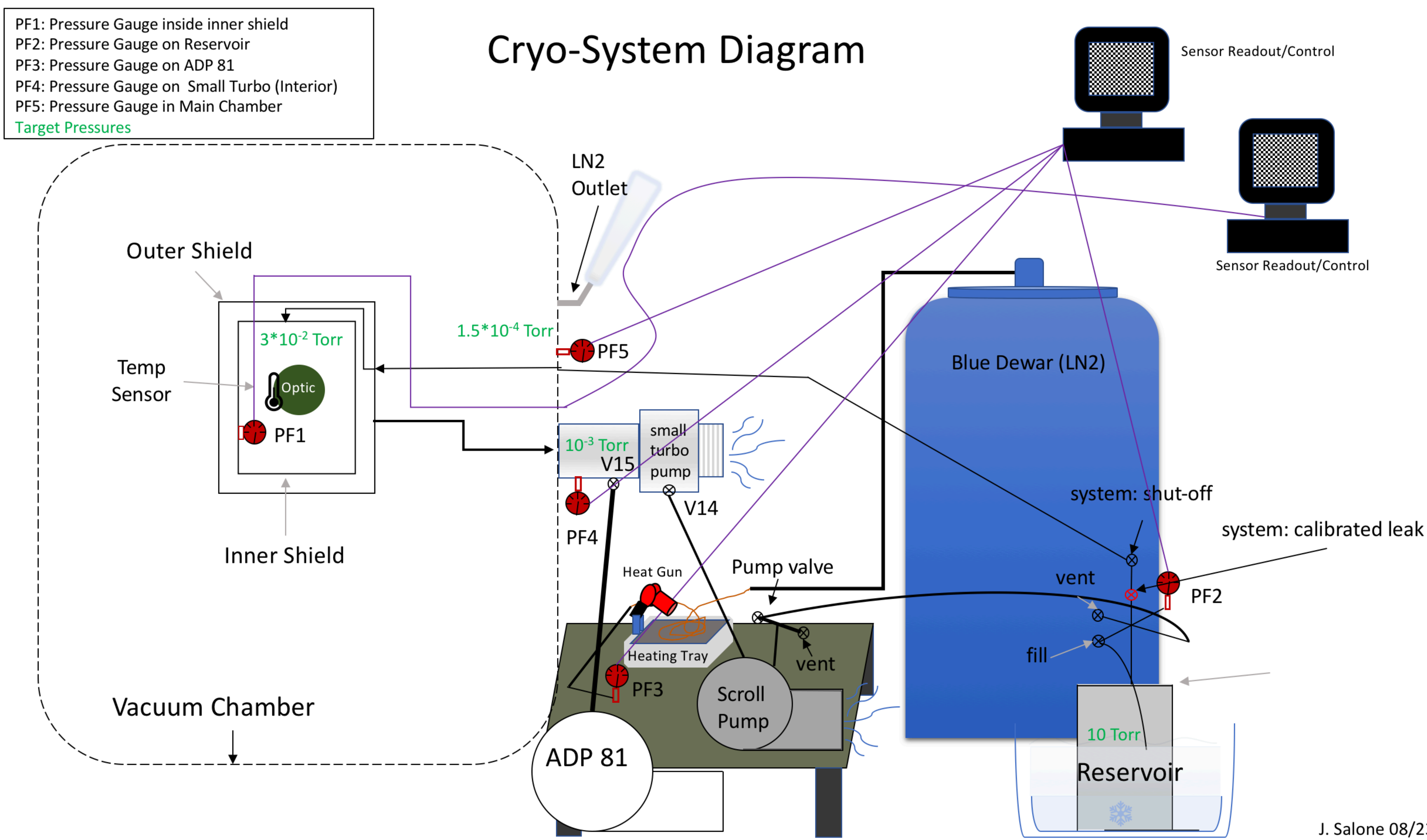


(View from top with inner shield closed)

