PoF/SoF optical fiber qualification at SDSMT

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Outline

- Standard QA/QC procedure
  - visual inspection
  - light transparency test
  - power test
- Stress testing of the optical fibers
  - Thermal stress in LN2 (fiber assembly)
  - Stress over the PTFE tube and eight fibers
  - PTFE tube straightening tube using heat gun
- Power loss studies
  - Bending radius in AIR and LN2
  - Dependence on temperature
- Materials testing in LN2

Standard QA/QC procedure

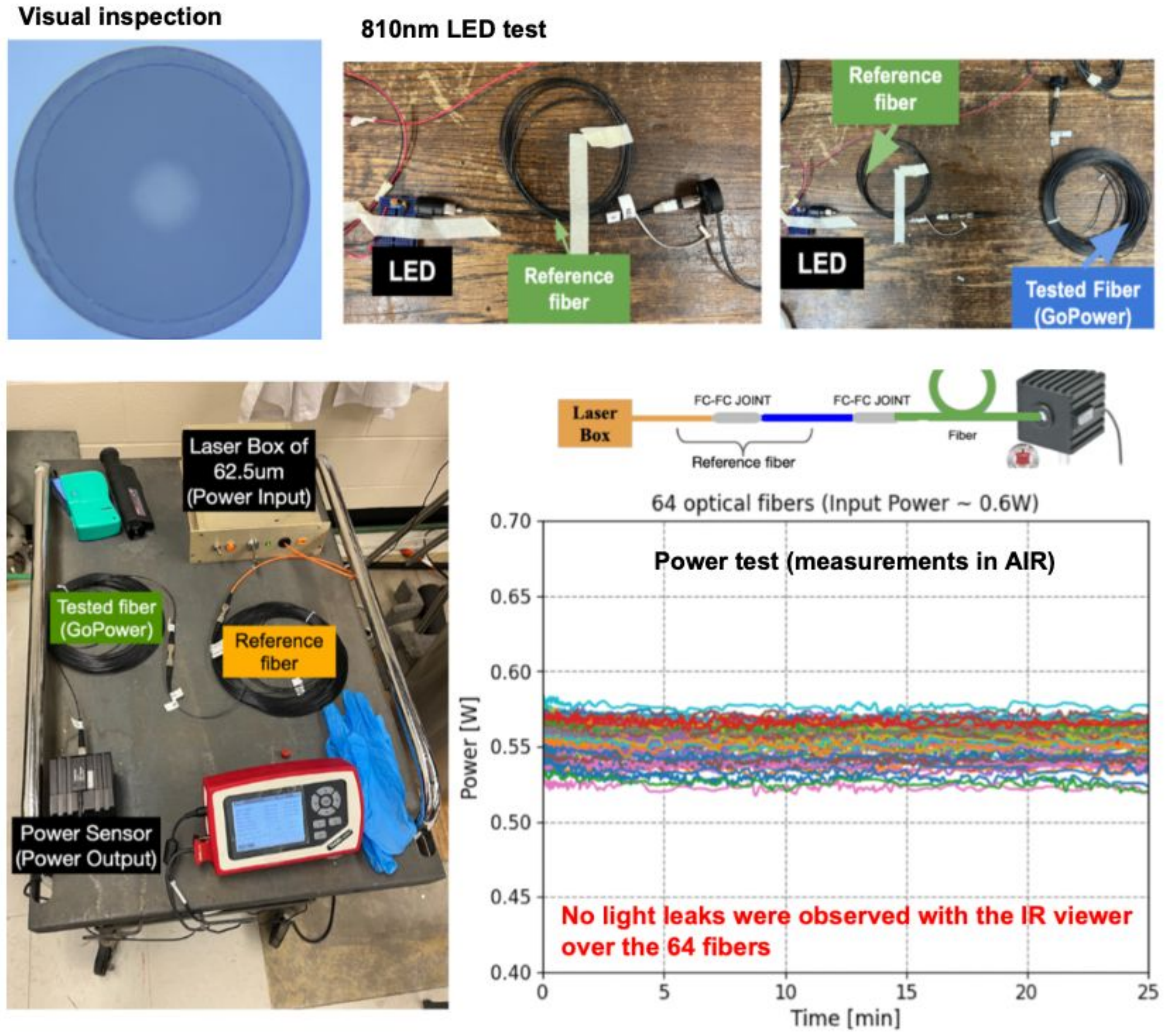
Standard QA/QC procedure

A three-step QA/QC has been successfully applied to 64 optical fibers (62.5um core and 40 m) used in ProtoDUNE VD (module-0) and later this procedure will be applied for DUNE FD2:

1. ***Visual Inspection:*** General overview of the fiber to see if there is any obvious damage to the fiber's jacket and fibers ends are inspected using a fiber inspection scope.

2. ***810 nm LED test:*** Using a LED of 810nm we measured the power input using a reference fiber and power output using the fiber to be tested.

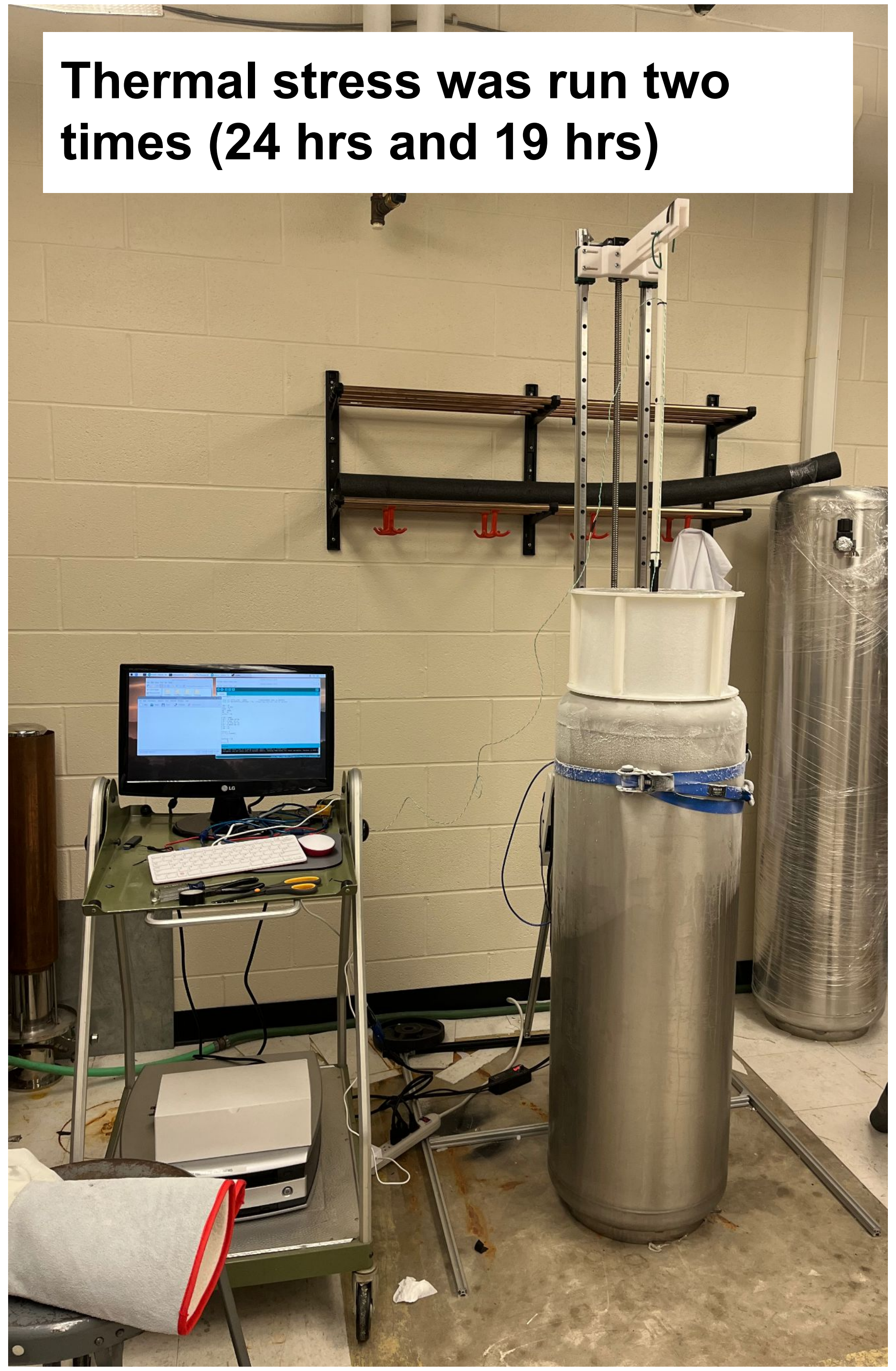
3. ***Power test:*** Monitor the power performance during certain period of time (i.e. 25 min) of the laser box operation at 0.6W and visual inspection using and IR viewer over the jacket and fibers ends.

