CERN Mock-up test results

LONG RUN

17/07/2023

1. Setting up the Mock-up
2. LN2 results
3. LAr tests
   a) Overall conditions of the test
   b) Stress test and long stay test
   c) Humidity tests
4. Conclusion

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(1) CPPM, (2) CERN,(3) Queen's University

Mock-up
INTRODUCTION

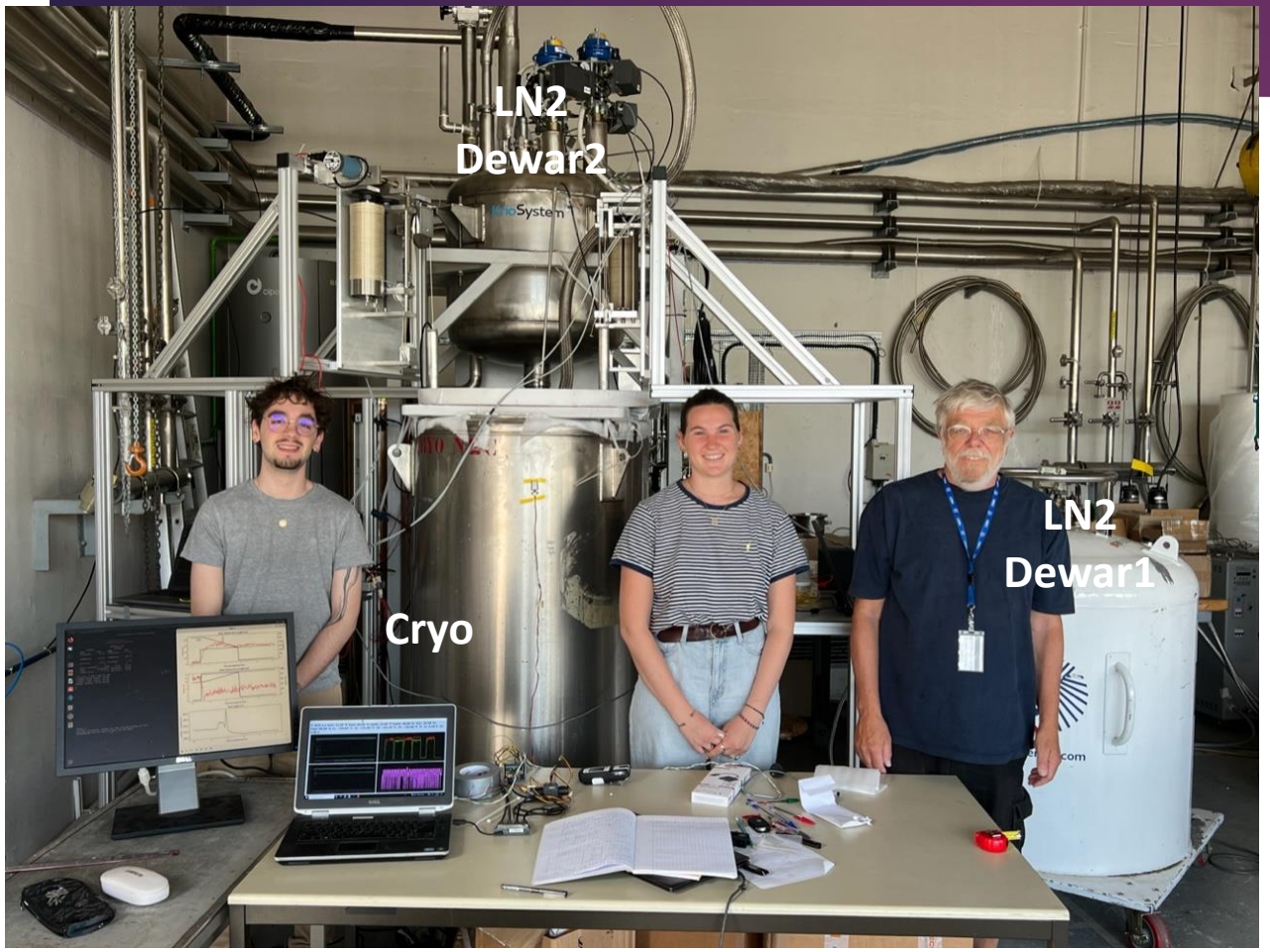
Determine robustness of calibration system at cold, and during a long period (LN2 then LAr).

	MU_CShort	MU_CLong	MU_Warm
Purpose	Robustness against ice formation, source blocked, bend, pipe leak		Behaviour in bends, DS20k Length
Temp. (K)	LN2 (77)	LN2 (77), LAr (88)	Room (290)
Location	CPPM	CERN	CPPM
Pipe lgth (m)	4	2	15 (~DS-20k)
Nb bends	2	1	15 (11, 7)
Runs	09+11/22, **03/23**	***1 month @ June 23***	**03-04/23**

Huge thanks to the CERN Cryolab for providing and running the Cryostat, the LN2 and the LAr

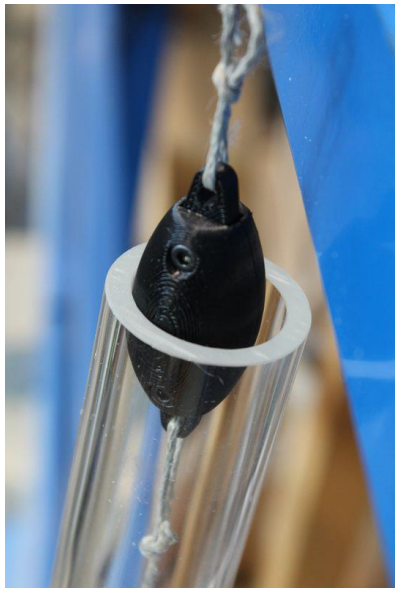
Mock-up

TEST'S SCHEDULE



Pseudo–source

- L = 5.5cm
- ϕ = 2.5 cm
- M= O(100) g

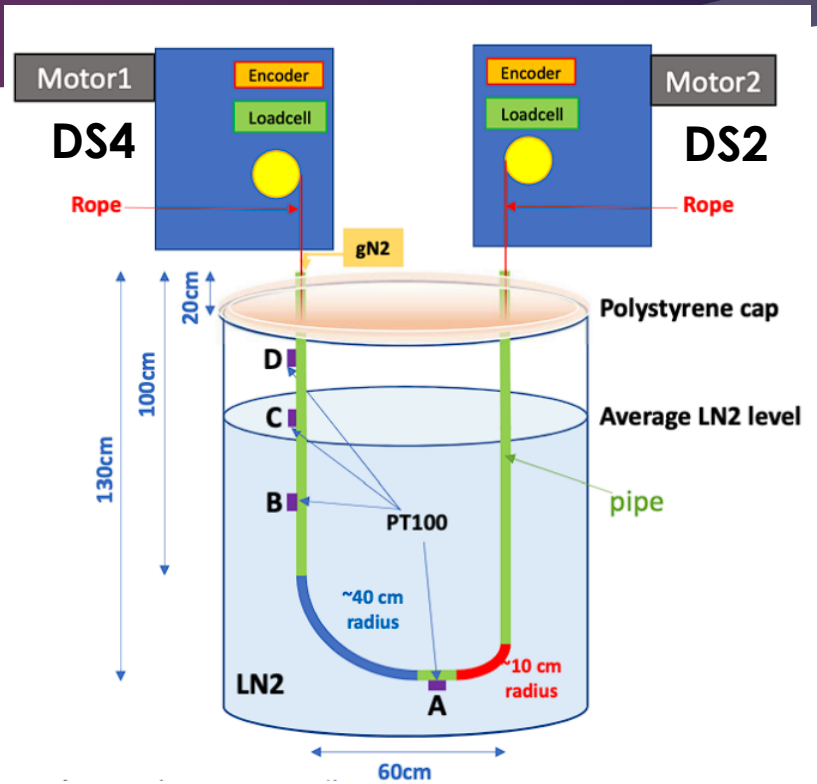


In CERN Cryolab, building 159

- **30/05-2/06 : Installation**
- **5-9/06 : Settings**
- **9-26/06 : LN2 tests**
- **26/06-03/07 : Warming up Cryo to put LAr**
- **03-17/07 : LAr tests**

Mock-up

SETUP



The tube cap is **not fully hermetic** because of rope and gN2 flushing

The cryostat is **not fully adiabatic**
➔ **Need constant refill with LN2**
➔ **Only one fill for LAr**

- 4 PT100 probes (A, B, C, D)
- 1.3 meter of useful tube (from A to D)