*Electric feedthrough not included in diagram

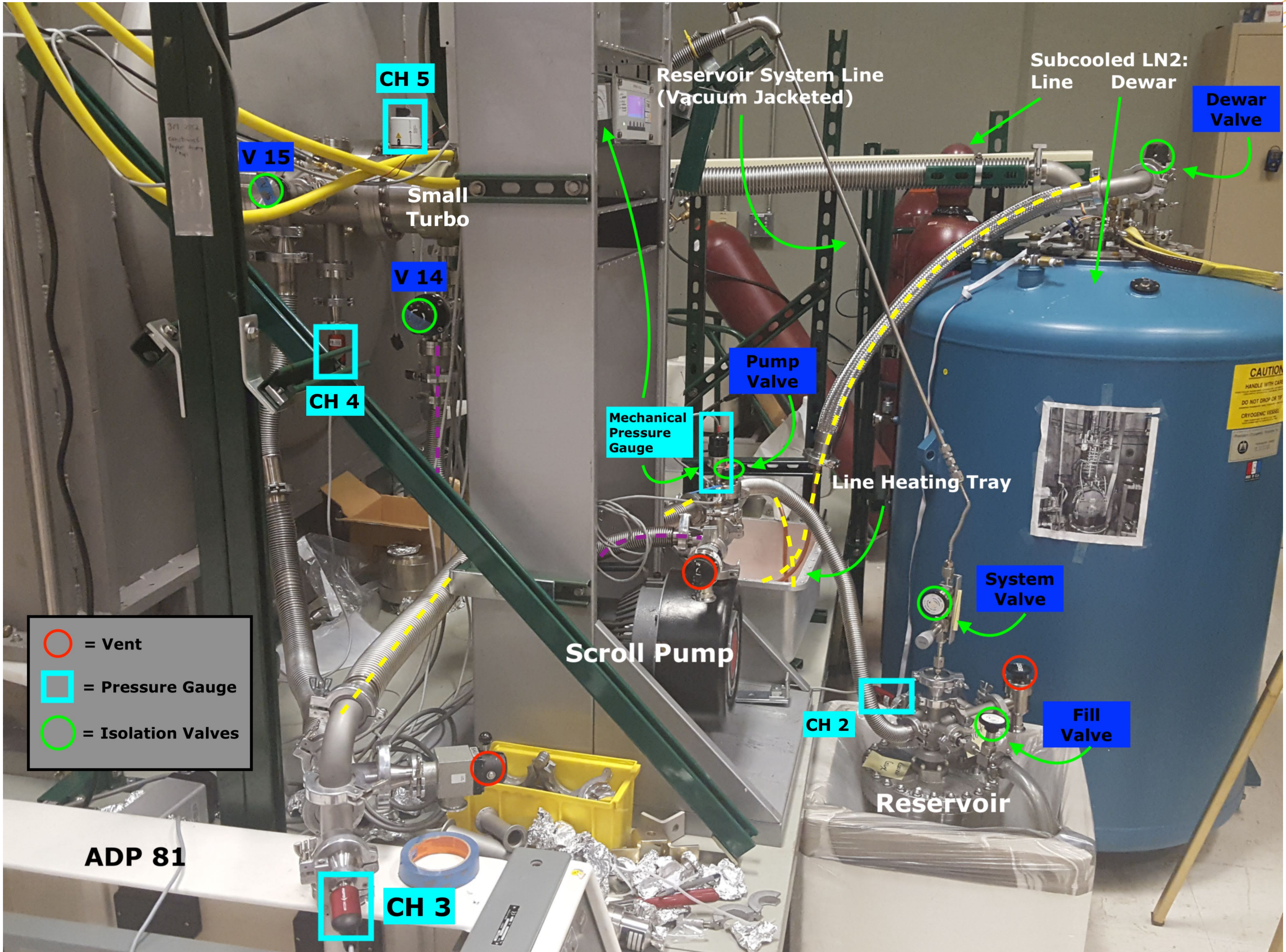
J. Salone 08/02/18

more plumbing



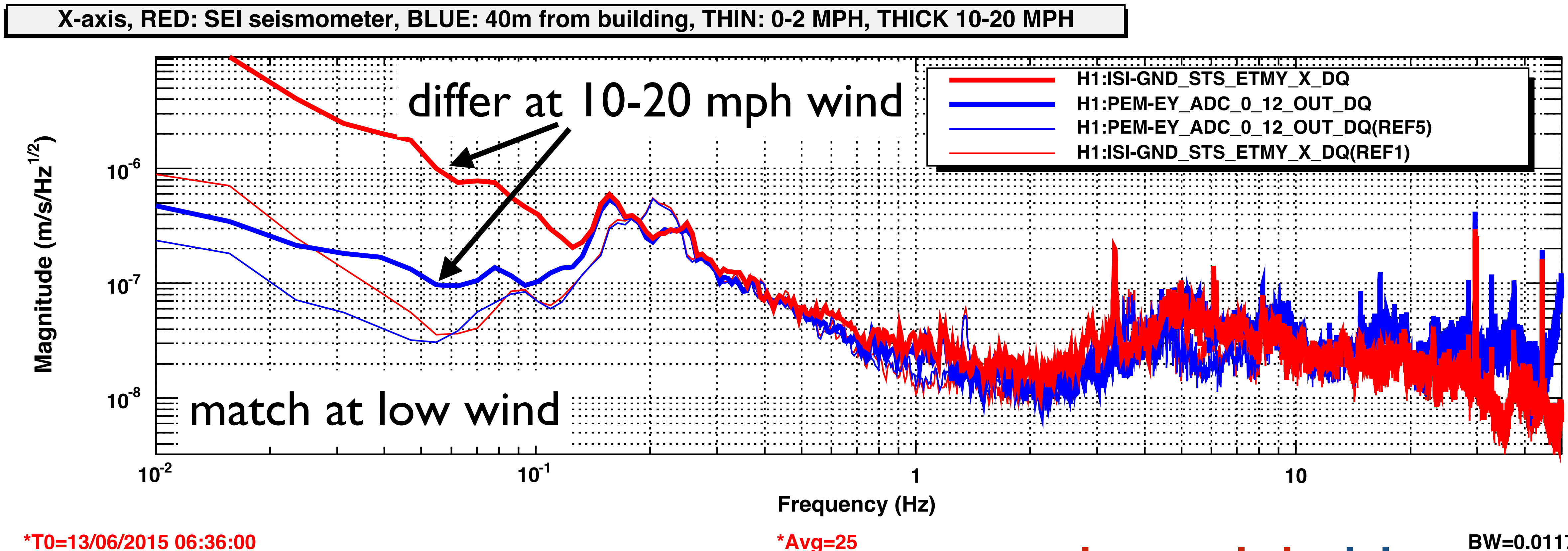
J. Salone 08/23/18

more plumbing



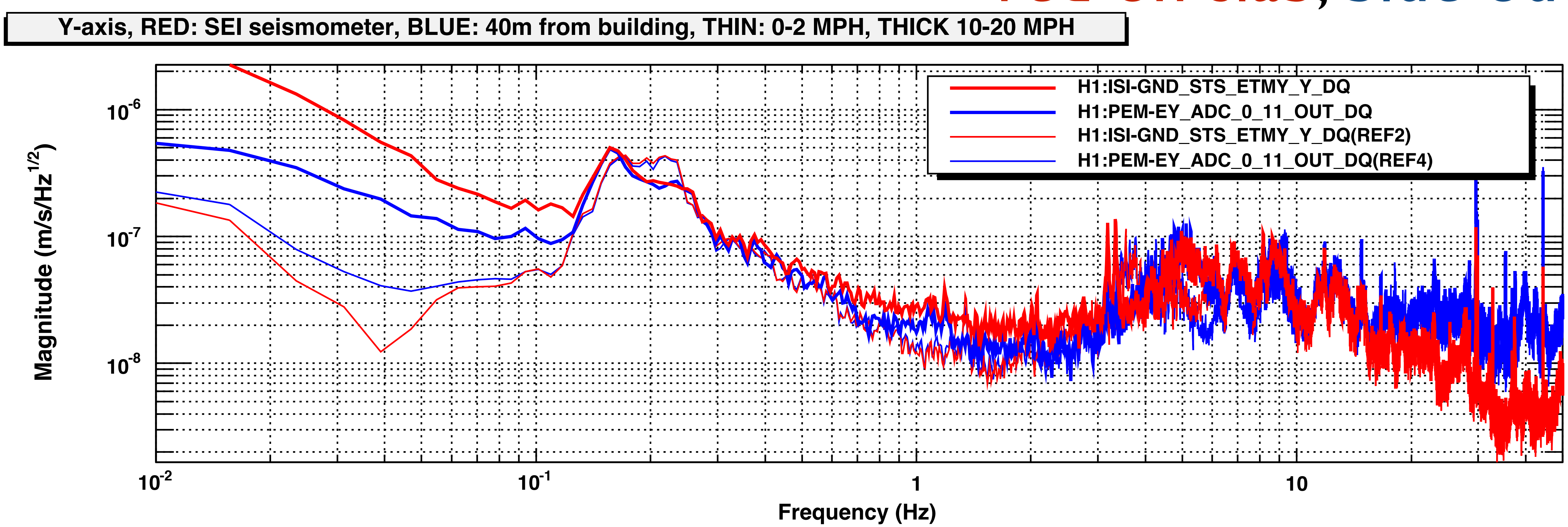
Robert's outdoor STS-2

X



red on slab, blue outside

Y

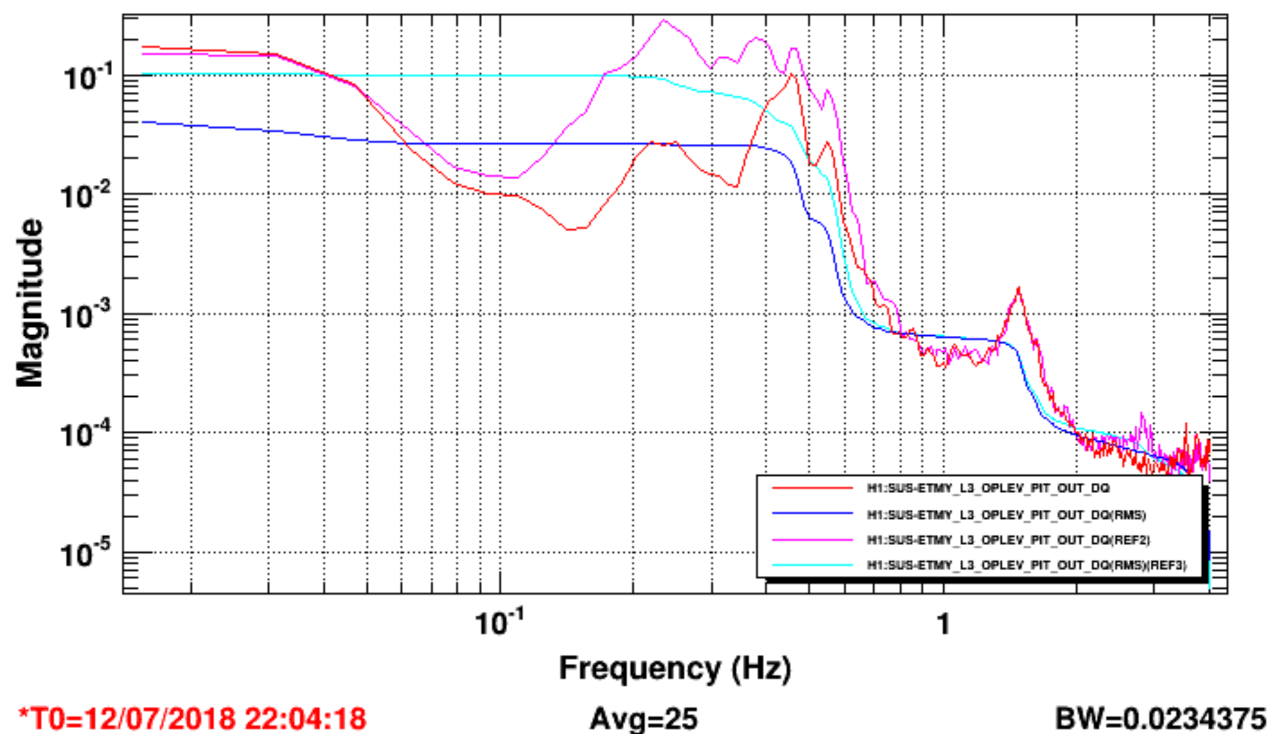


LHO log 19210, June 17, 2015. STS-2 in a 1 m deep hole 40 m from EY

ISI->M0 FF -- x2.5 reduction in pitch rms achieved

LHO log 42875, Hang Yu, Edgard Bonilla, Jeff Kissel

oplev pitch, ETMY, improved by FF



- (SUS-ETMY_SUSPOINT_ETMY_EUL_L_DQ --> SUS-ETMY_L3_OPLEV_PIT_OUT_DQ) / (SUS-ETMY_M0_TEST_P_OUT --> SUS-ETMY_L3_OPLEV_PIT_OUT_DQ),