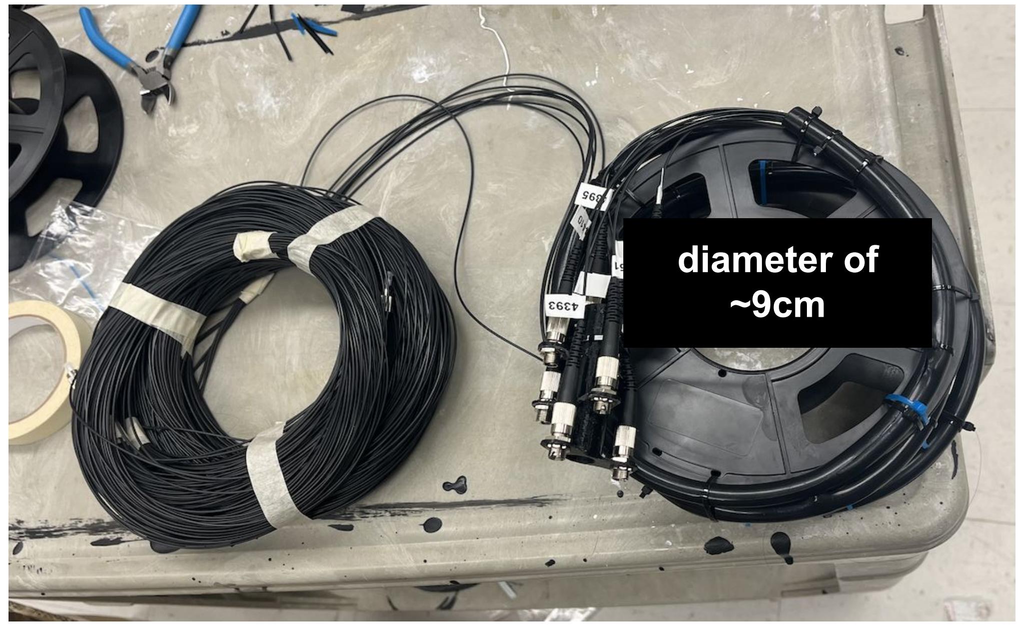


Stress testing of the optical fibers

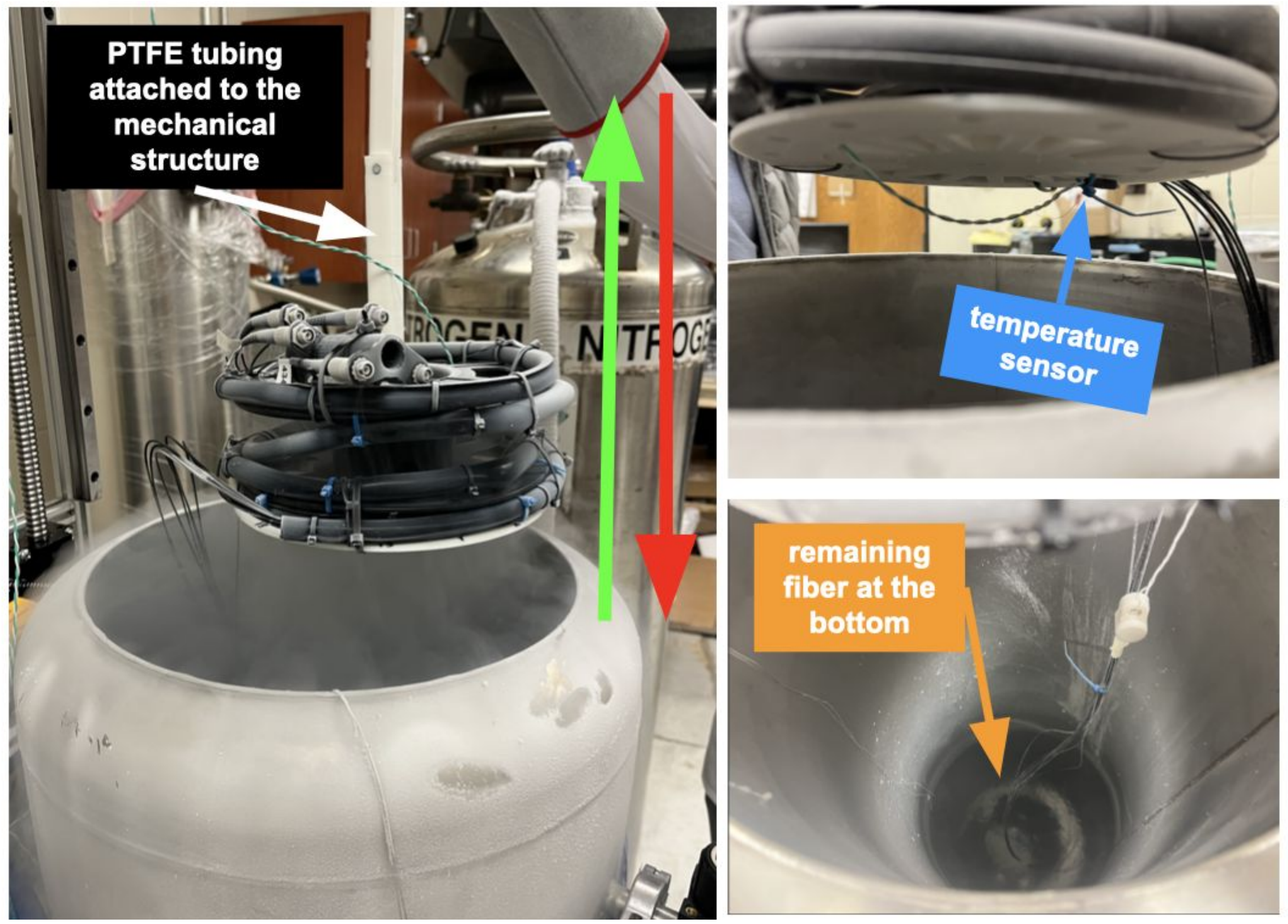
Thermal stress in LN2

A thermal stress was performed with eight optical fibers (62.5um core and 40m) from GoPower company. Fibers were inserted into a black tube PTFE tube, which was bent to ~3.5cm (~9cm diameter).





Optical Fiber [62.5um core and 40m length]	
$ratio = P_{output}[nW]/P_{input}[nW]$ Before	$ratio = P_{output}[nW]/P_{input}[nW]$ After
0.78 ± 0.02	0.78 ± 0.01



We made a visual inspection (PTFE tube and fibers) and transparency test before and after the thermal stress test.

- No damage over the PTFE tube and fibers
- No difference in the LED light test before and after this thermal stress

Stress test over one PTFE tube and fibers

- We suspended an optical fiber from only the FC connector, and left the fiber hang with the weight of 40 m worth of fiber for 24 hrs. No visual damage to the connector end was observed.
  - Light test using an LED of 810nm was performed before and after, and no difference in its functionality was observed.
  - A power test were performed to confirm its suitability for PoF, and no light leak was observed by the IR viewer.

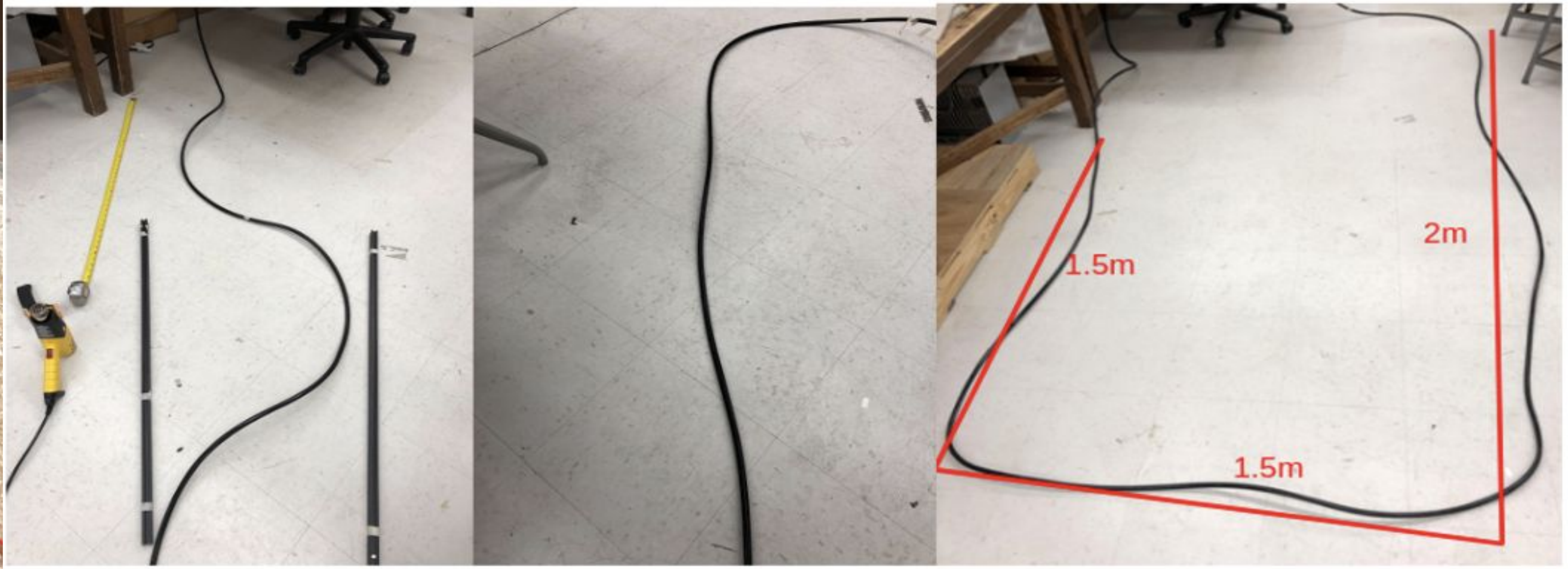
- One 70kg person jumped and stood on top of the PTFE tube with eight fibers inside. We performed a light test using a 810 nm LED and we did not find a difference before and after the 70kg person jumped (similar results as above).

Optical Fiber [62.5um core and 40m length]	
$ratio = P_{output}[nW]/P_{input}[nW]$ Before	$ratio = P_{output}[nW]/P_{input}[nW]$ After
0.79 ± 0.01	0.77 ± 0.01

PTFE tube straightening tube using heat gun

During the assembly and shipment of the optical fiber bundle to CERN (tubes were packaged in a box), the PTFE tube acquired a helix shape. We have two potential solutions:

- *Heating gun:* SDSMT lab has shown that is possible to straighten the tubes using a heating gun.
  - To show that no damage is sustained during this process, we ran a light test using an 810nm LED before and after straightening a 5m section of tube, no difference in the light test was observed.