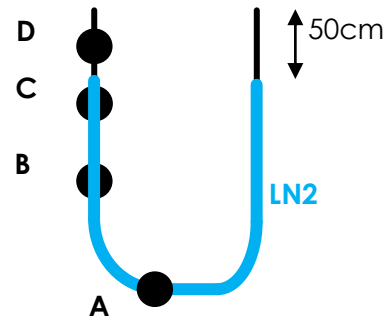
LN2 results

1. 18 days of test at LN2 temperature, gN2 flux 60L/h, 3.9% of motor usage (DS20k <1%)

2. Regular refill of LN2 in cryostat to keep level around 80%
   a) Temperature probes A,B,C below -186 °C

3. LN2 inside the tube after few hours, and during all the test
   a) LN2 block gN2 flush on right side → Ice formation
   b) Flushing also right side at 250L/h for 1 night
   → Ice mitigated (turns into frost)

4. Source moved ~750m (5x DS20k)
   a) Tension stable between 15-30N
   b) Small impact on tension when stopping the source during long periods (1min → 2 days)



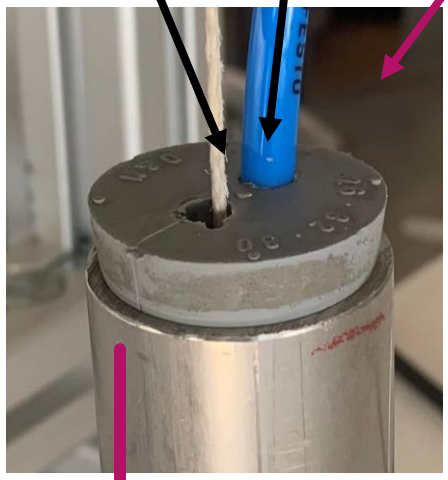
System robust at LN2 temperature

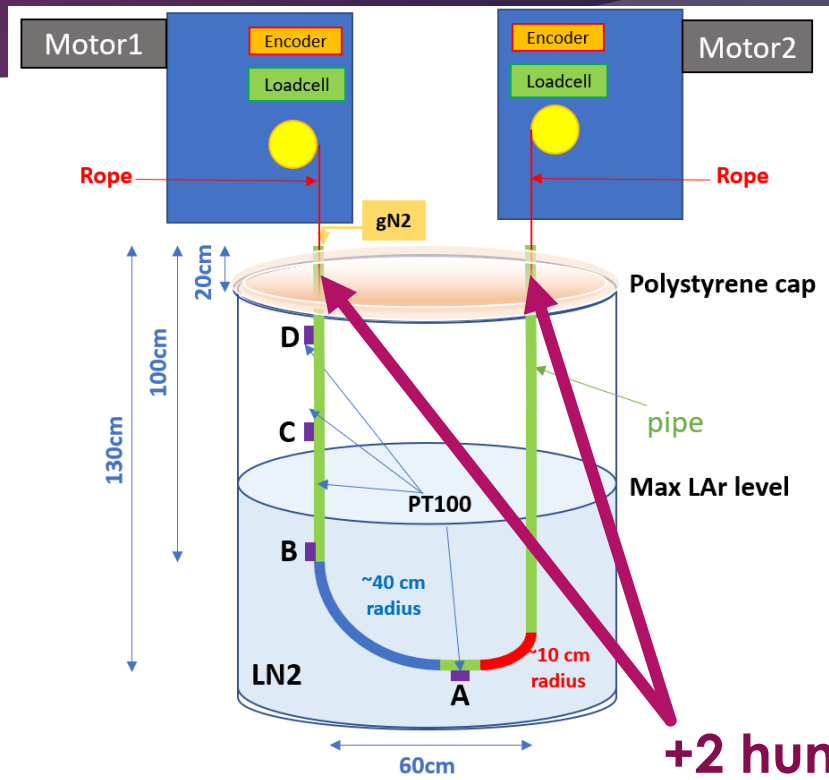
Link to the LN2 presentation

Liquid Argon tests

Mock-up – LAr

SETUP





+2 humidity sensors 10cm below

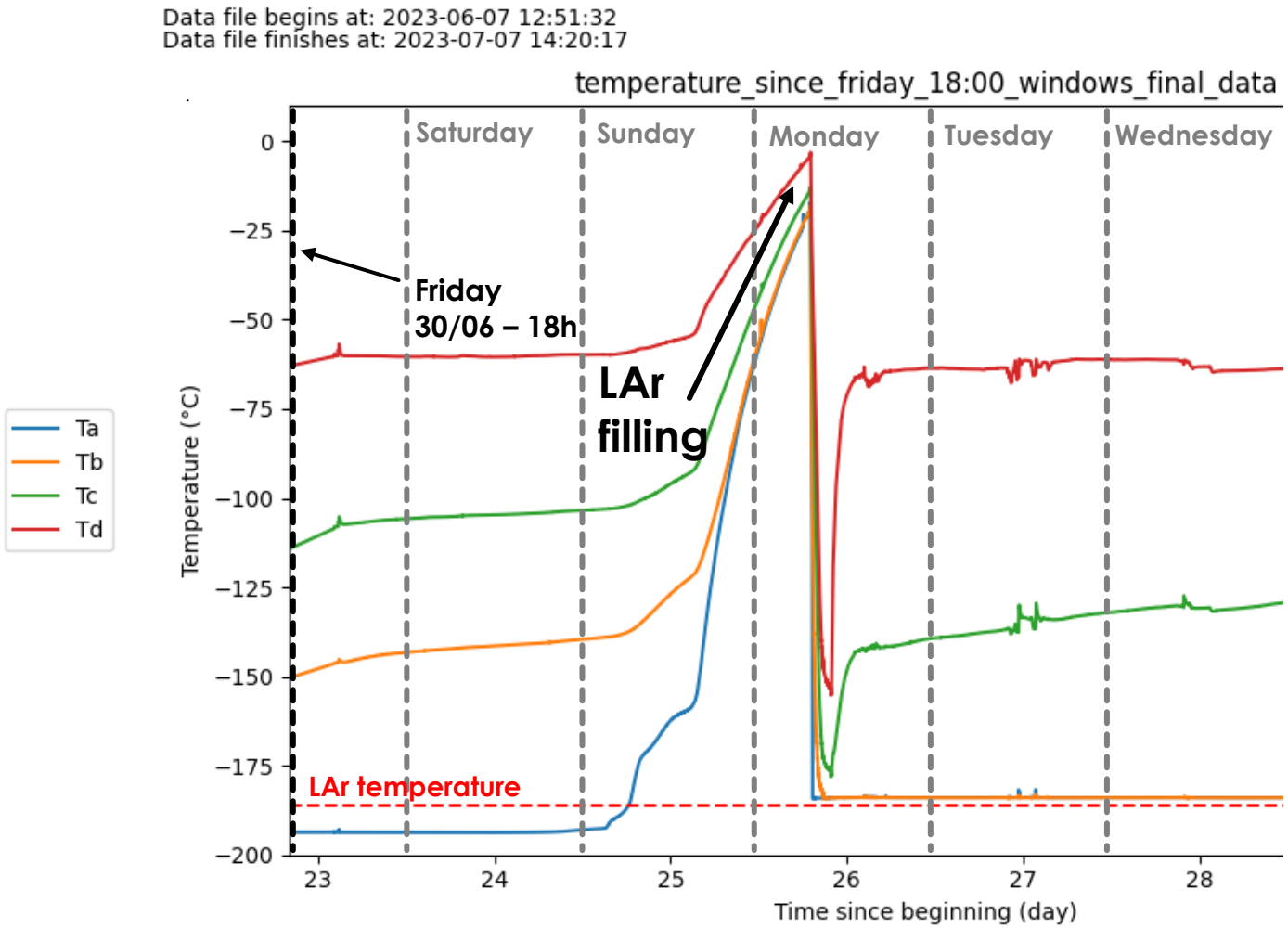
No liquid in the tube
→ Flushing gN2 only on left side

+2 humidity sensors

DS4 (left) | DS2 (right)