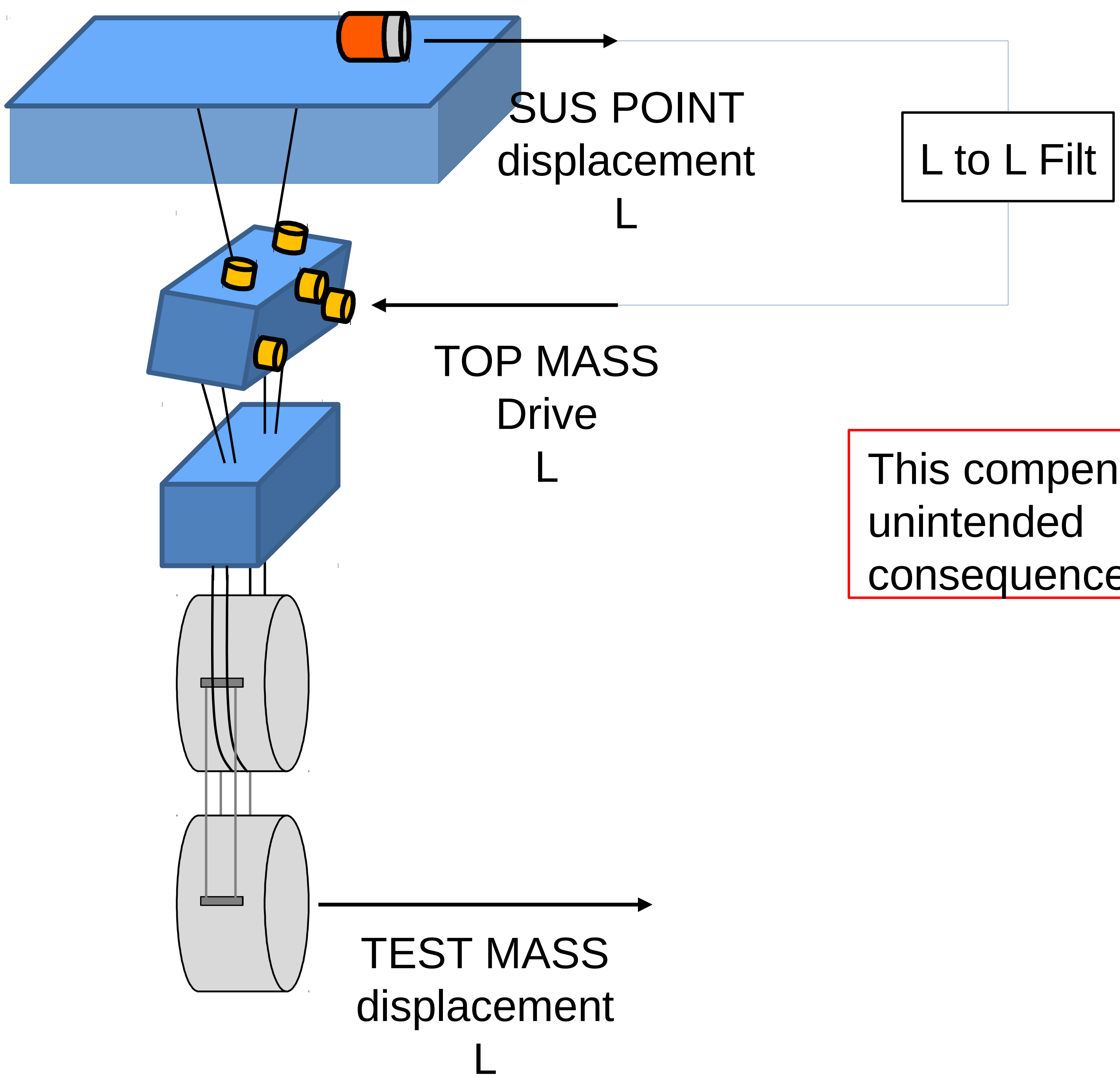
ISI to SUS Feedforward

Edgard Bonilla, Hang Yu, Jeff Kissel, Jim Warner,
Conor Mow-Lowry, Brian Lantz, et. al.

Reminder of Edgard's talk in March (G1800467):

- There is coherence at the microseism between DARM and ISI-Suspension point motion combined like DARM
- Coherence exists in Length and Pitch
- By applying a simple (scalar) correction from ISI Suspension-point Length to SUS-topmass Length & Pitch, you should be able to get about 3x improvement in DARM Length.