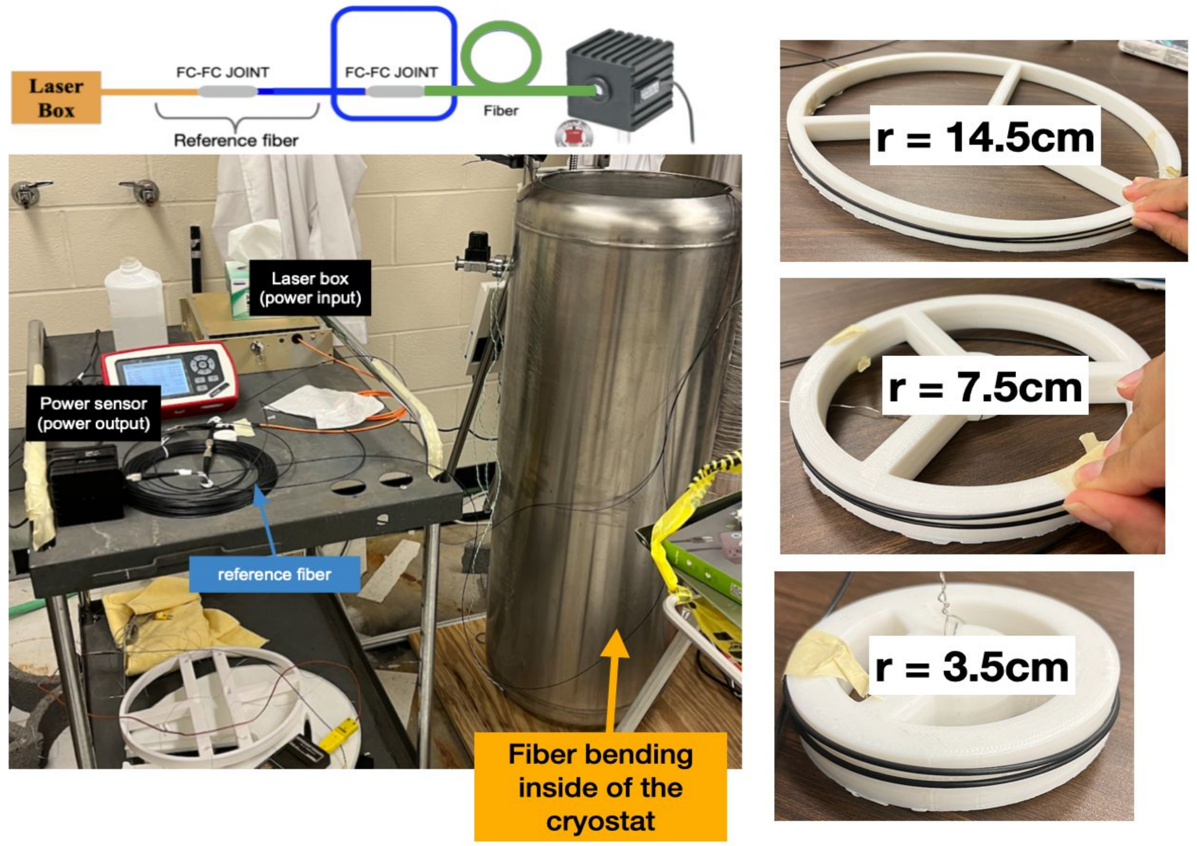


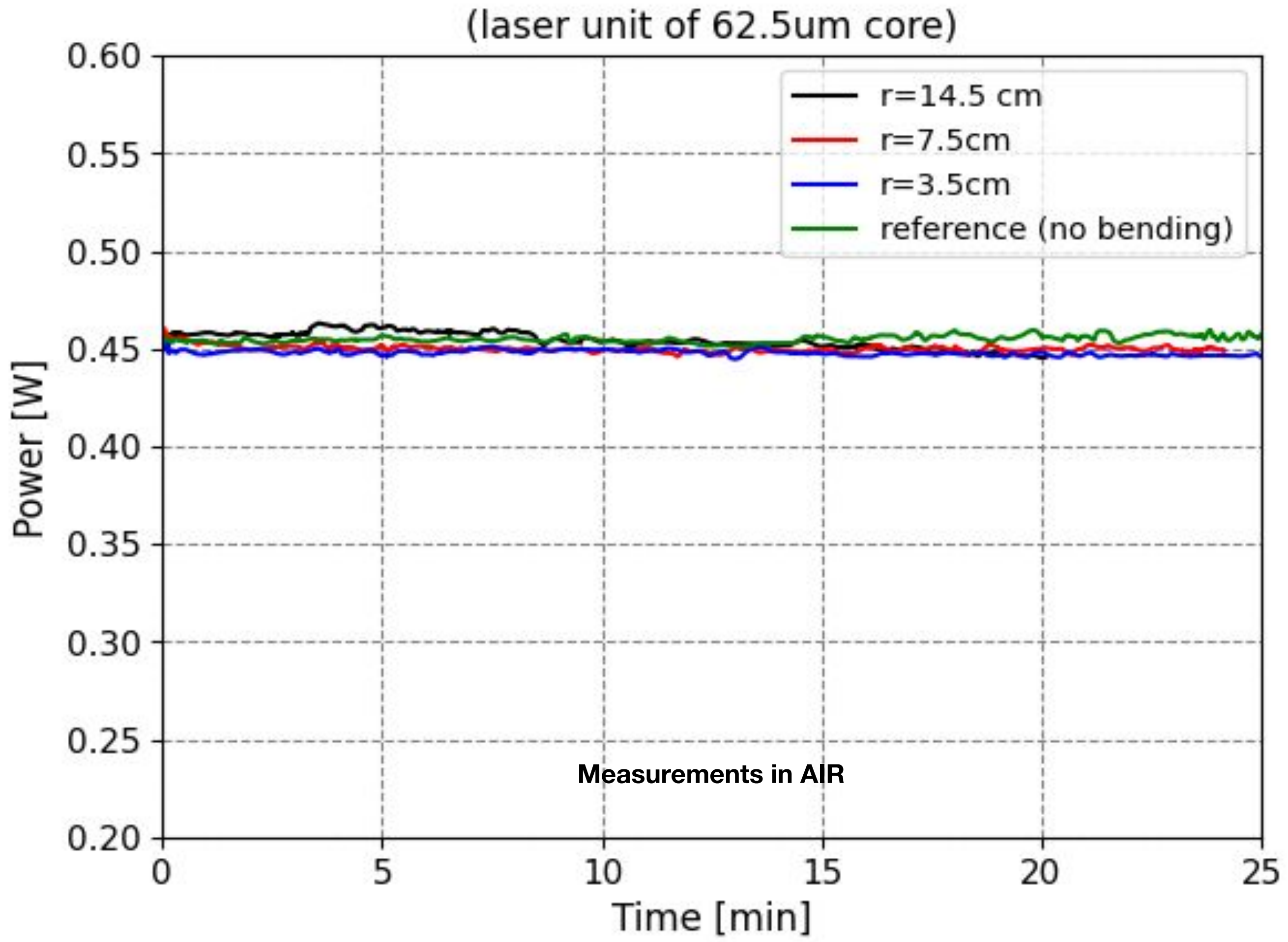
Bending radius tests

First measurements of bending radius test AIR

- Using an optical fiber of 62.5 um core and 40 m length (GoPower). We conducted a bending test with three bending radii (14.5cm, 7.5cm and 3.5cm) in AIR:
  - Fiber were wrapped **twice at each radii**
  - No power loss was observed and no light leak was observed by the IR viewer

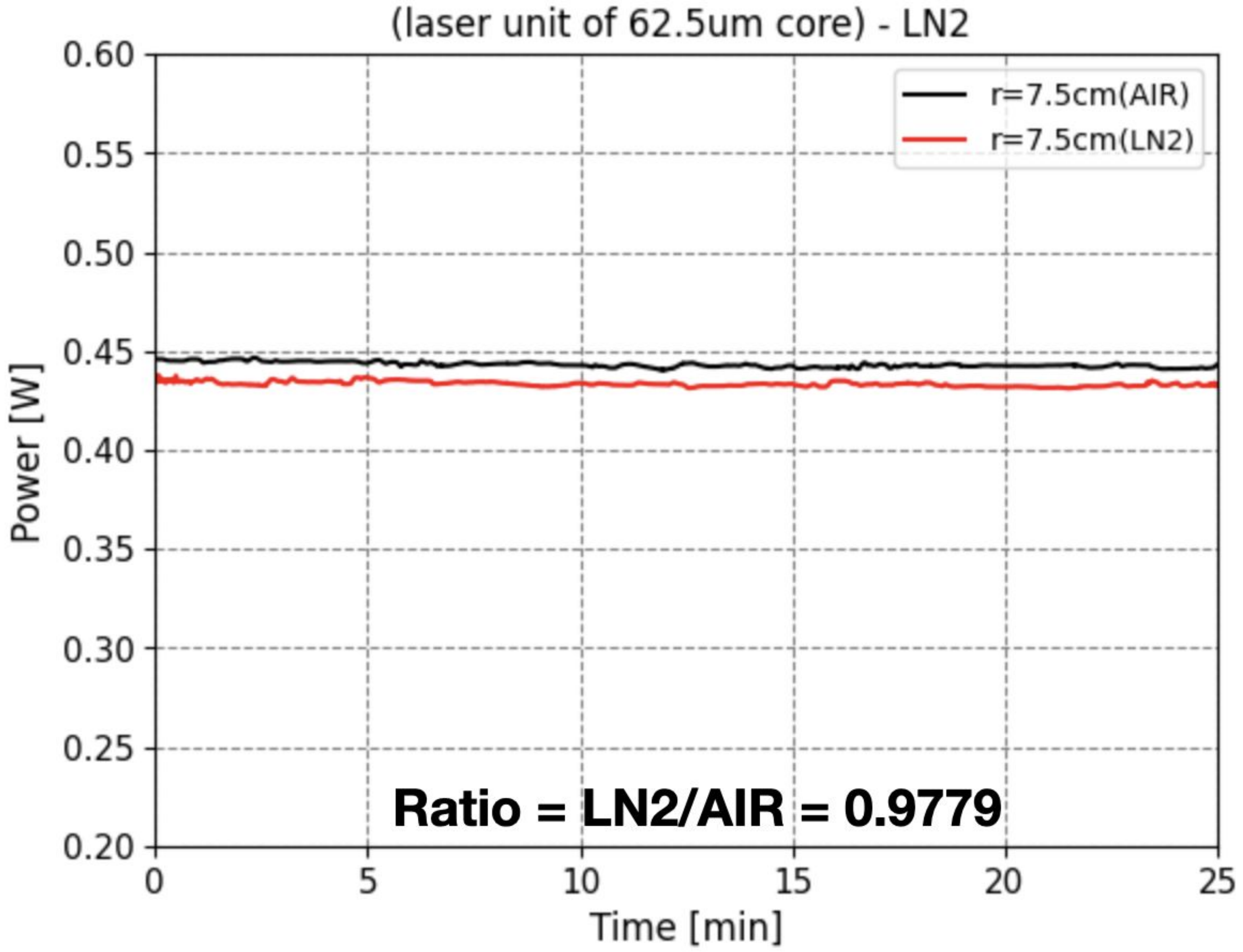
- The bending radius for Module-0 (and later DUNE FD2) is **expected to be > 9cm**.
  - Based in our results we don't expect power losses for bending radius > 3.5cm.

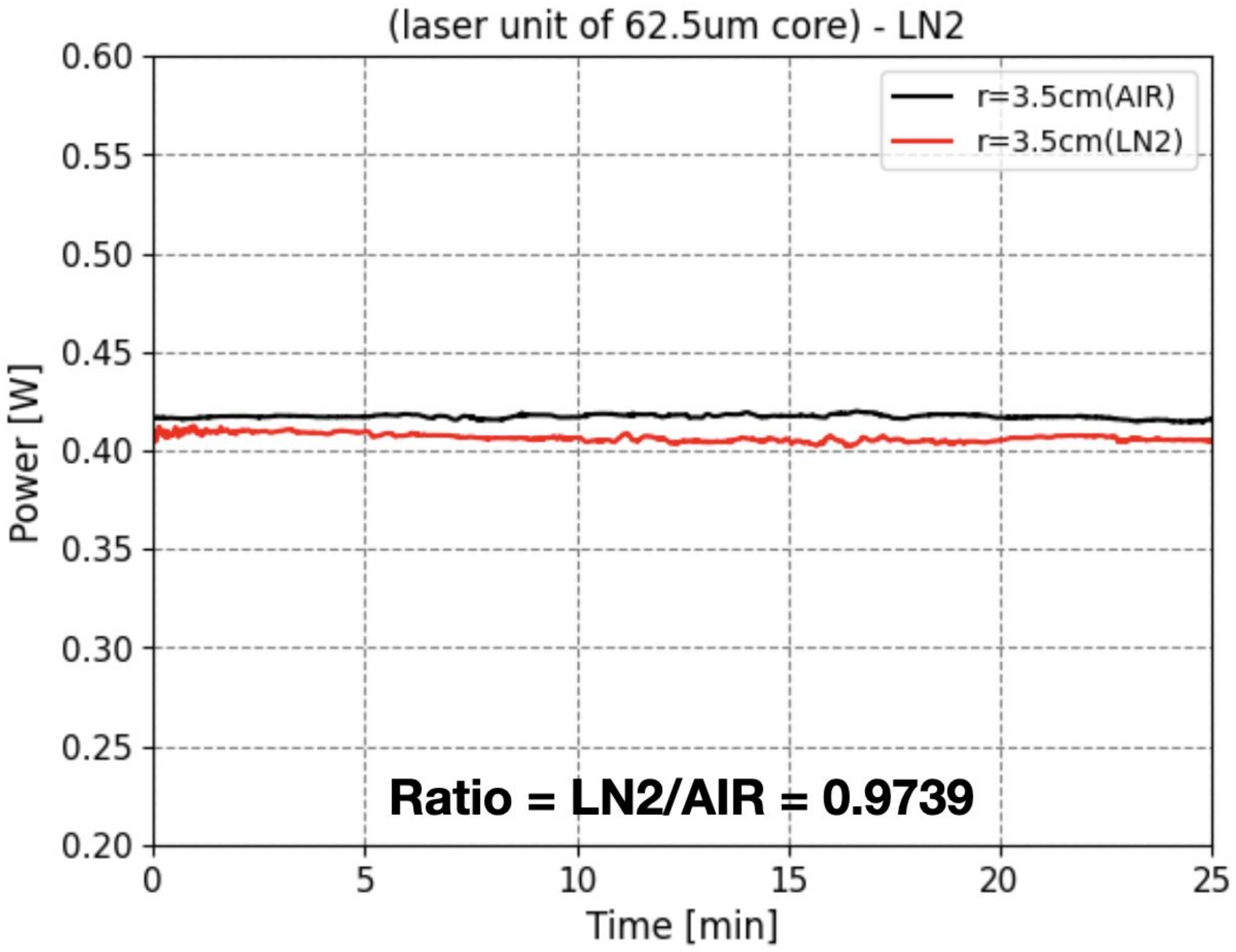




First measurements of bending radius test LN2

- Using an optical fiber of 62.5 um core and 40 m length (MH-GoPower).
- We conducted a bending test with two bendii (7.5cm and 3.5cm) LN2
  - Fiber were wrapped **twice in the radii**