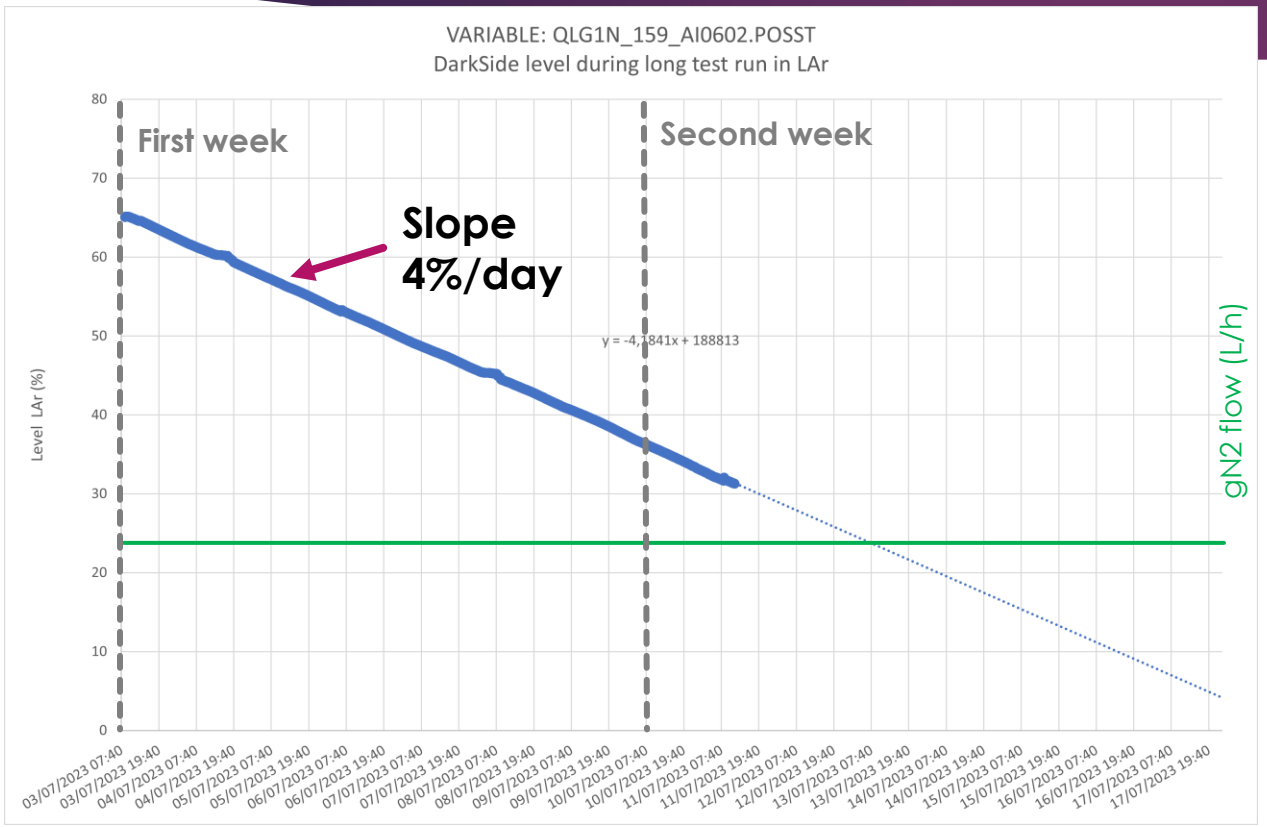
Tank filling with LAr

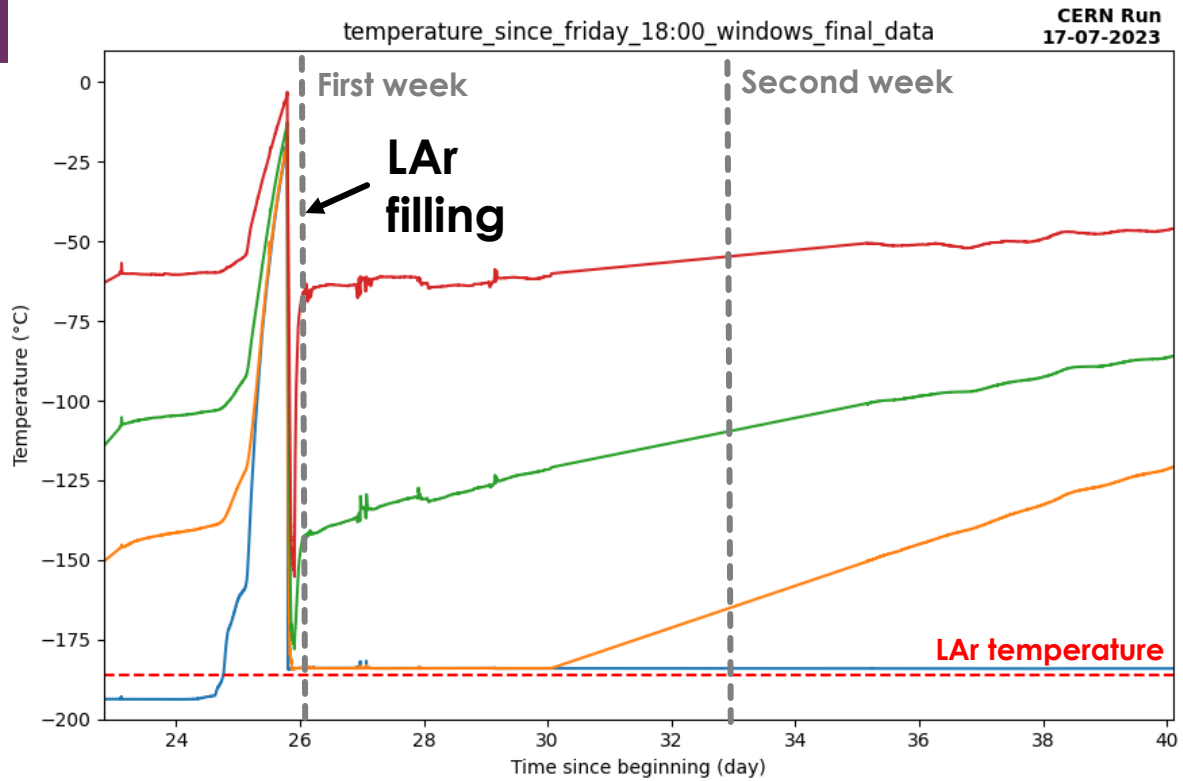
- Monday 26/06 :
  Start the heating process. Small heater placed in the tank.
- Thursday 29/06 :
  Heating process accelerated : larger heater inside the tank, lid of the tank removed → had to move motor system
- Friday 30/06 :
  End of the active heating process, letting tank heat with ambient temperature.
- Monday 03/07 :
  Filling of the cuve with LAr



Test conditions for LAr (14 days)

TANK FILLING AND TEMPERATURE OF PT100





- **Only one fill of LAr in tank**
- Flushing at 60L/h

Motorized system used for 0.8% of 2 weeks

- T_A at T_{LAr} for 2 weeks
- T_B at T_{LAr} for 4 days
- $T_D, T_C \in [-186, -30]\ °C$

Overall conditions of the test

ICE FORMATION MITIGATION

Date	Monday 03/07	Tuesday 04/07	Wednesday 05/07	Friday 07/07
Left Side (DS4)				
Right Side (DS2)				

Blowing into tube **(Extreme nonrealistic scenario)**

→ Increase humidity to 100%

→ Ice formation

➔ **After 20h of 120L/h gN2, turns into frost**

Pictures are cropped to be visible so do not pay attention on sizes, more on shapes.

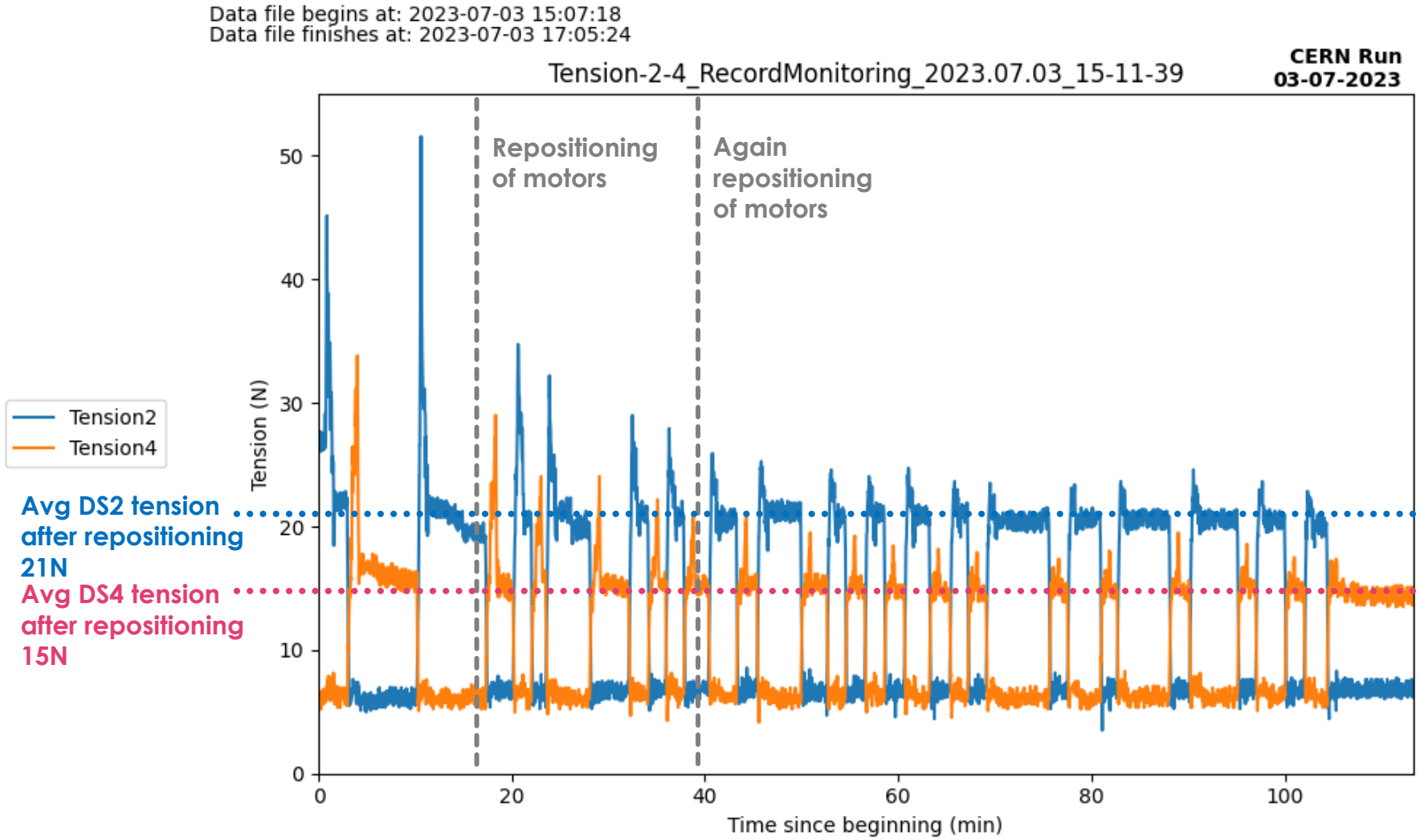
The rope on the corner of tube to take the picture, in center usually