ISI to SUS feedforward

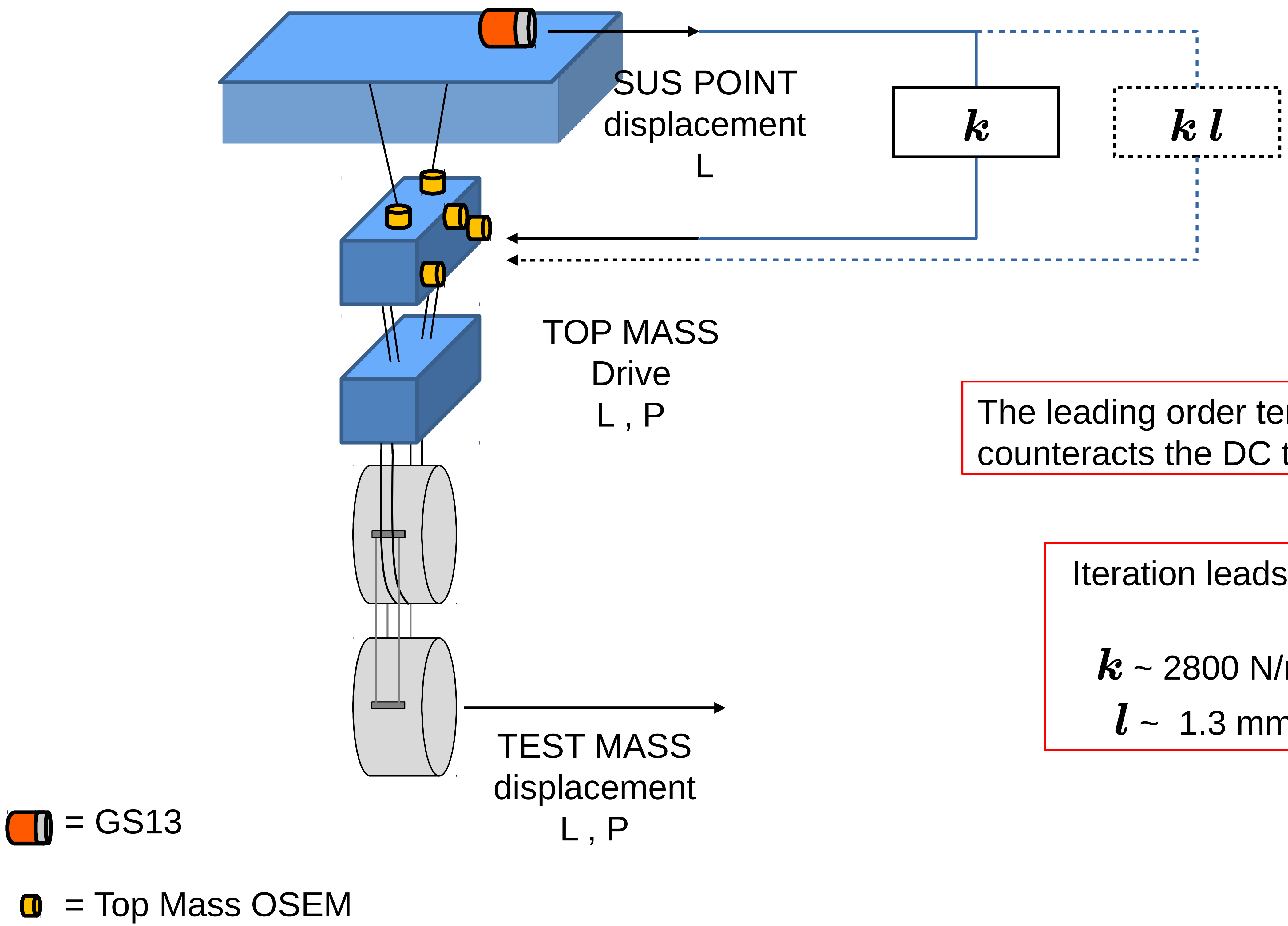


This compensation has unintended consequences...

= GS13

= Top Mass OSEM

ISI to SUS feedforward



The leading order term counteracts the DC torque

Iteration leads to:

$\boldsymbol{k}$ ~ 2800 N/m

$\boldsymbol{l}$ ~ 1.3 mm

Feedforward Update

Update:

- Pitch is worth fixing.
- Length is worth fixing if/ because
  it reduces the ISC Length drive which couples to pitch.
- Edgard went to try it at LHO, some success, more work is pending.

Details:

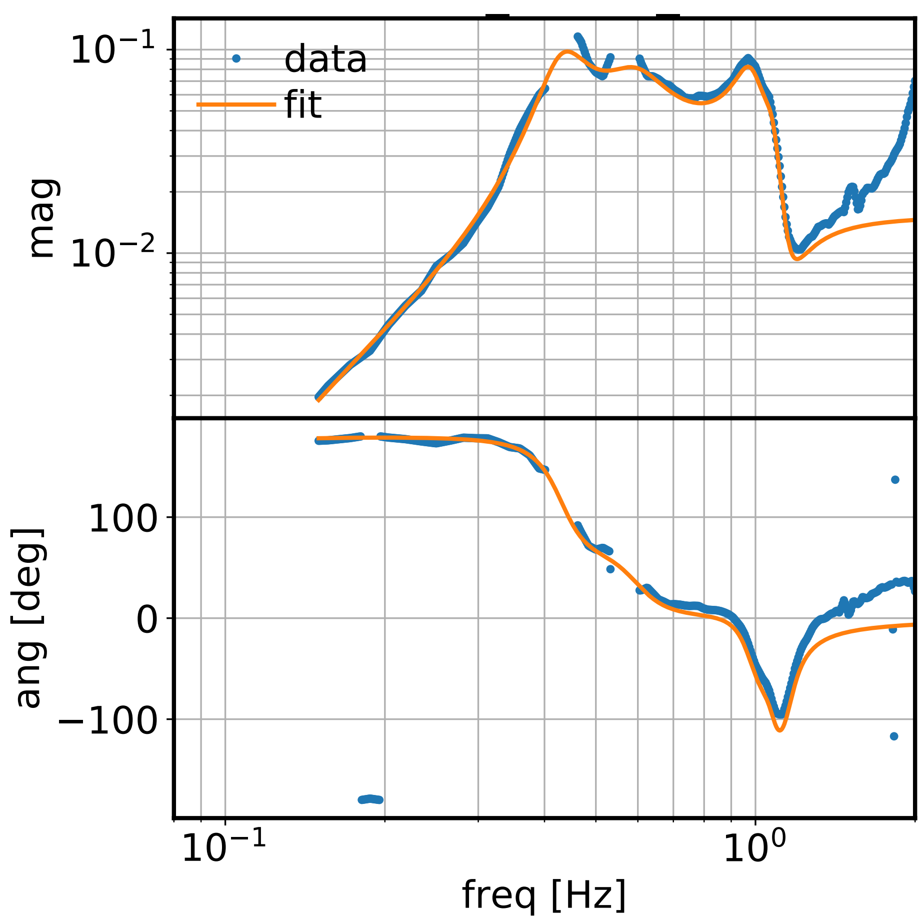
- First attempt pushed ISI into oscillation, because ISI rx & ry feedback loops
  stage 2 (optical table) are AC coupled right now.
- Pushing against the SUS tilts the ISI.
- This is under discussion.
- In the meantime, Hang & Edgard made fancy ISI-Length -> SUS pitch filters