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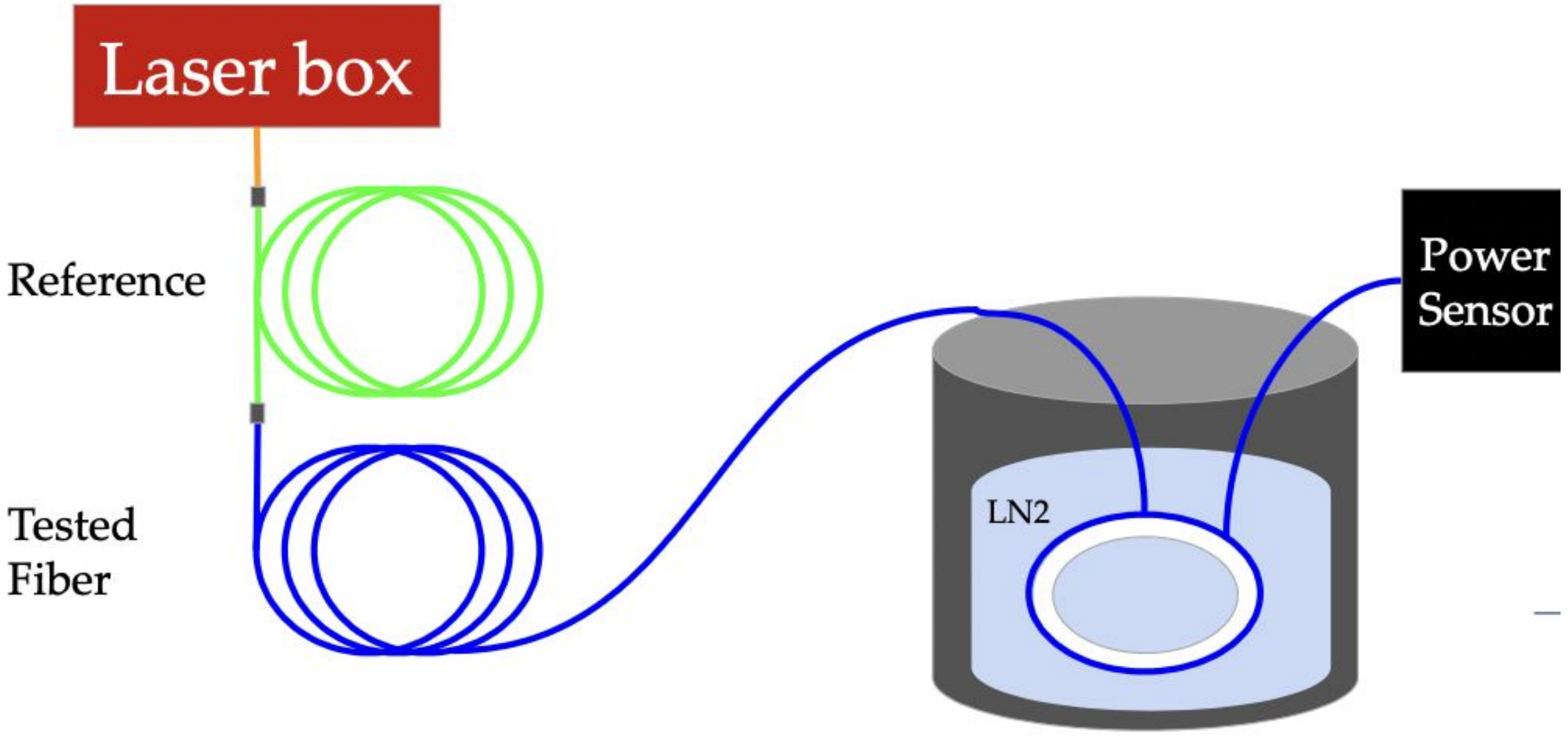
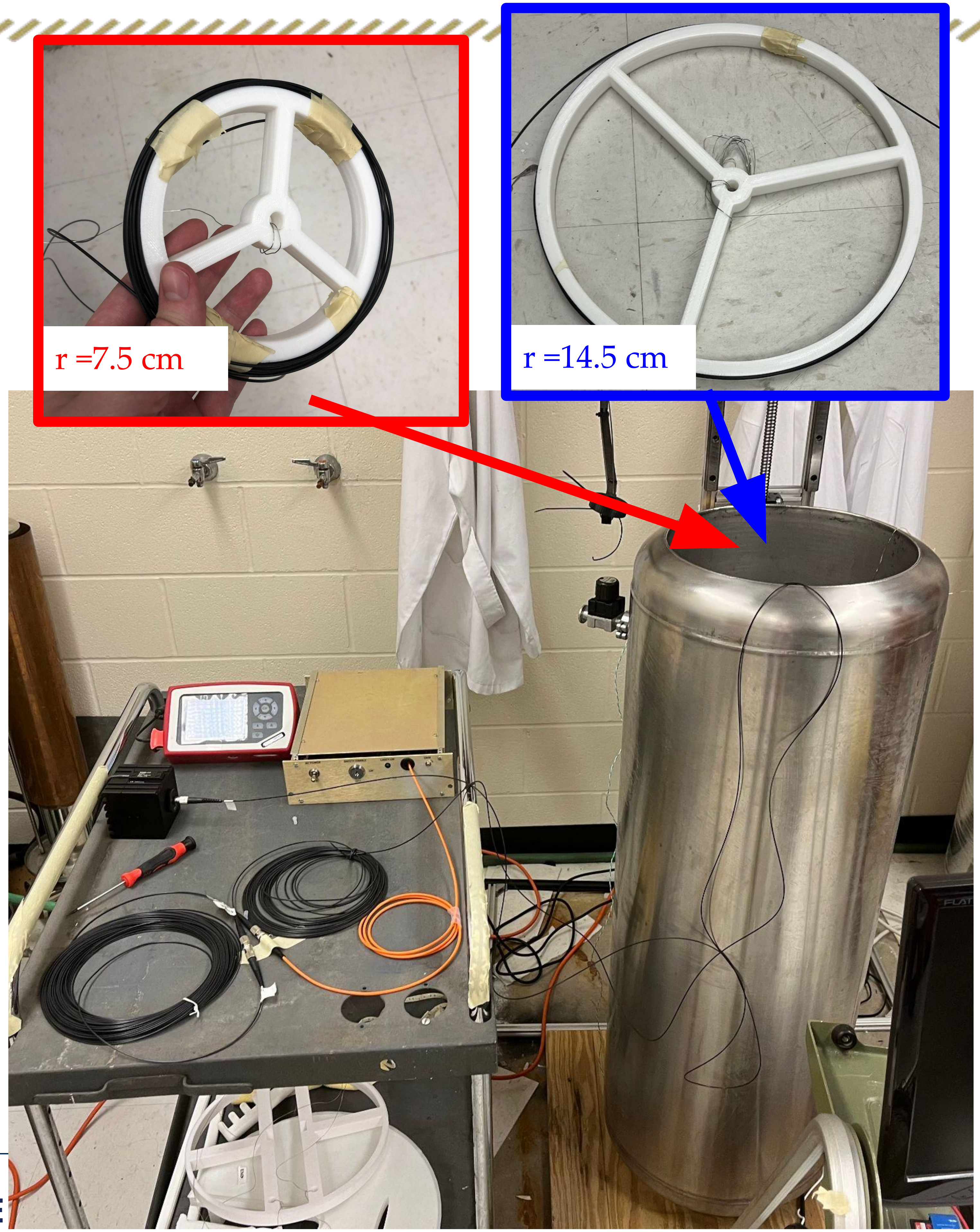
Power loss different bending radius and loops (AIR & LN2)

Using a GoPower optical fiber (62.5um core and 40m) we are starting to characterize the power loss as function of the number of loops under two different radii:

1. r = 7.5 cm
2. r = 14.5 cm

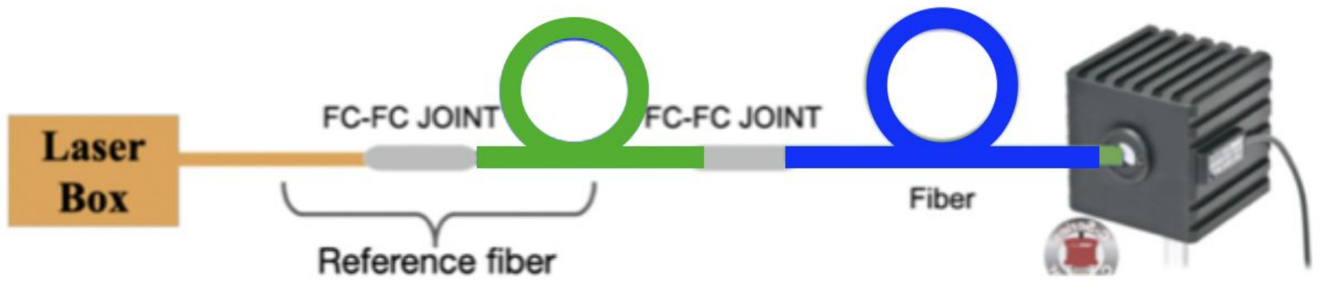




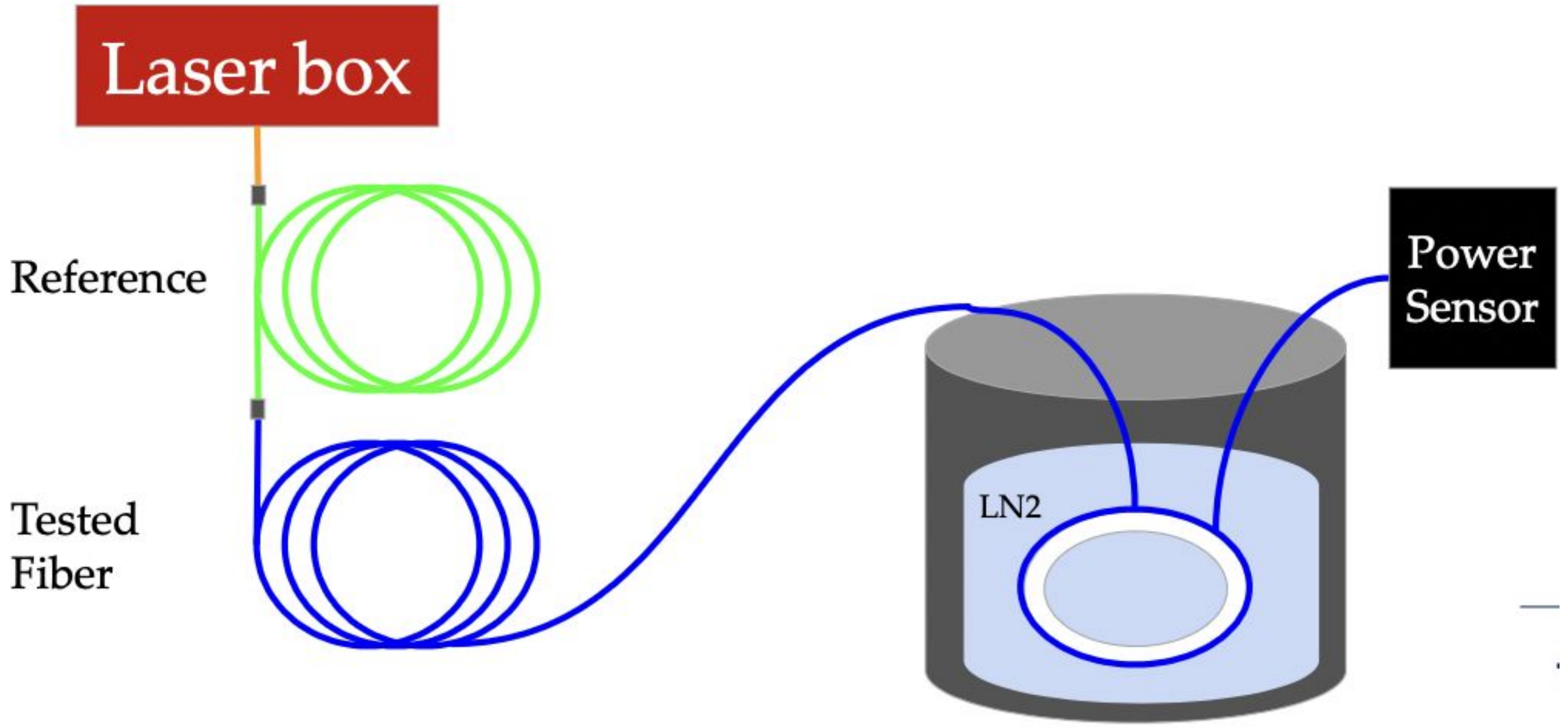
Power loss different bending radius and loops (AIR & LN2)

We will measure the power loss as a function of the number of loops in AIR vs LN2:

1. We set up a power output of 300 mW in AIR

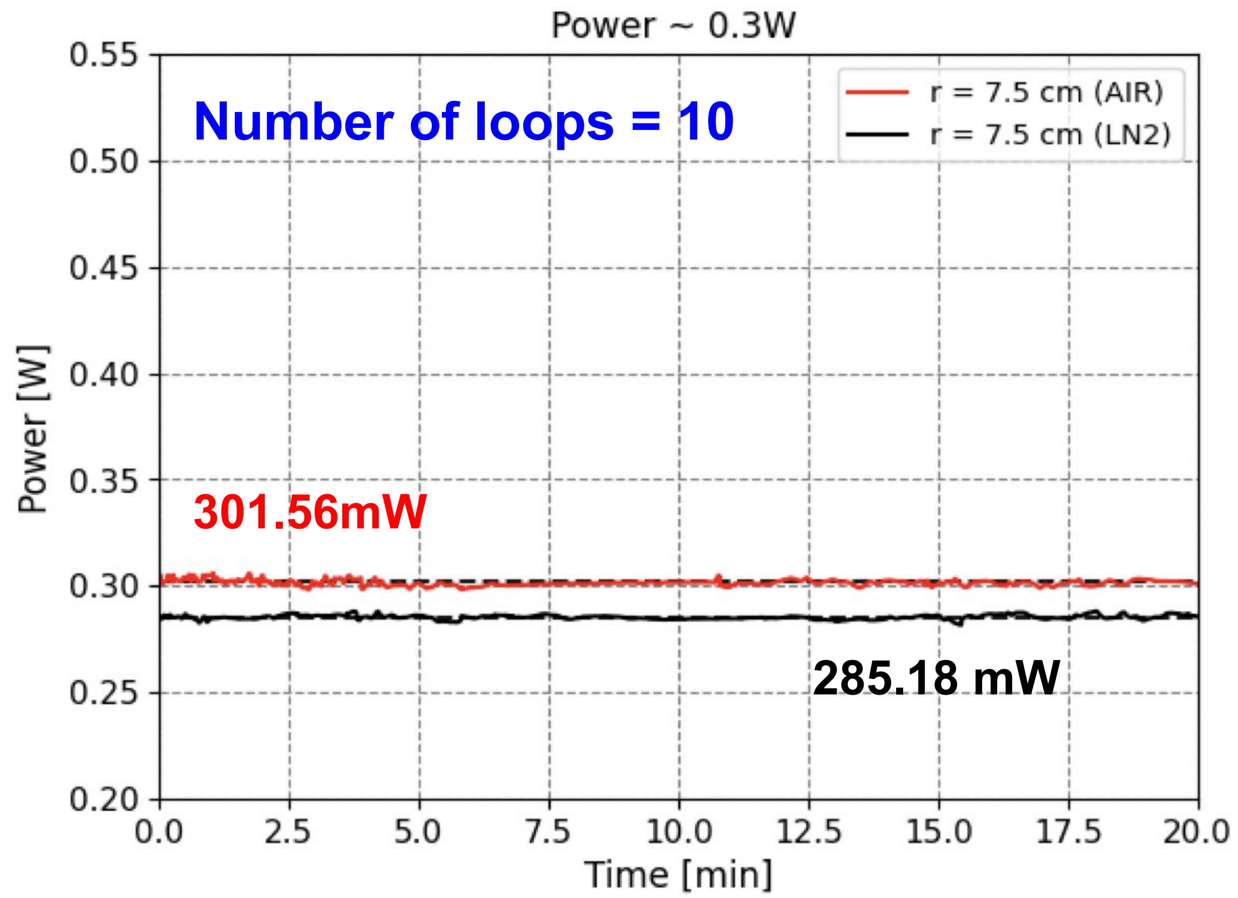


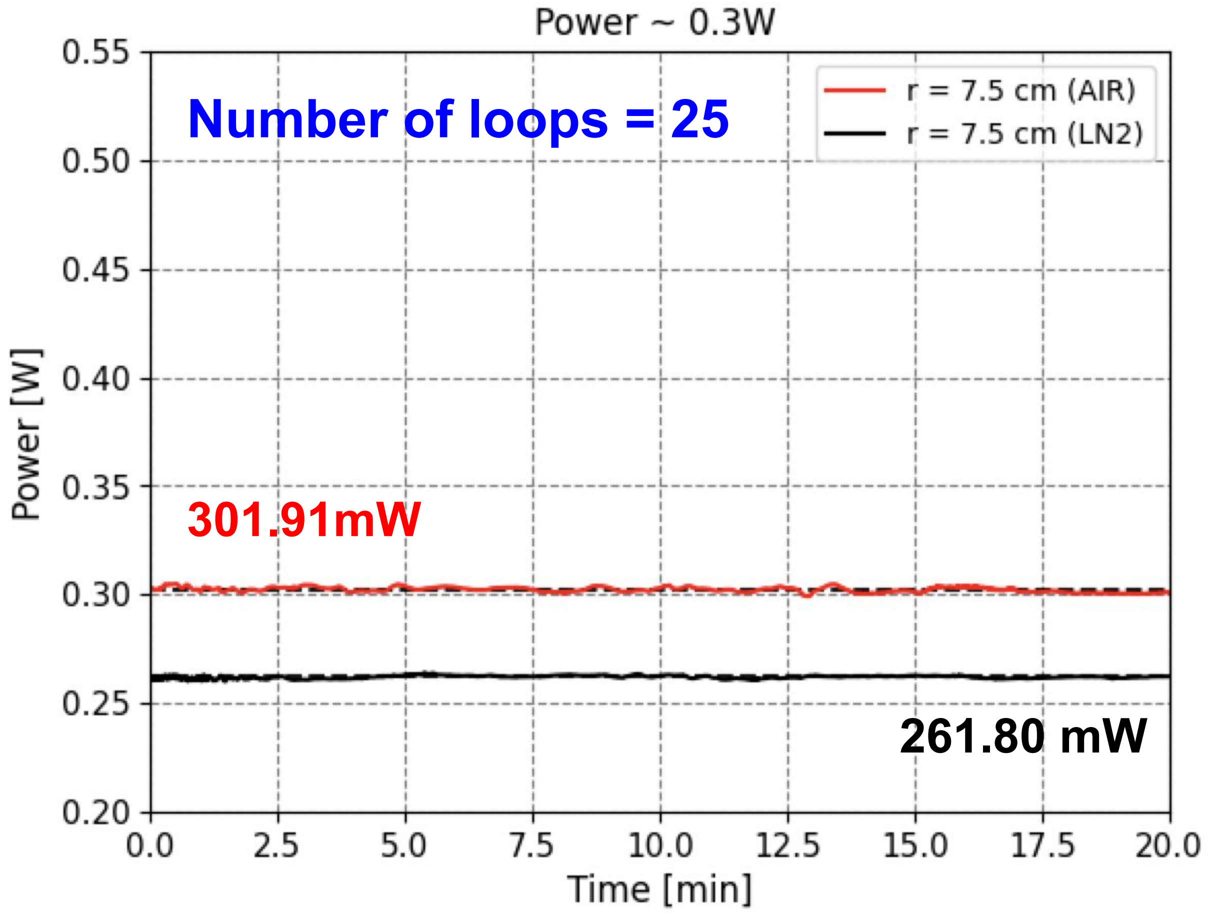
2. Without changing the setup (same 300 mW) we measure the power performance after submerging into the LN2:

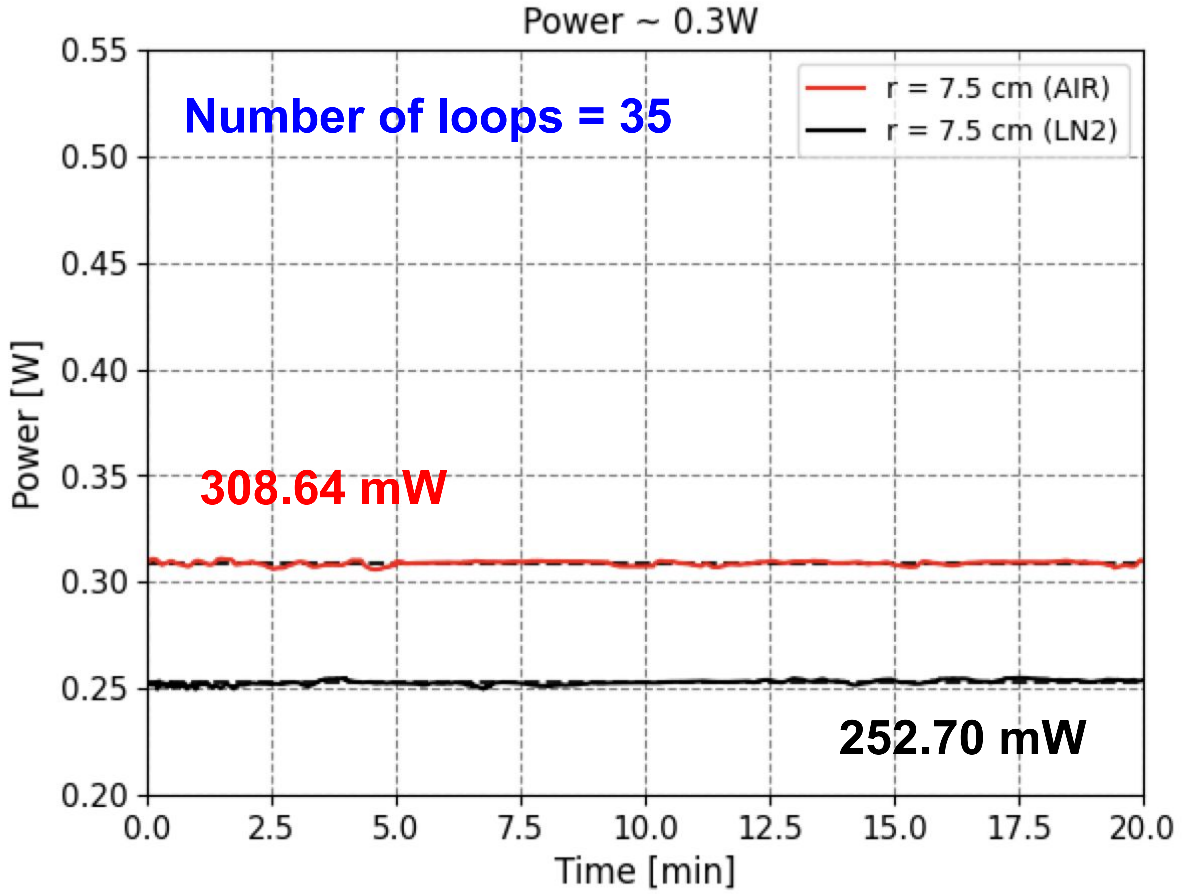


Power loss different bending radius and loops (AIR & LN2)