Similar conclusion as LN2

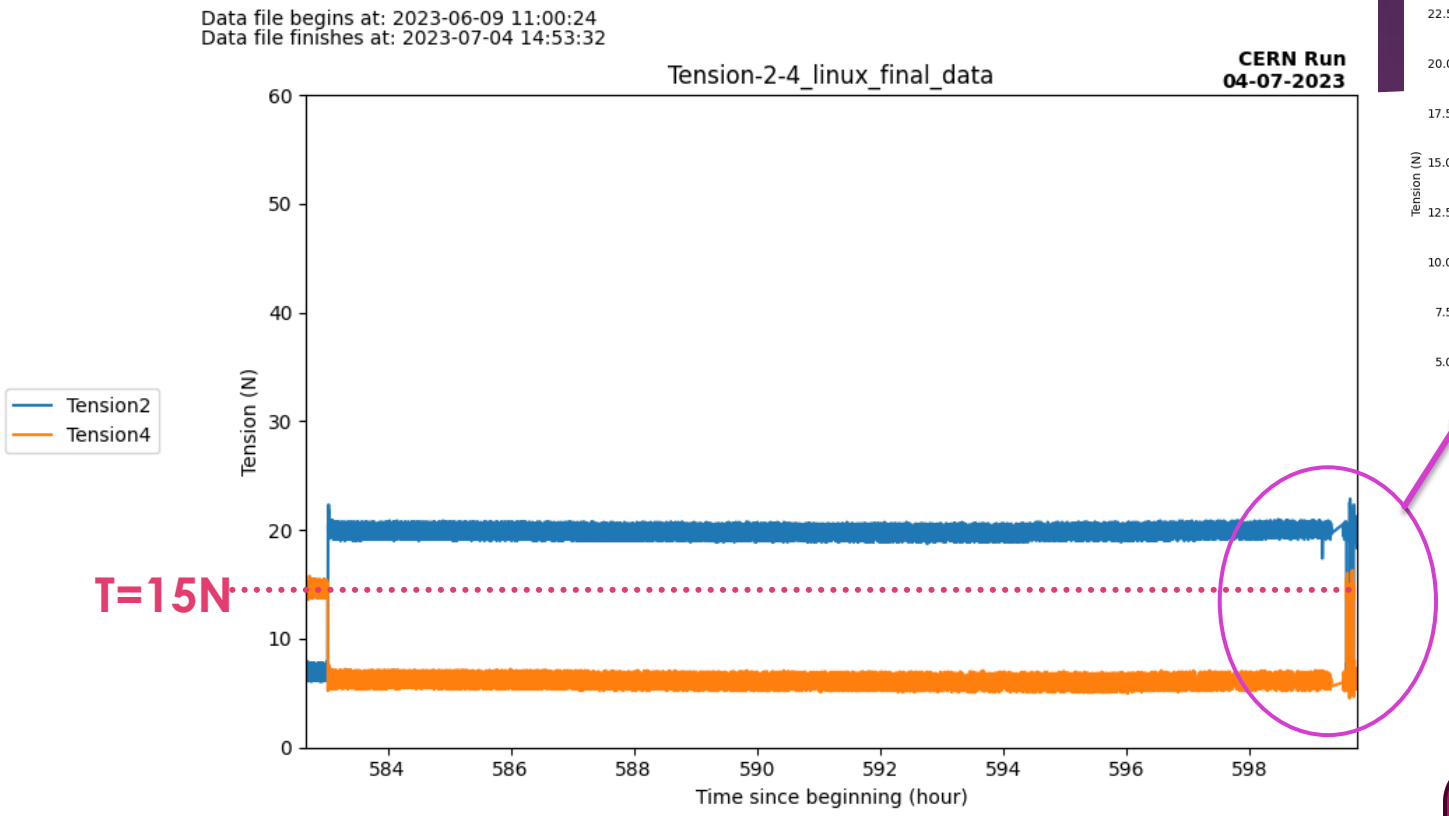
Tension during stress test

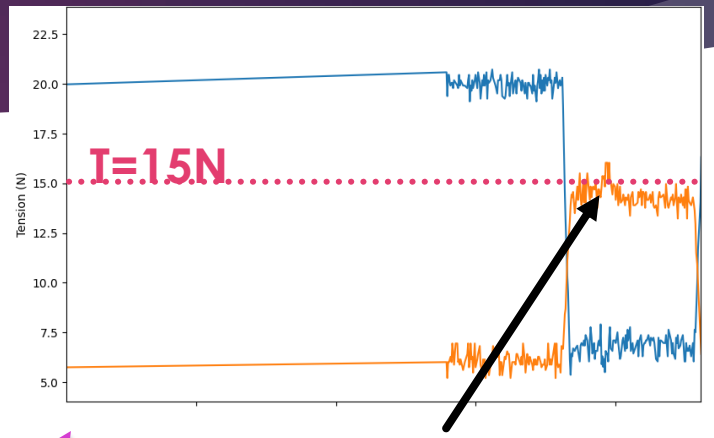
- At beginning, up to 50N due to incorrect motor alignment
  → Solve by repositioning motors

➔ Tension value stable and comparable to LN2



Long stay test





Max tension 16N

Source left at D for 16h, no high tension after moving it back to A (DS4)