Performance on a SUS

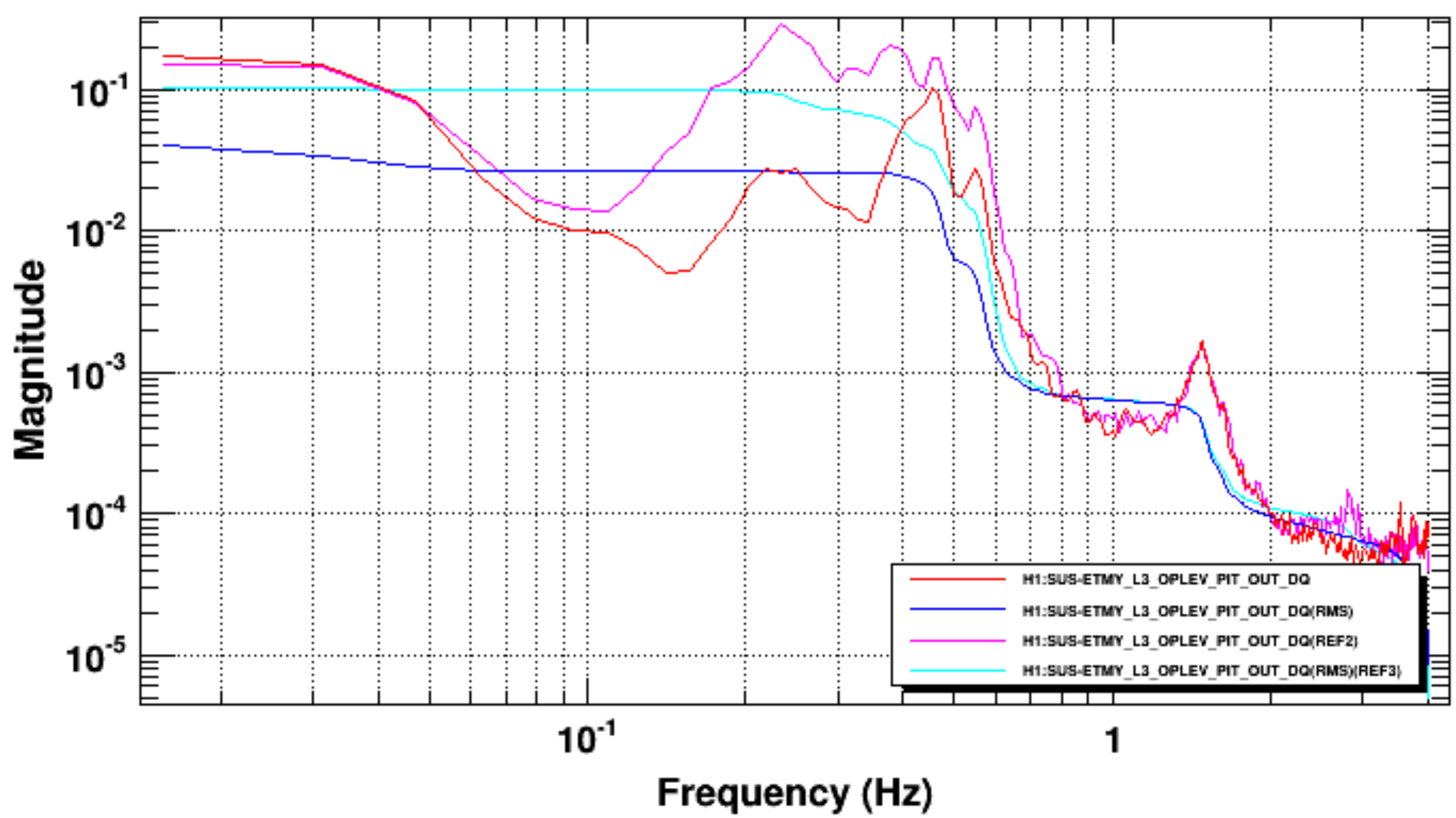
When you do the fitting of the feedforward TF this well using good data and new IIRational fitting tool..

you can get performance like this, with improvements from 0.1 to 0.6 Hz and reduction of rms at 0.1 by ~3.