Bending radius of r = 7.5cm





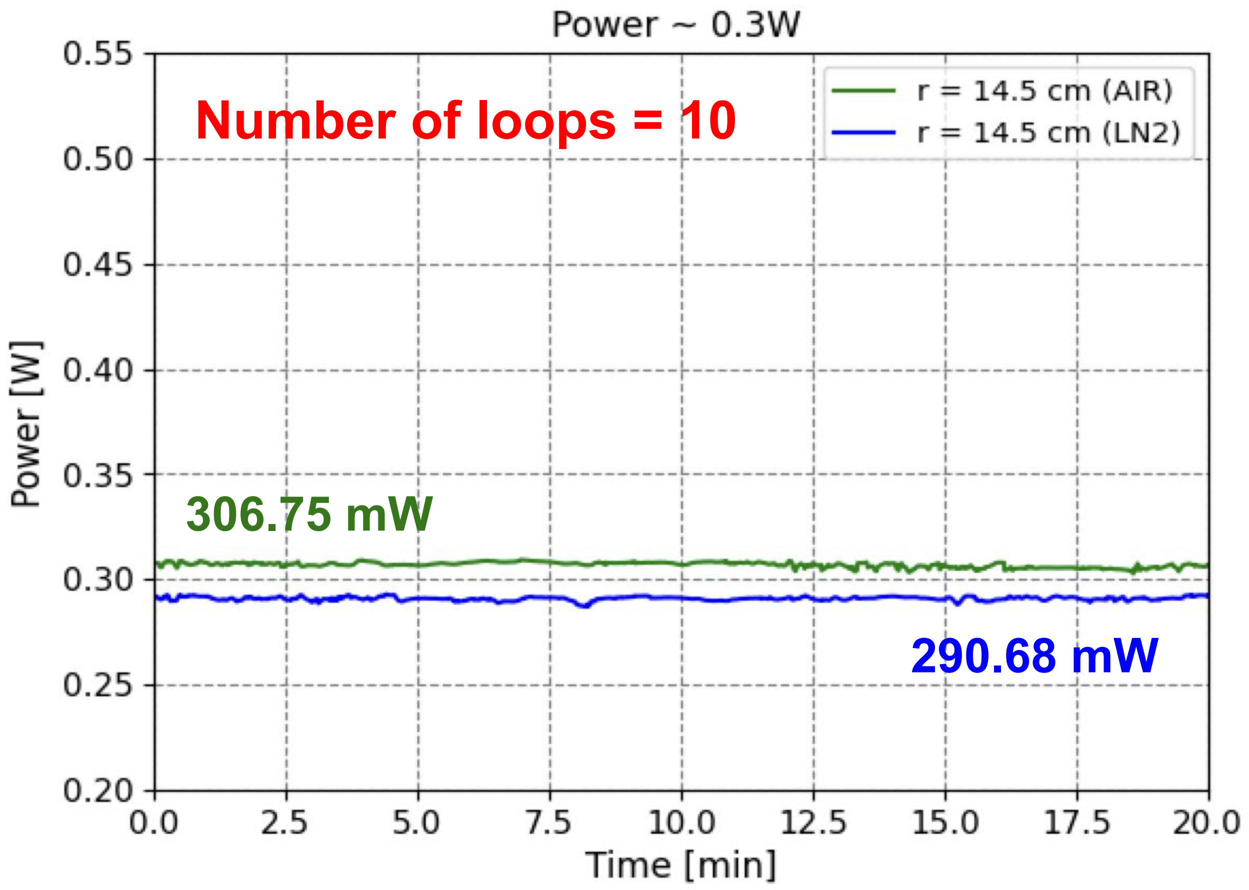


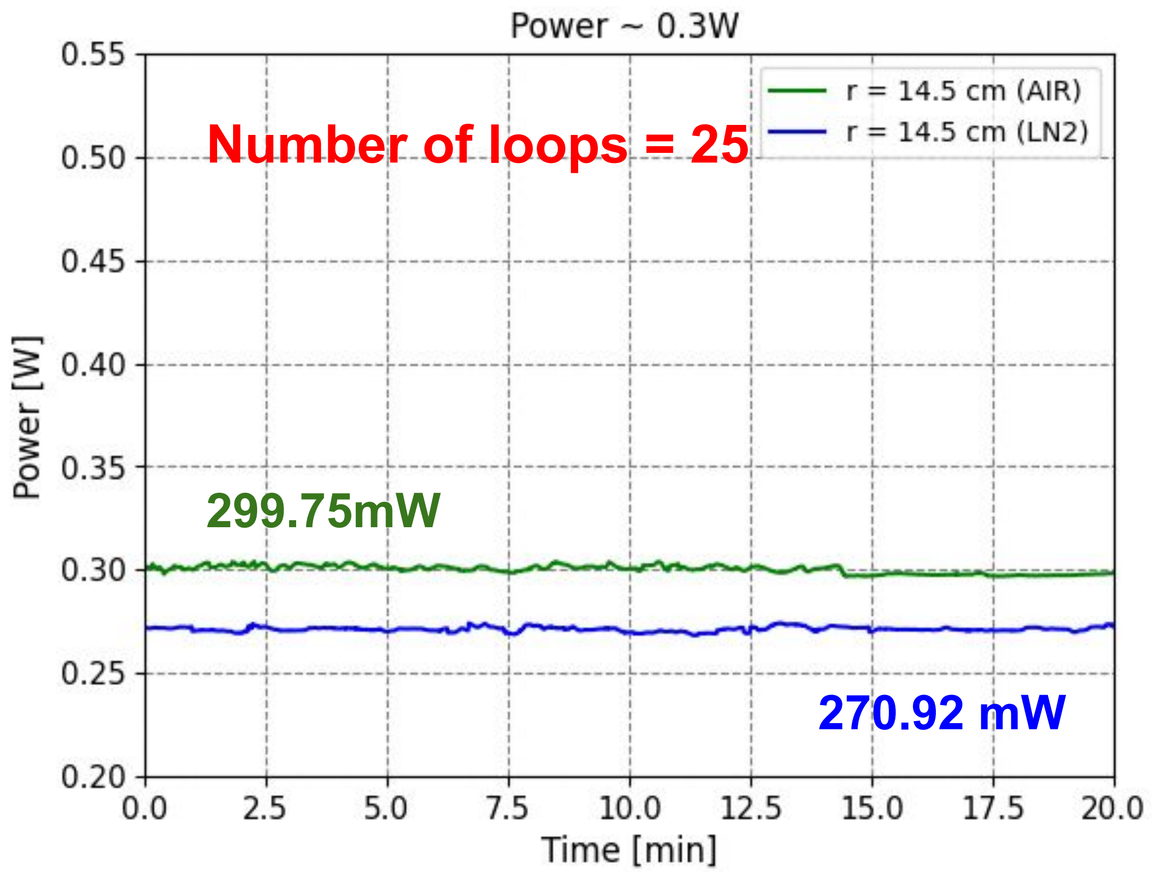
number of loops	length (n-loop $= 2\pi$ r n) [m]	Power loss (AIR-LN2) [mW]
10	4.71	16.38
15	7.06	25.44
20	9.42	32.17
25	11.78	40.11
30	14.13	43.53
35	16.49	55.94

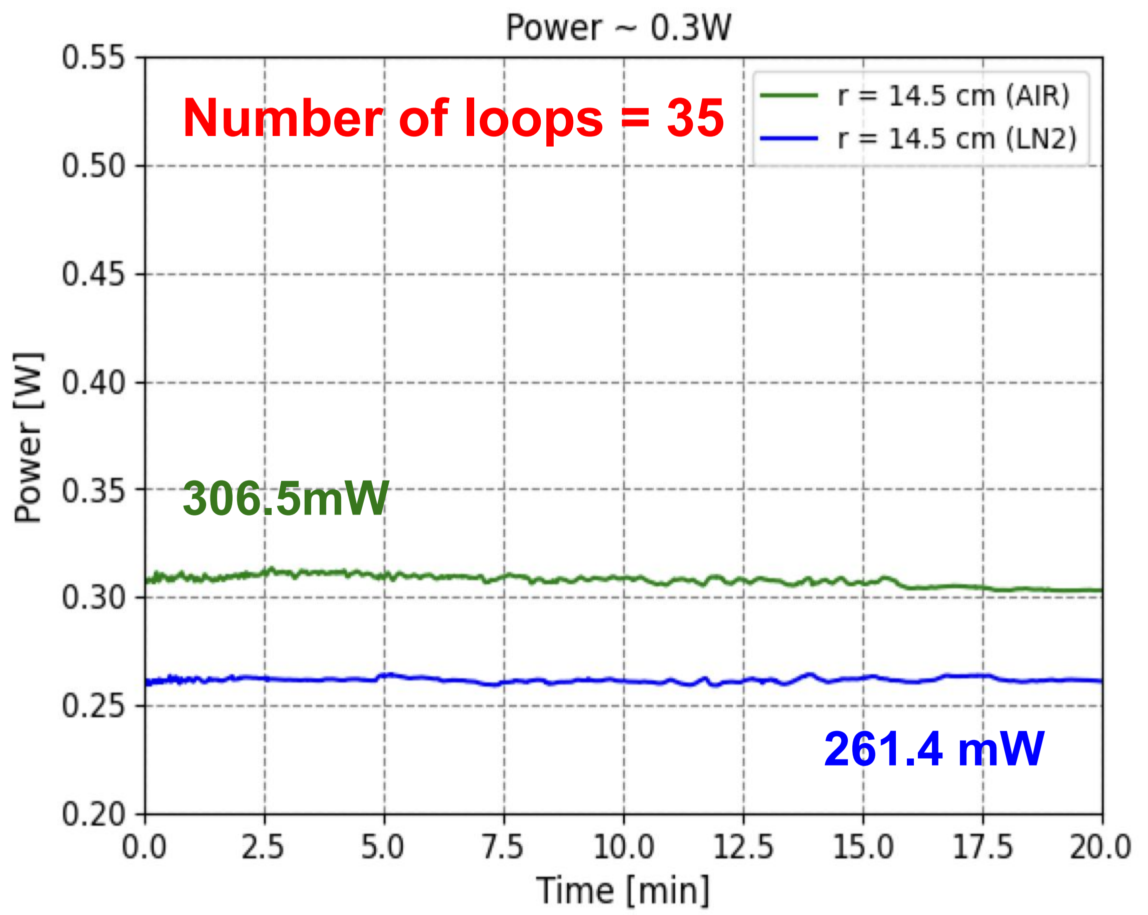
- **~10 turns** are expected for Module-0 based in the current proposed fiber routing.
- Power loss power meter ~ 3.38mW

Power loss different bending radius and loops (AIR & LN2)