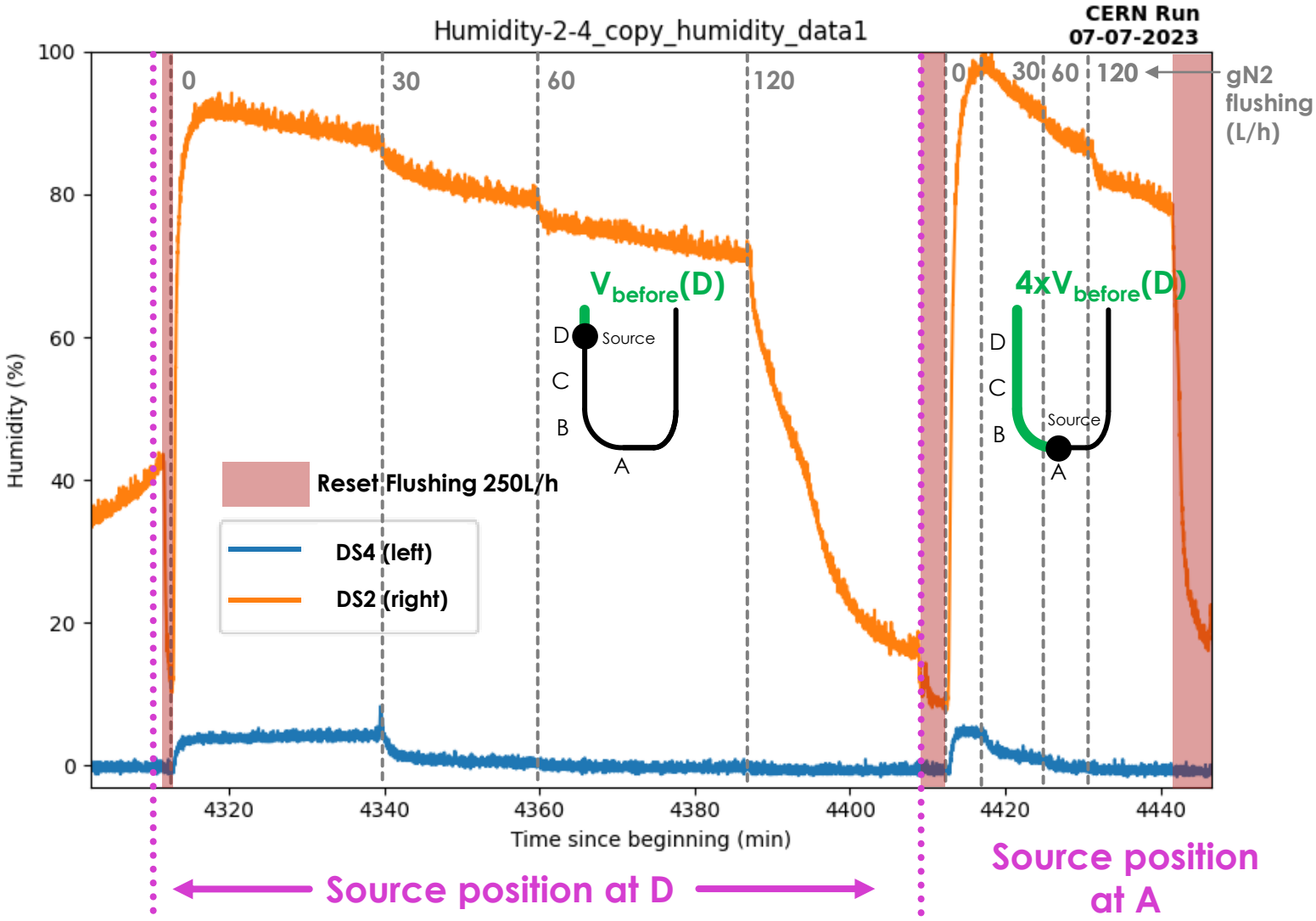
➔ **Same plots when source stays for 5 days at same position**

Tension is not related to the duration of the stay at the same position for LAr neither

Humidity test without moving source

- Vary gn2 flushing F and measure humidity when source at two positions : top-left (D), bottom (A)
- Determine F which remove humidity "instantly" (<=5min) → $F_{threshold}$
- Source Top-left : V_{before} small
  → $60 < F_{threshold} < 120$ L/h
  ➔ **Measure : $F_{threshold}$ = 100L/h**
- Source Bottom: V_{before} larger
  → $120 < F_{threshold} < 250$ L/h
  ➔ **Measure : $F_{threshold}$ = 150L/h**

➔ **Assuming same scaling, $F_{threshold}$ for DS20k with source at bottom might be around 300L/h**