Suspension Point L -> ISI Pitch



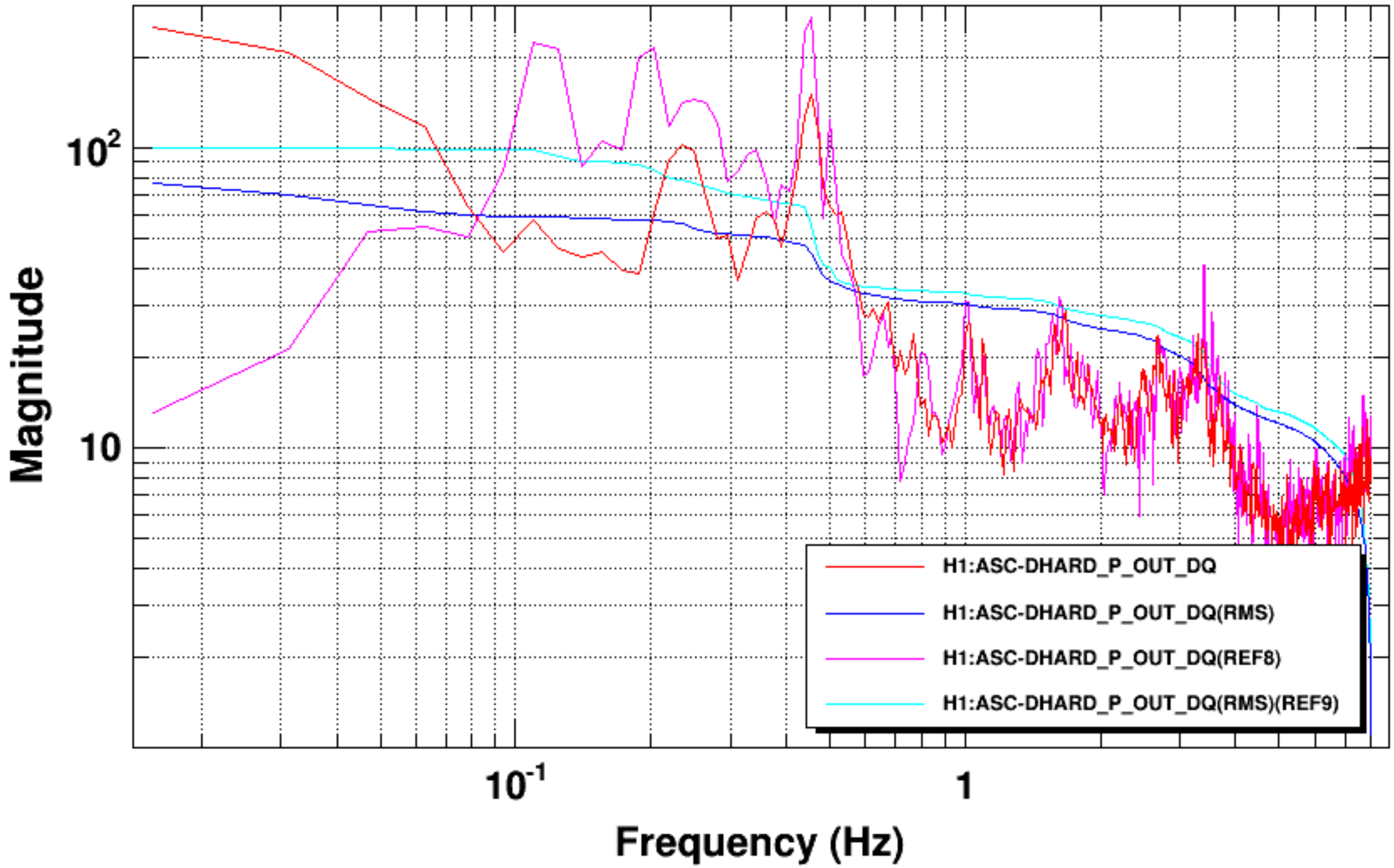
Optical Lever Pitch, ETMY, improved by FF



LHO log 42875, Hang Yu, Edgard Bonilla, Jeff Kissel

Impact on the IFO

Pitch motion in the IFO



ISIFF reducing DHARD ctrl

Hang Yu, https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=43480

Jeff K., Edgard, Lee (by providing IIRrational for fitting), Hang

Feedforward plans

Try the feedforward with rx/ ry loops ON & measure the feedforward performance.

Do a noise calculation to correctly trade ISI tilt against feedforward perform
Look at noise impact of DC coupling rx/ ry loops, vs