Bending radius of r = 14.5cm



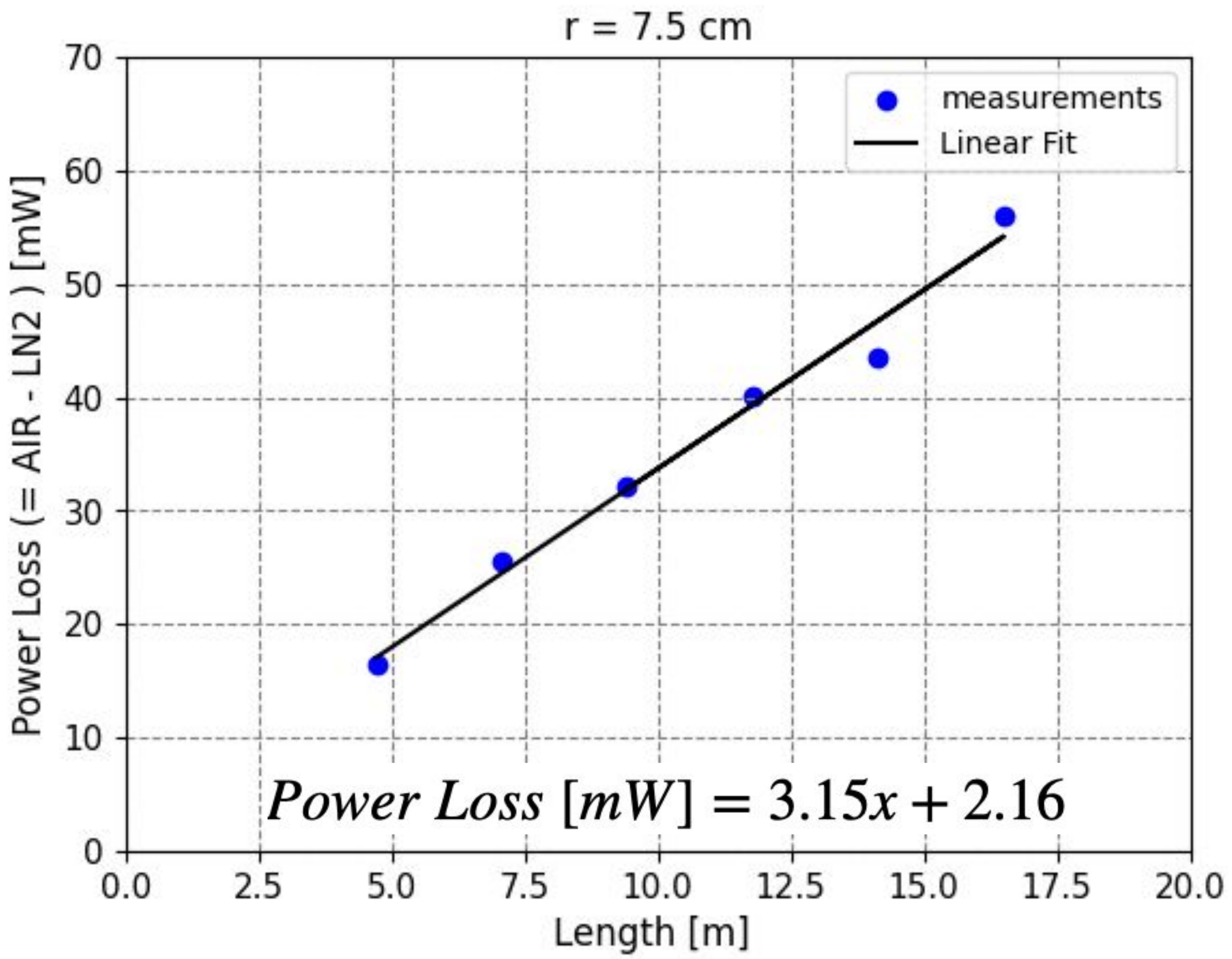


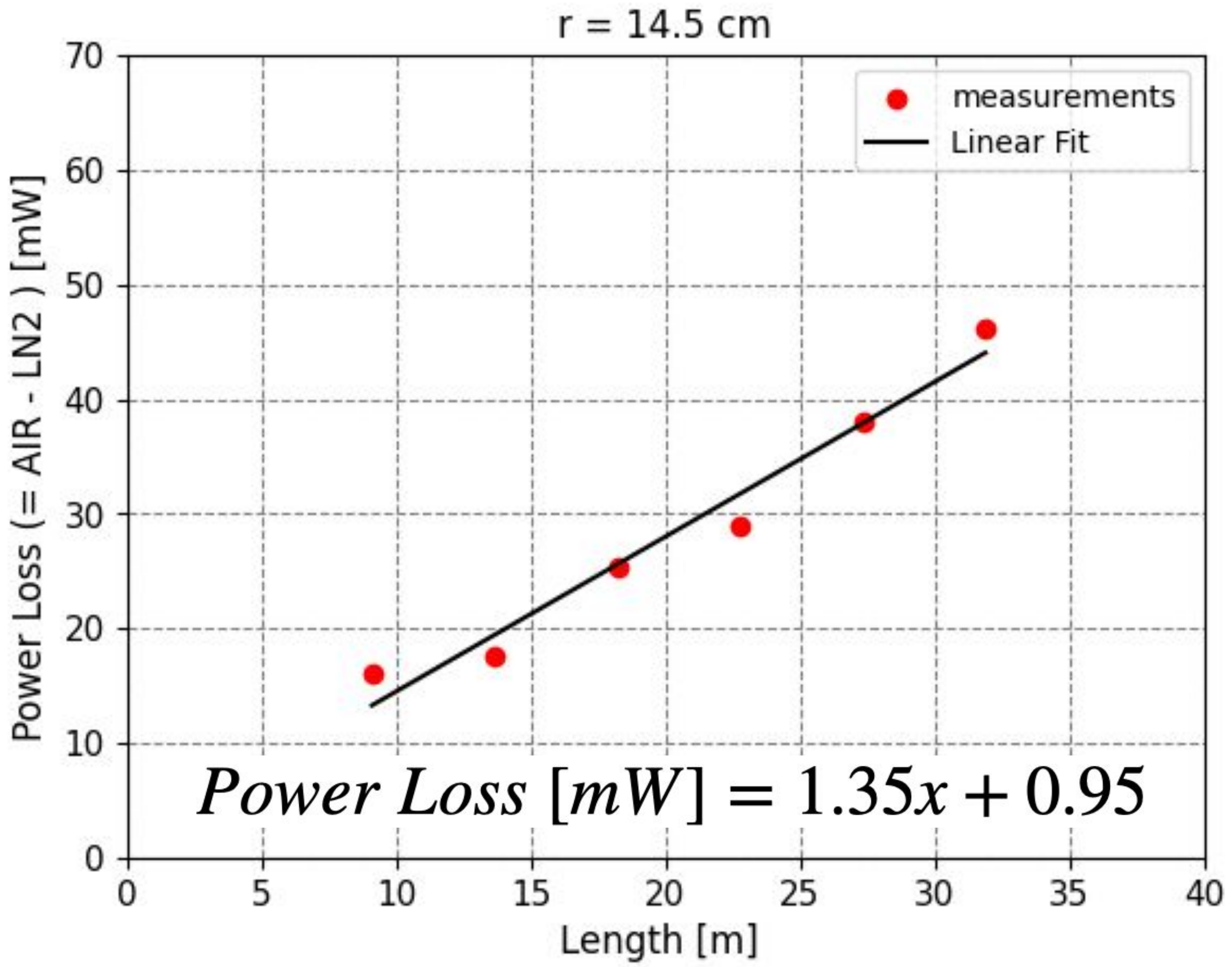


number of loops	length (n-loop $= 2\pi$ r n) [m]	Power loss (AIR-LN2) [mW]
10	9.11	16.07
15	13.66	17.53
20	18.22	25.26
25	22.77	28.83
30	27.33	38.10
35	31.88	46.10

- **~10 turns** are expected for Module-0 based in the current proposed fiber routing.
- Power loss power meter ~ 1.37mW

Power loss different bending radius and loops (AIR & LN2)





r [cm]	Power loss per meter [mW] (measurements)
7.5	3.38
14.5	1.37

We can estimate the power loss of fiber length in LN2 under two approaches:

1. Measurements: *Power loss = Power loss per meter * length*
2. Linear fit: *Power loss* = $m\boldsymbol{x}+b$, where **x** is the fiber length

Bending radius (r) [cm]	length (n-loop = 2π r n) [m]	Power loss (linear fit) [mW]	Power loss (measurements) [mW]
7.5	12 (25.46 loops)	39.96	40.56
14.5	12 (13.18 loops)	17.15	16.44

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Power loss dependence on temperature

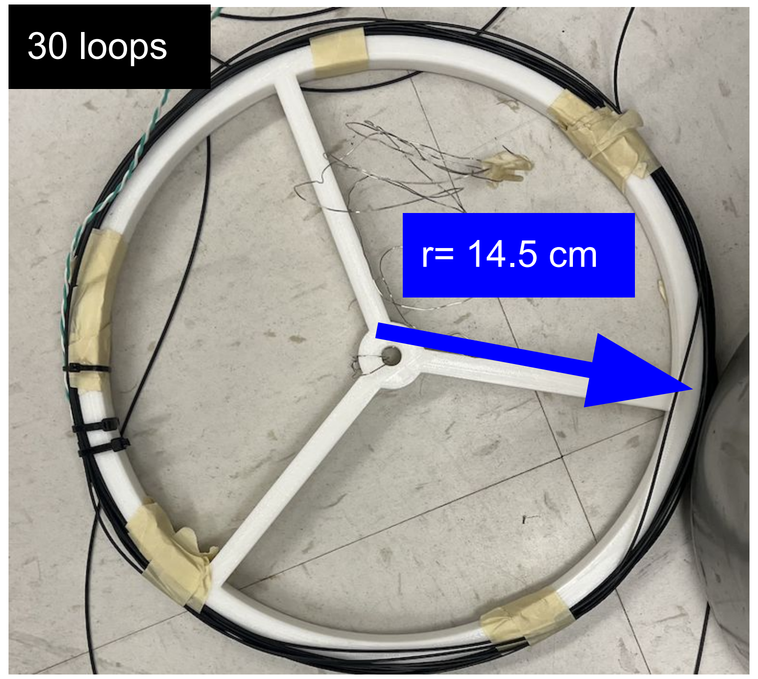
The optical fibers (GoPower) have an external black PVDF jacket, which at low temperatures gets compressed.

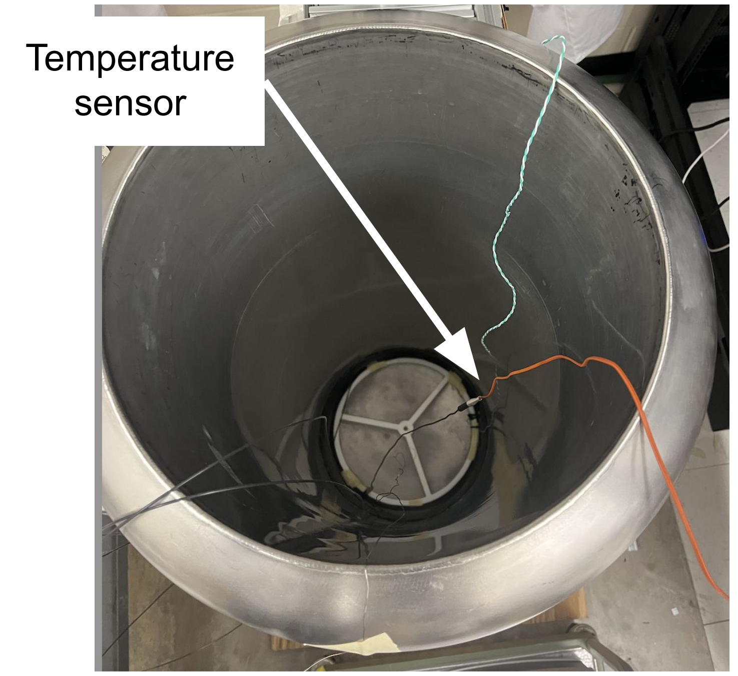
- This effect results in power loss along the fiber.

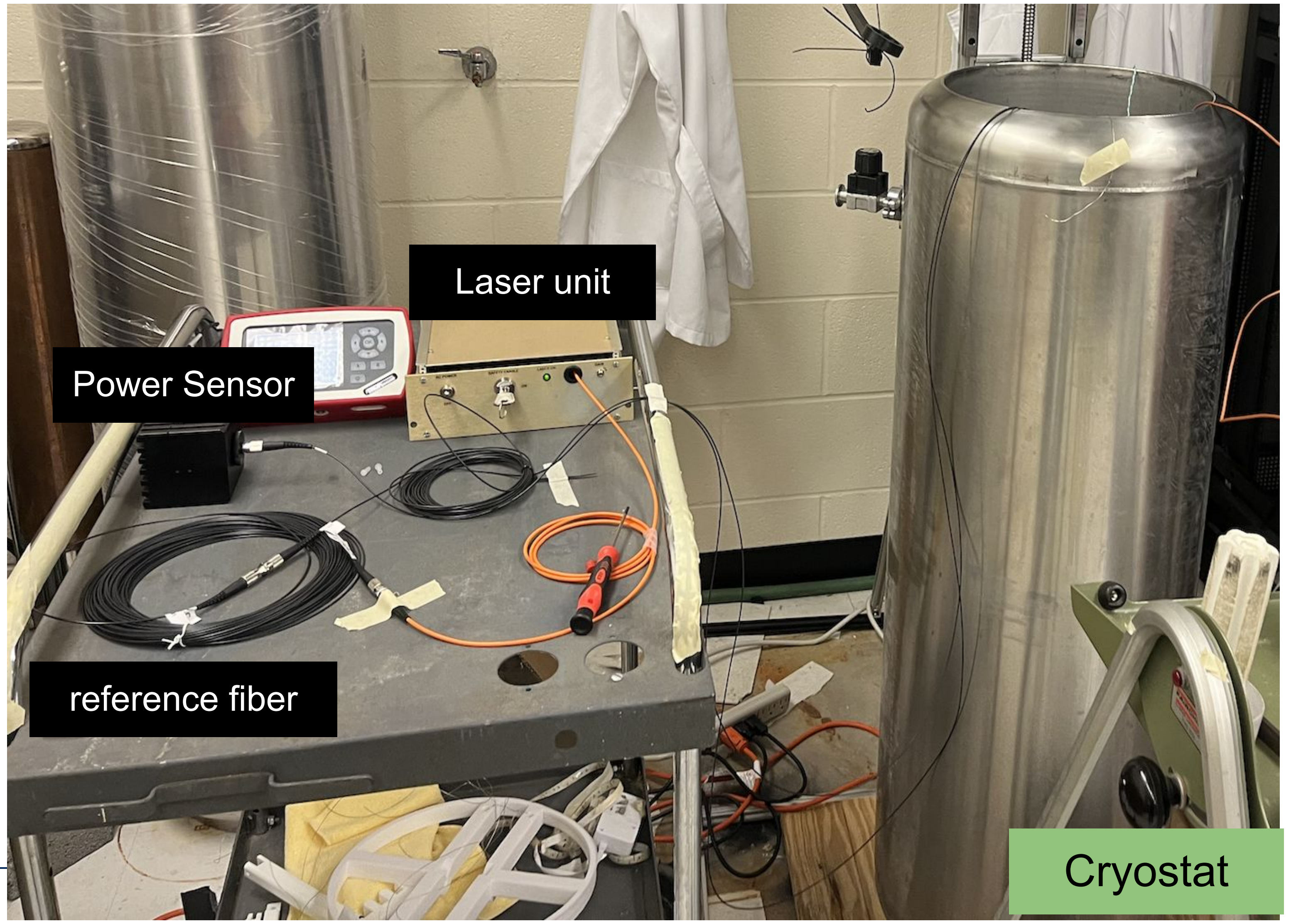
In this test, we started to study the power loss in function of temperature:

- Using a fiber (62.5 um core and 40 m) we wrapped 30 loops around a ring of r = 14.5 cm and placed inside the cryostat that has LN2.