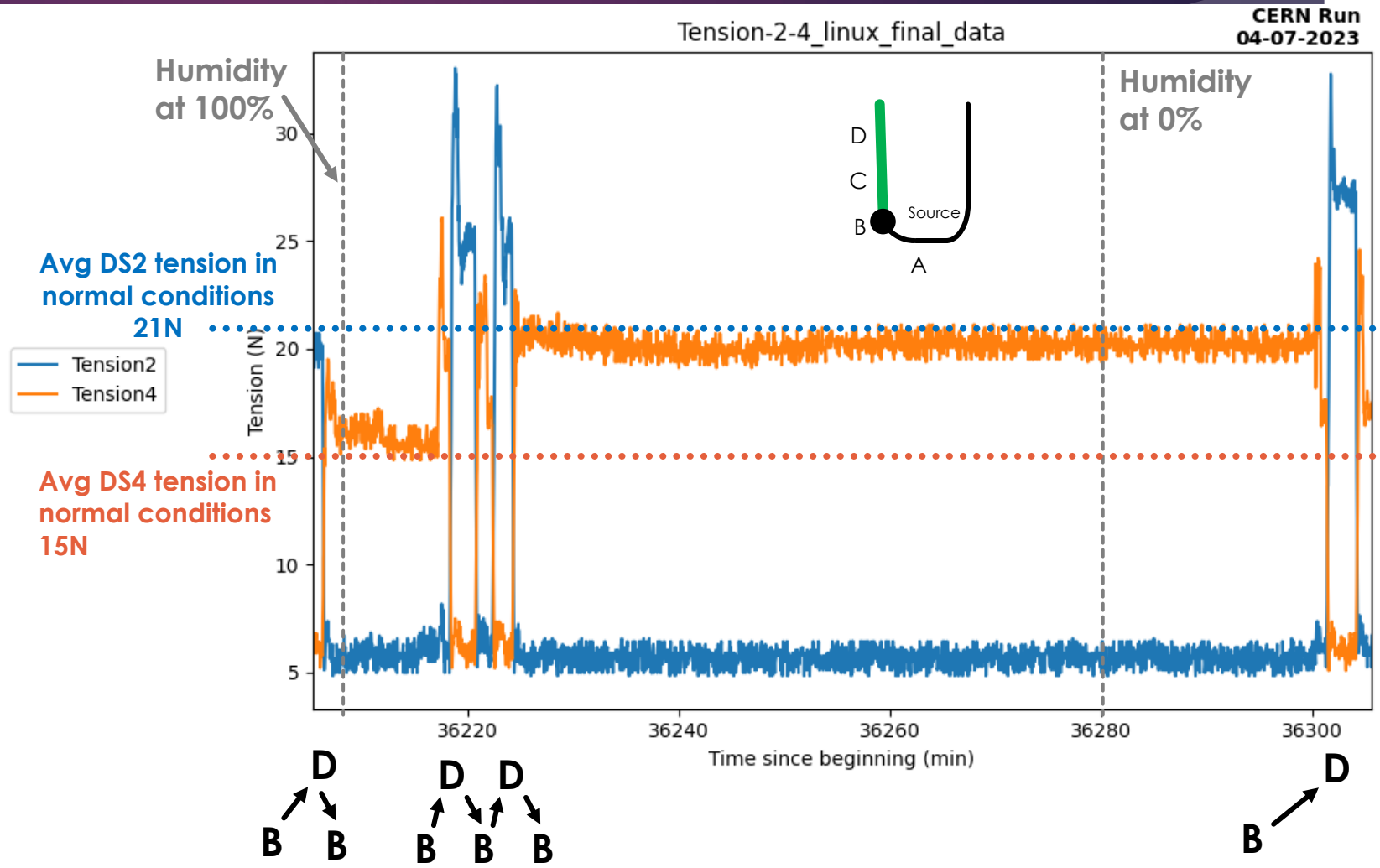
Humidity test when moving source 1/2

- Blow in tube from both sides → **After 5min, both humidity are at 100%**

→ **B → D → B : +12N/+11N wrt normal**

- gN2 at 120L/h, put back top caps → **After 1h30, both humidities at 0%**

→ **B → HG* → CG* : +12N/+9N wrt normal**

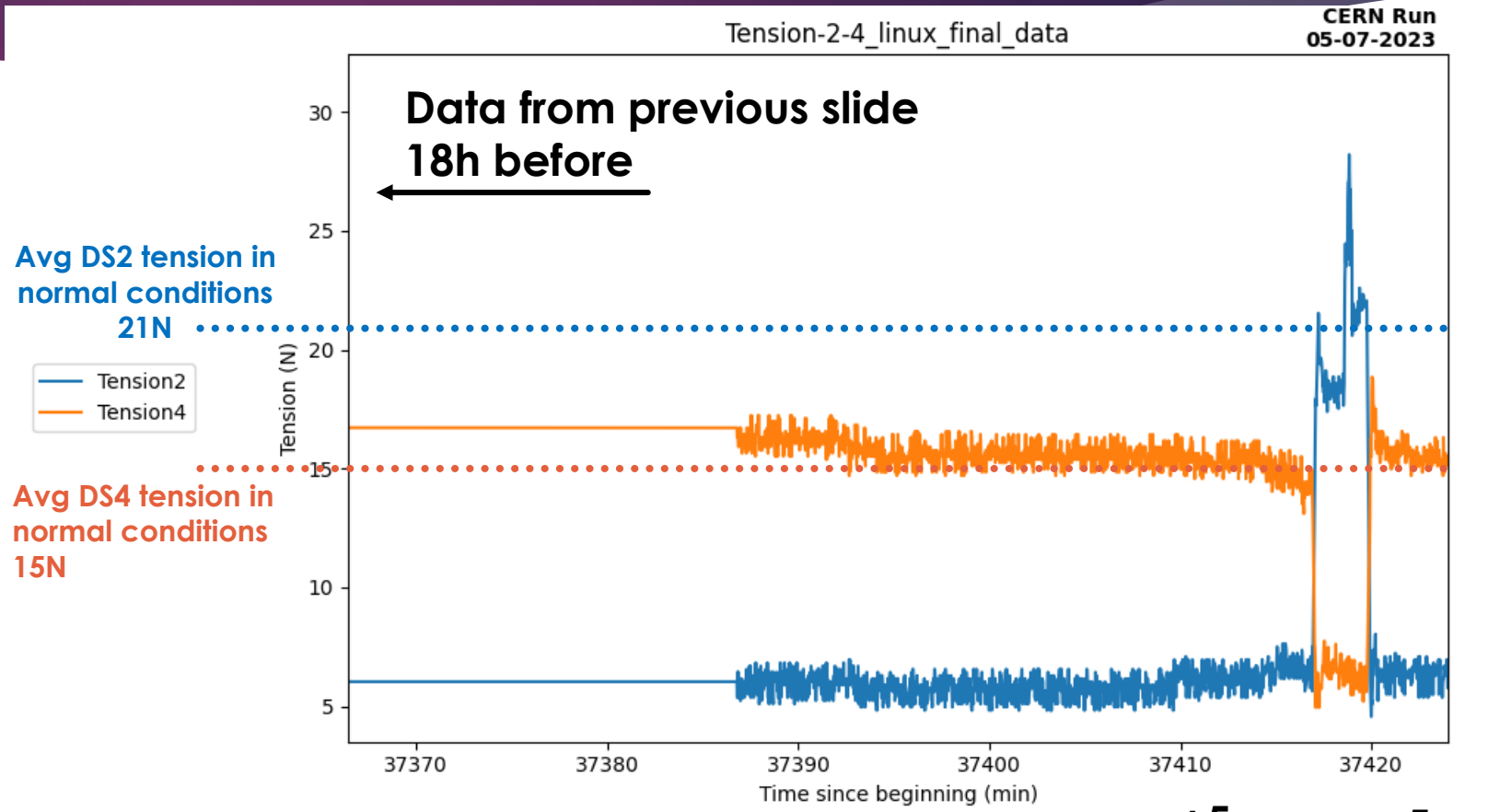


Humidity test when moving source 2/2

- Pseudo-source in position D for 1 night

→ **D → +5cm → -5cm : +8N/+5N wrt normal**

➔ With long-time flushing, maximum tension due to ice formation decreases



Ice formation conclusion

1. Everything should be done not to introduce any humidity in the tube
   → This will be achieved by the glove box design, flushing gN2 and the strict procedure foreseen for its usage

2. By default, gN2 should be flushed continuously in the tube→ **should be O(100) L/h**

3. In case humidity is inadvertently introduced in the tube*, it will gradually be clustered on the tube internal surface. As demonstrated by the mock-up, increasing gN2 flushing will mitigate the situation

* Note that with the plastic top cap used for the mock-up, this was the case, explaining why a thin layer of frost is visible even when flushing gN2.

Conclusion

- **Run at CERN for one month (18 days LN2 / 14 days LAr) ➔ COMPLETED**
  - ✓ Liquid in the tube 50cm from top with LN2 ➔ Not observed for LAr
  - ✓ Ice formation mitigated using gN2 ➔ Frost
  - ✓ Average tension 15-30N during stress test
  - ✓ Small impact on tension when stopping the source during long periods.

Robust behavior of calib system at LN2 and LAr temperature for 2 weeks each

	DS-20k	MU_CS	MU_CL		MU_W
	General				
Goals	NA	Cold behav.	Robust at cold		bends scale 1:1
Availability	10/24	09/22	05/23		02/23
Runs	>02/26	2022-23	2023		2023
	Conditions				
Temperature (K)	88	**77**	**77**	**88**	290
Usage time / run (days)	30	0.3	18	14	0.3
Location	LNGS	CPPM	CERN		CPPM
	Mechanics				
Tube total length (m)	20	~ 4	~ 3		~15
Tube thickness (mm)	1.5	1.65	1.5		1.5
Tube internal diameter (mm)	30	30	33		30
Tube Material	SS	Ti	SS		Plastic
Nb of bends / tube (ϕ=40cm)	14, 15	2	1		**15**
Source length (cm)	TBD	3	5		5
Source diameter (cm)	TBD	1	2.5		2.5
	Requirements / Performance				
Speed of the source (cm/s)	> 1	3	1		2
Position accuracy (cm)	±1	±1	1		±1
Tension (N)	< 150	25-40	15-30		60-90
Ice formation (block)	No	No	Yes but sublimated		NA NA
Total distance for all sources (m)	160 (/yr)	> 100	800	100	> 100
Total nb of back&forth / tube	4 (/yr)	44	280	35	>6

BACK-UP

Humidity test 2/3 – Moving source at A

- Pseudo-source in position A
- Blow in tube from both sides to increase humidity at maximum and remove gN2
  = Extreme nonrealistic scenario

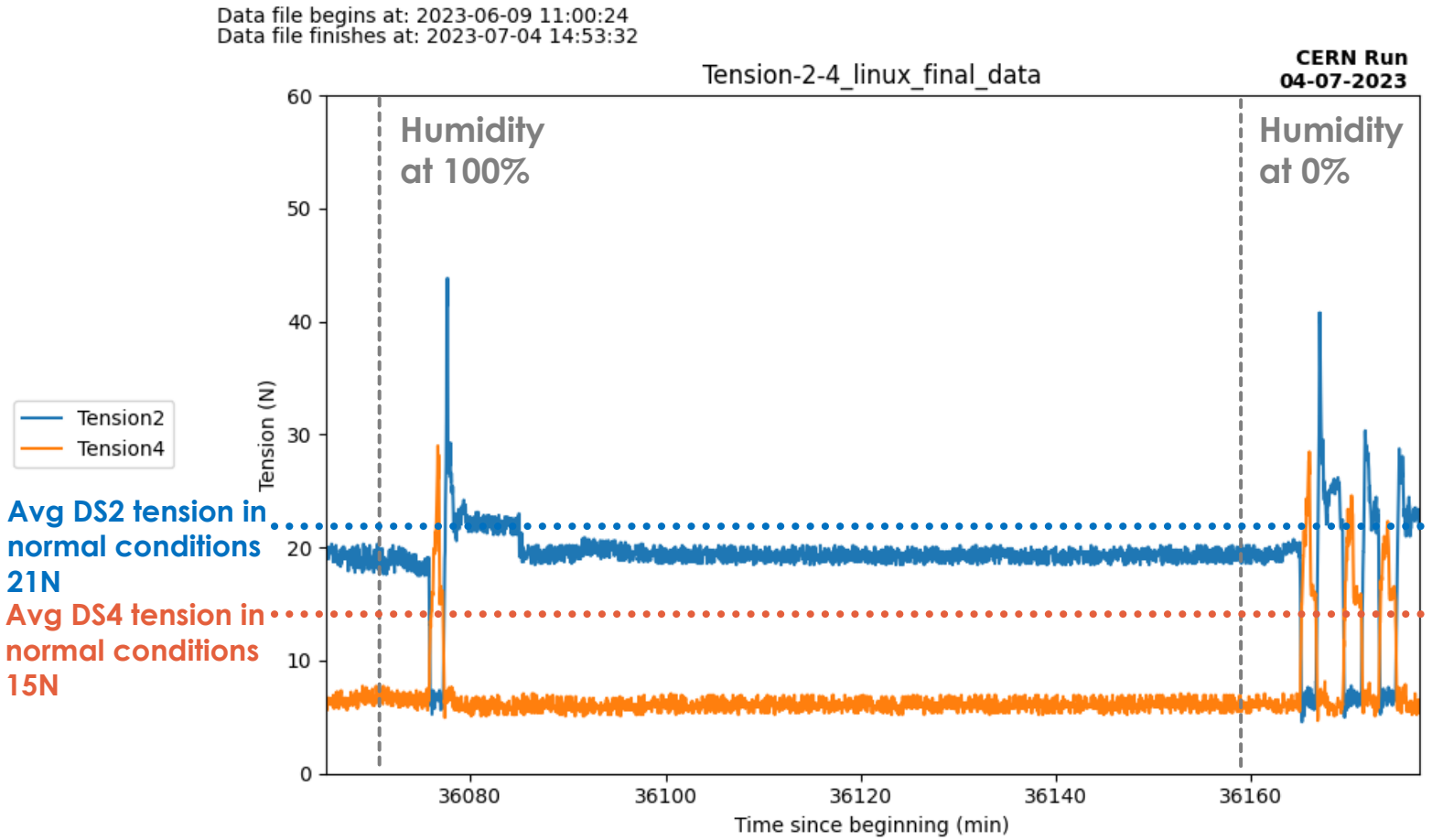
→ **After 5min, both humidity are at 100%**

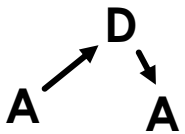
→ **A→ D → A : +23N/+15N wrt normal**

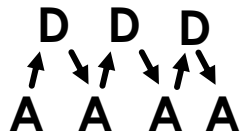
- After 15min, put back the top caps and gN2 at 120L/h