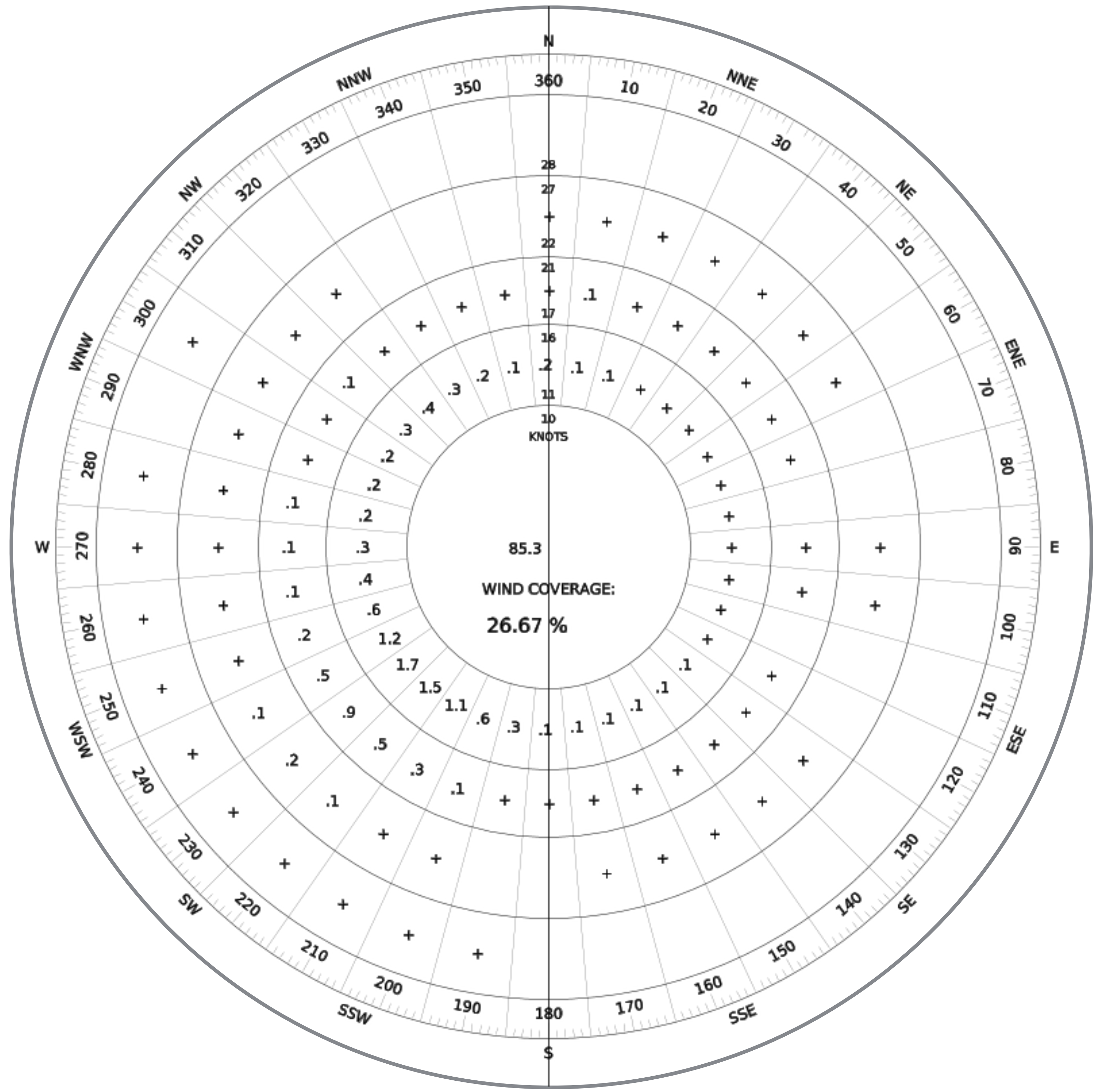
FAA tabulated data for Pasco Airport, high winds come from SW

HOURLY OBSERVATIONS OF WIND SPEED (KNOTS)

DIRECTION	0-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	> 41	TOTAL
10°	521	948	146	121	46	7	0	0	0	1789
20°	322	641	99	86	42	7	0	0	0	1197
30°	227	387	56	45	14	6	0	0	0	735
40°	184	295	33	24	15	1	0	0	0	552
50°	202	280	38	18	7	6	0	0	0	551
60°	186	296	27	11	4	1	0	0	0	525
70°	226	316	17	9	3	0	0	0	0	571
80°	269	397	28	8	0	0	0	0	0	702
90°	329	532	41	10	1	1	0	0	0	914
100°	313	562	65	16	2	1	0	0	0	959
110°	311	626	72	34	0	0	0	0	0	1043
120°	279	609	118	44	2	0	0	0	0	1052
130°	271	715	159	67	4	1	0	0	0	1217
140°	240	751	200	83	6	1	0	0	0	1281
150°	192	652	158	77	11	1	0	0	0	1091
160°	177	579	141	64	20	4	0	0	0	985
170°	145	572	154	70	20	4	0	0	0	965
180°	150	672	250	129	16	0	0	0	0	1217
190°	182	872	467	282	26	0	3	0	0	1832
200°	167	1023	776	551	98	8	3	1	0	2627
210°	168	1113	939	981	239	26	2	3	0	3471
220°	177	1123	1131	1337	497	106	13	4	0	4388
230°	230	957	1054	1581	837	219	25	2	0	4905
240°	188	816	769	1103	479	117	18	0	0	3490
250°	170	641	466	518	147	38	4	1	0	1985
260°	157	544	289	335	92	17	6	0	0	1440
270°	189	487	224	249	88	14	4	0	0	1255
280°	235	567	173	162	53	15	7	2	0	1214
290°	346	805	204	151	28	4	0	0	0	1538
300°	421	1220	287	188	29	3	1	0	0	2149
310°	578	1607	457	311	64	7	0	0	0	3024
320°	751	1874	494	355	45	8	0	0	0	3527
330°	887	2000	520	270	17	0	0	0	0	3694
340°	927	2097	434	176	9	0	0	0	0	3643
350°	829	1984	345	129	12	0	0	0	0	3299
360°	701	1432	210	145	23	2	0	0	0	2513
Calm	24493									24493
TOTAL	36340	30992	11041	9740	2996	625	86	13	0	91833

SOURCE: "727845 TRI-CITIES AIRPORT ANNUALPERIOD RECORD 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 "

REFERENCE: Appendix 1 of AC 150/5300-13, Airport Design, including Changes 1 through 17.


N
NNE
NE
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KNOTS
85.3
WIND COVERAGE:
26.67 %