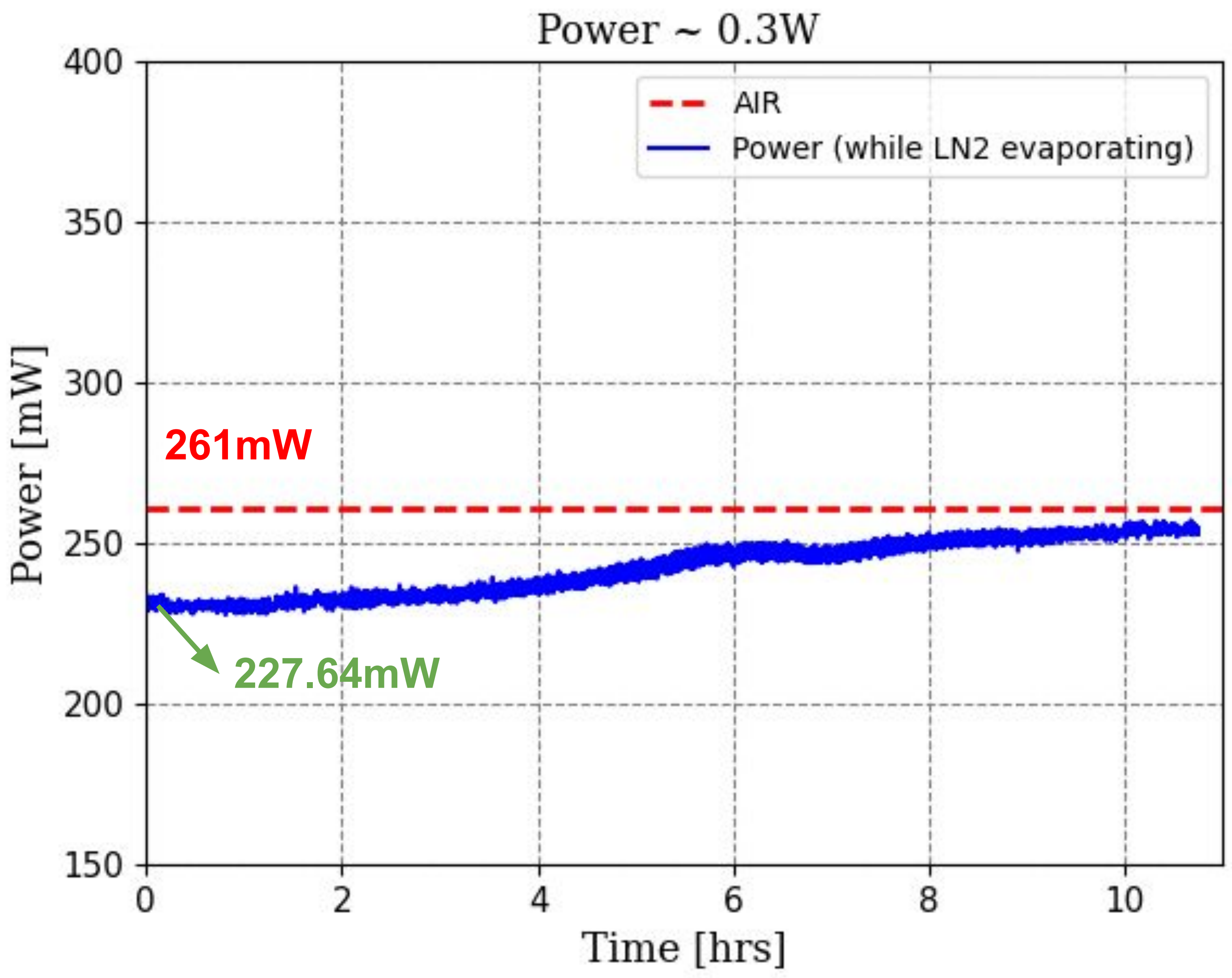
- Using a power input of ~0.3W we registered the power output while letting the LN2 evaporate (~10 hrs).

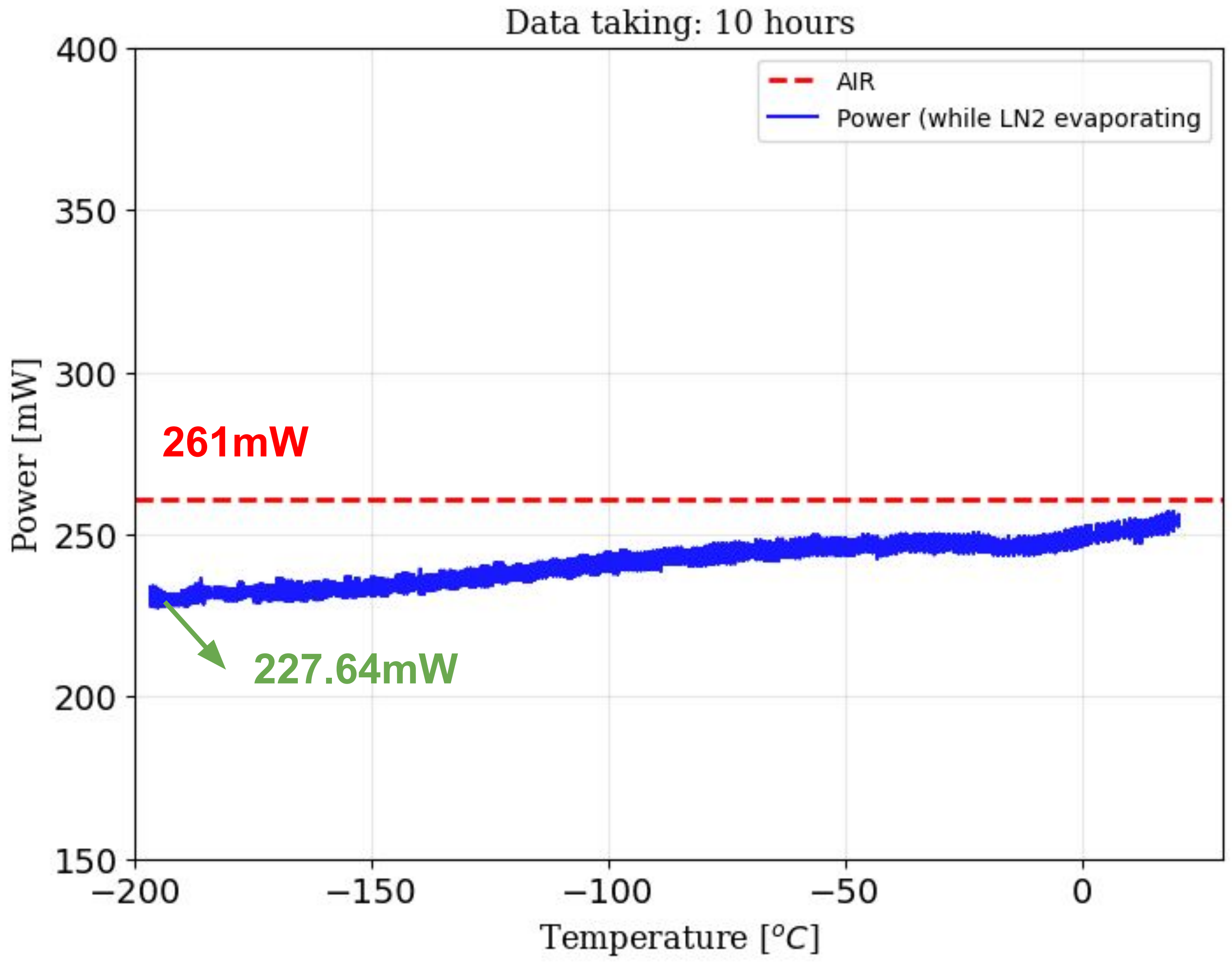






Power loss dependence on temperature





At the lowest temperature we registered a power loss of ~13% with respect to the room temperature (AIR).

Materials testing in LN2

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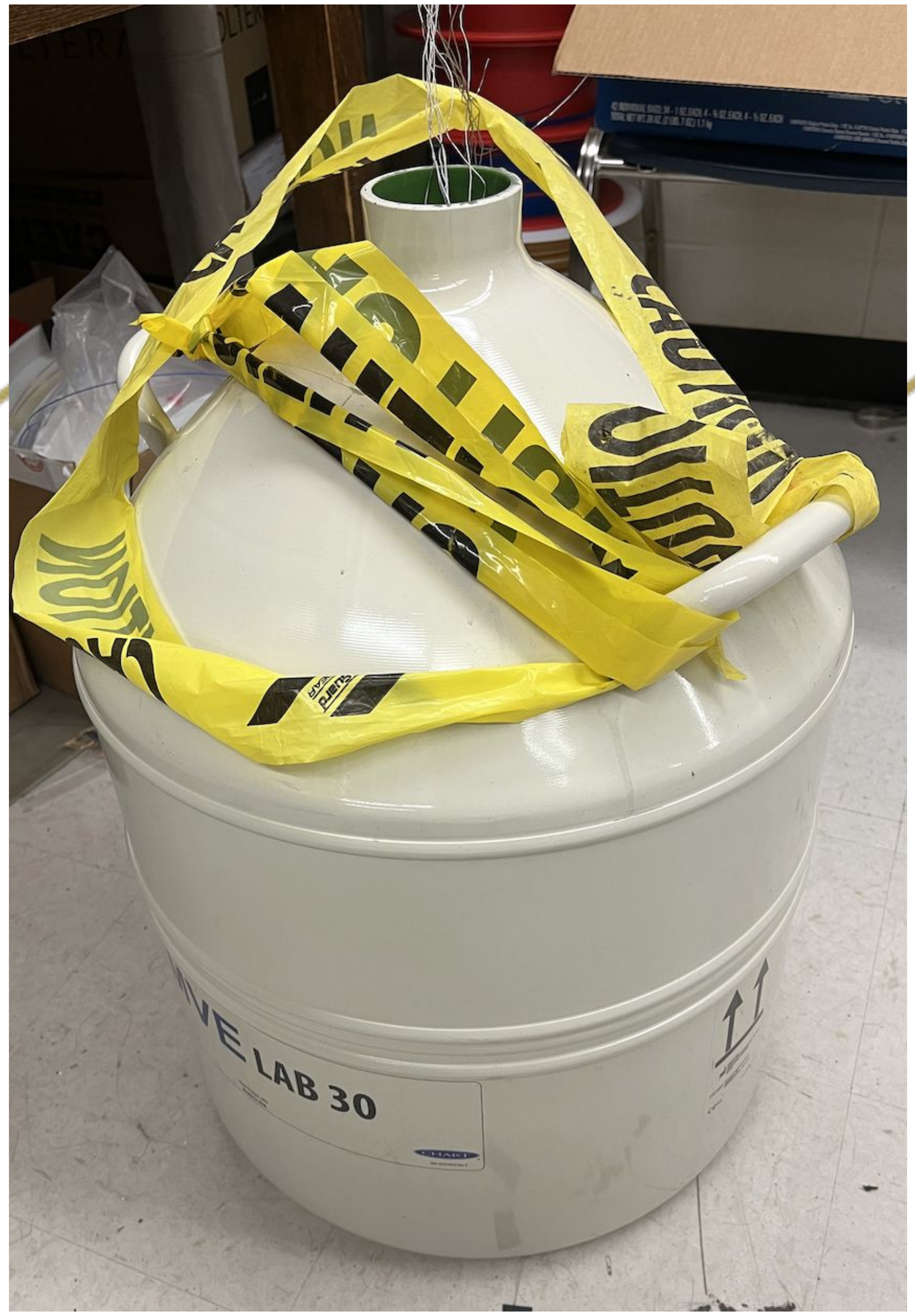
Materials test in LN2

We are testing PTFE tube and fibers immersed in dewar, which is constantly refilled with LN2. In total we are testing:

- PTFE tube that was use in module-0
  - One piece of PTFE tube (½” OD x ⅜” ID)
- PTFE tube that was will be use in module-1
  - One piece of PTFE tube (⅜” OD x ¼” ID)
- One GoPower optical fiber
  - 62.5um core and 1 meter length
  - light test and power test was record before fiber were immersed in LN2

Materials are periodically inspected and information is recorded in a excel.



PTFE tube (module-0)

PTFE tube (module-1)

Conclusions and next steps

Conclusions:

- We have developed a standard QA/QC procedure for the optical fibers
- Different test has been performed over the GoPower fibers; such as, thermal stress, power losses studies, etc.
- PTFE tube and fibers are immersed in LN2 and periodically inspected

Next Steps:

- Continue power loss studies:
  - Repeat the measurements using different power inputs by the laser box unit
- PoF/SoF fiber bundle for module-1 will be assembled:
  - 24 optical fibers will pass the three-steps QA/QC procedure
  - Fibers will be equally distributed in 4 PTFE tubes
    - 6 optical fibers per XA (4 tube x 6 fibers = 24 fibers)
  - Module-1 PTFE tube will be used (⅜" OD and ¼" ID)