→ **After 1h30, both humidities at 0%**

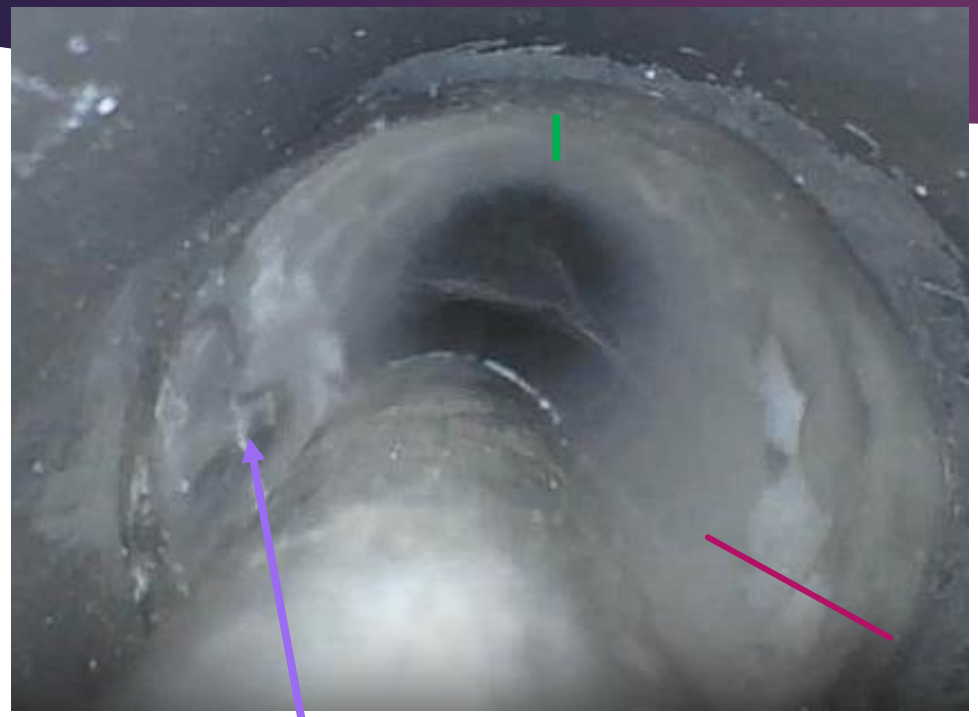
→ **A→ D → A : +20N/+15N wrt normal but back to normal after 3 times**



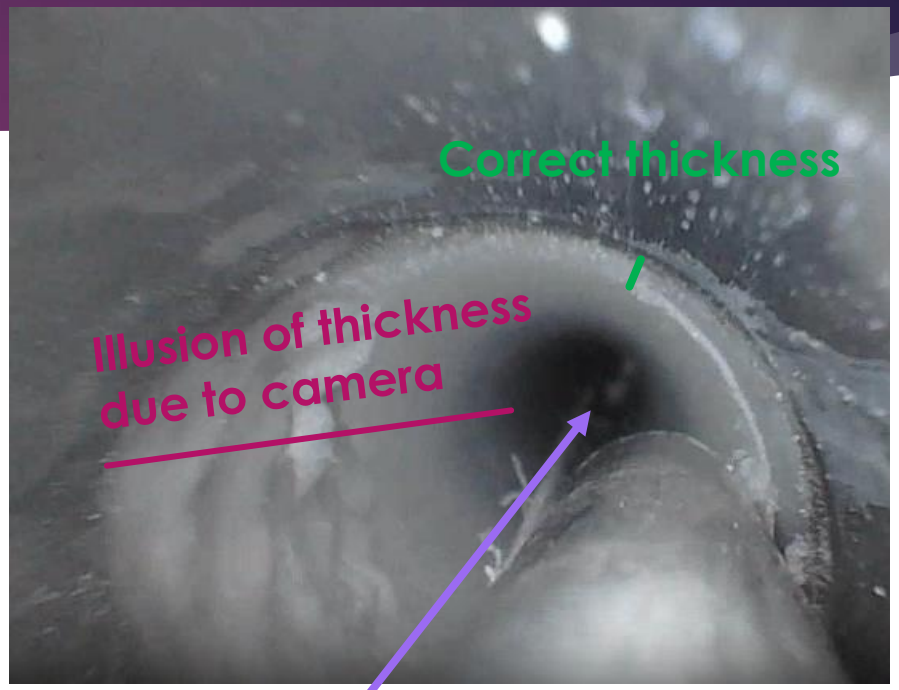




Ice/Frost identification (on DS2)



Soft frost removed with the stick



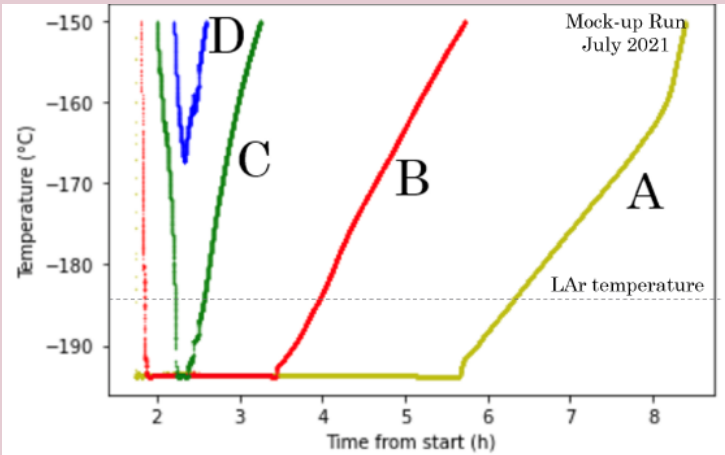
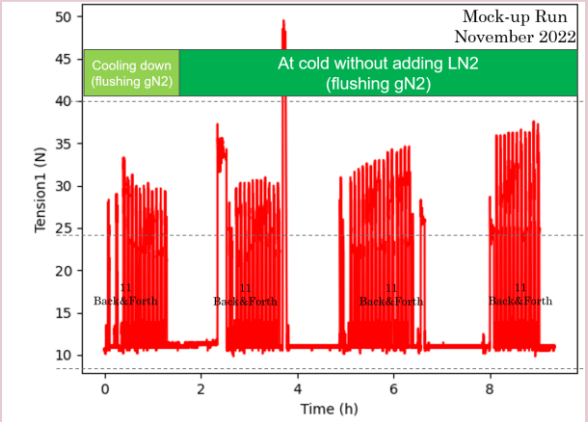
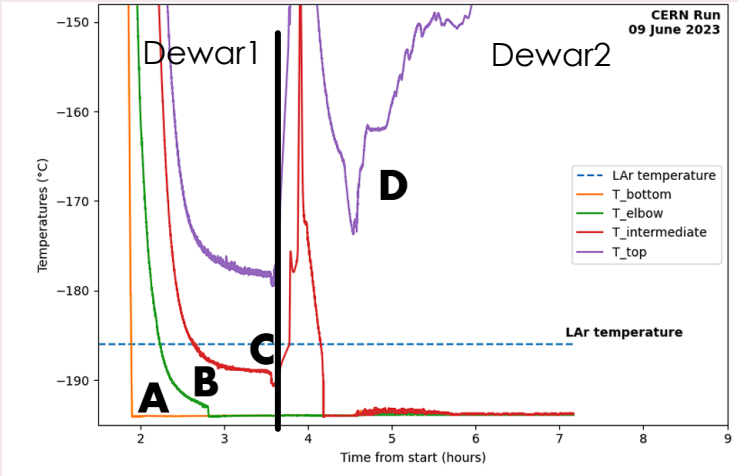
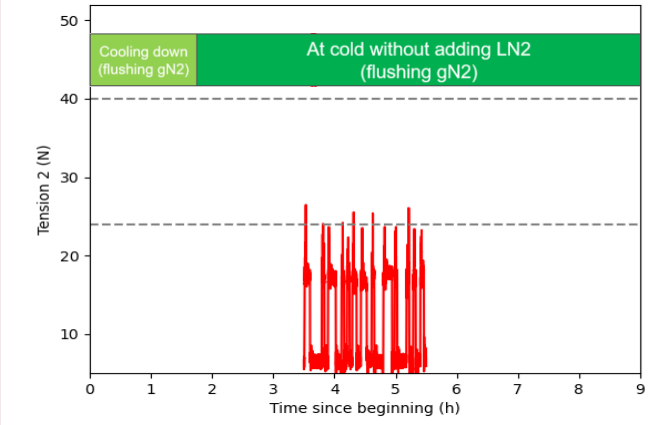
Frost pieces coming off

The top part is frost (~1mm thick)
Same on DS4

Liquid Nitrogen tests

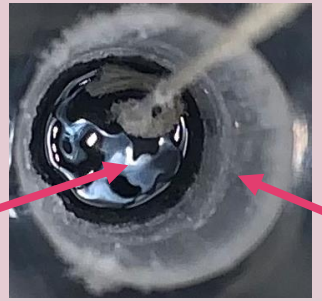
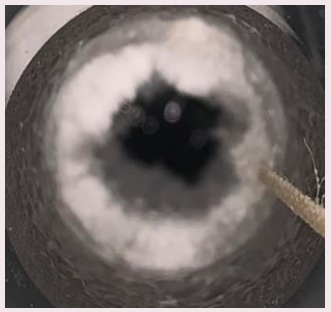
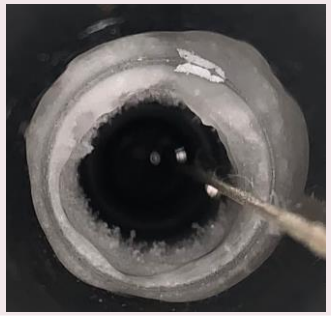
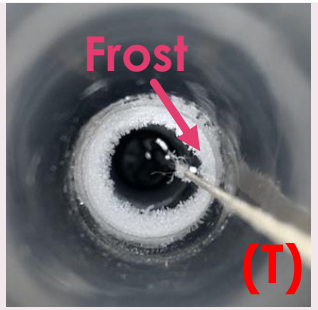
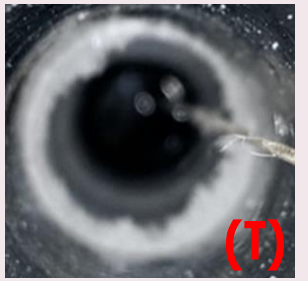
Mock-up

COMPARISON WITH CPPM MOCK-UP (FIRST 8 HOURS)

RUN	Temperature of A, B, C, D	Tension	Conclusion
CPPM short run, Poorly isolated cryostat (0.16 m³)			• Left gN2 flushing at 60L/h • T_A <= T_{LAr} for only 5h after filling • Tension 12-40N
CERN long run, Vacuum isolated cryostat (0.4 m³)			• Left gN2 flushing at 60L/h • T_A, T_B, T_C always below T_{LAr} once filled • Tension 5-25N **Motorized Systems work at CERN.**

Overall conditions of the test

ICE FORMATION MITIGATION

Date	09/06	10/06	12/06	13/06	26/06
Left Side (DS4)					
Right Side (DS2)					

1- Ice formation on both sides (09/06)
➔ **Flush hot gN2 on left at 250L/h (4x nominal)**
➔ **Left side ice turns into frost**

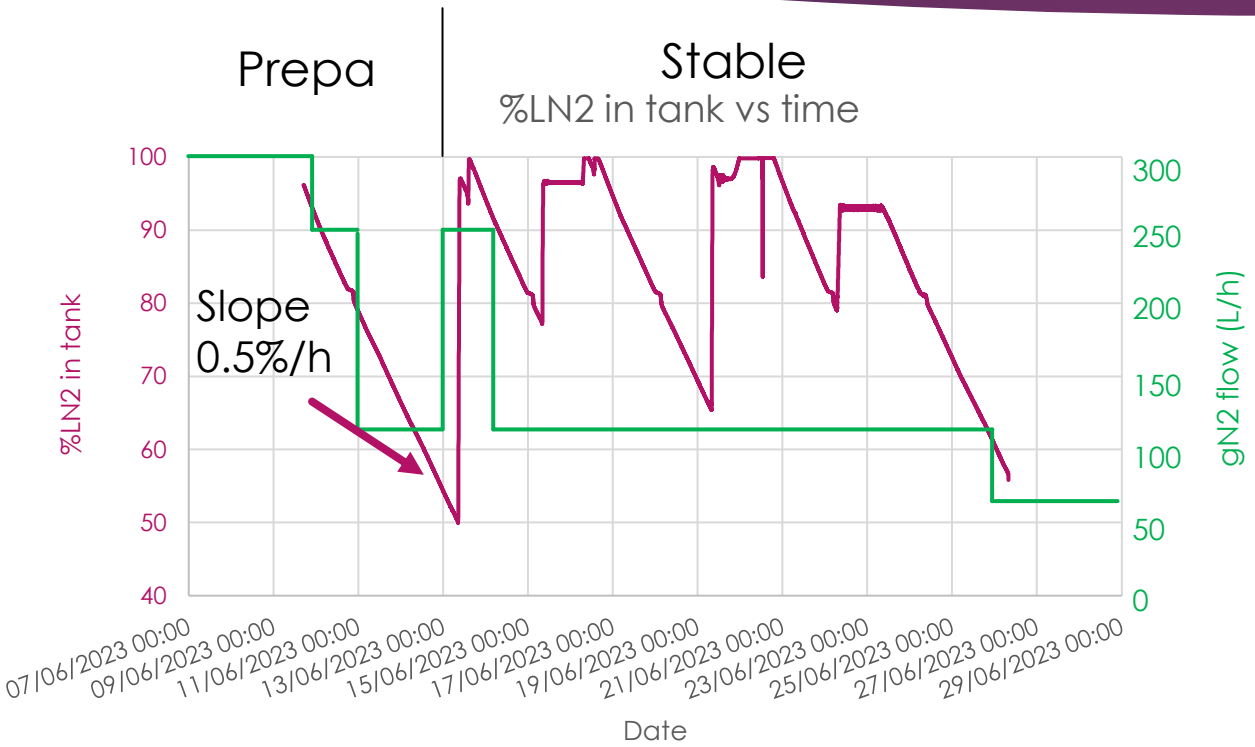
2- LN2 inside (-50cm) tube prevent gN2 to reach right side
➔ **T pipe to flush left and right (250L/h)**
➔ **Ice on right side turn into frost**

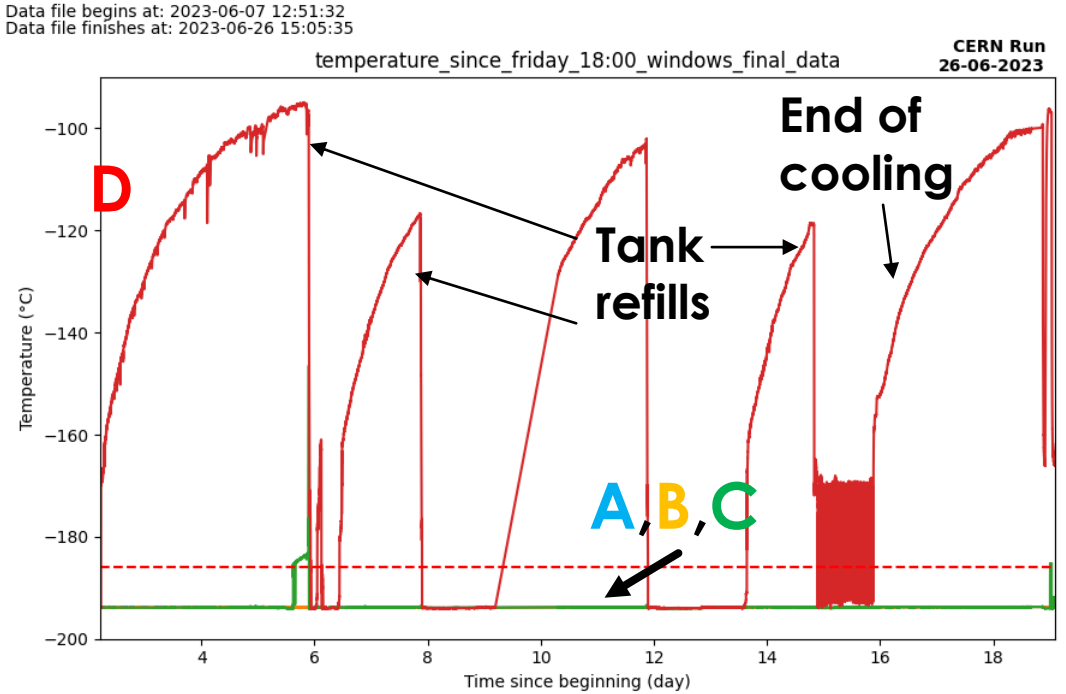
Pictures are cropped to be visible so do not pay attention on sizes, more on shapes.
The rope on the corner of tube to take the picture, in center usually

Ice turns into frost after 1 day of large gN2 flush on both sides ➔ Stable conditions for test

Test conditions for LN2 (18 days)

TEMPERATURE OF PT100 AND TANK FILLING





- **Filling process is automatic** (no auto-filling on the weekends and on Wednesday)
- Flushing at 120L/h (2x60 with T)

- T_A, T_B, T_C always below T_{LAr} for 18 days
- $T_D \in [-190, -100]\ °C$

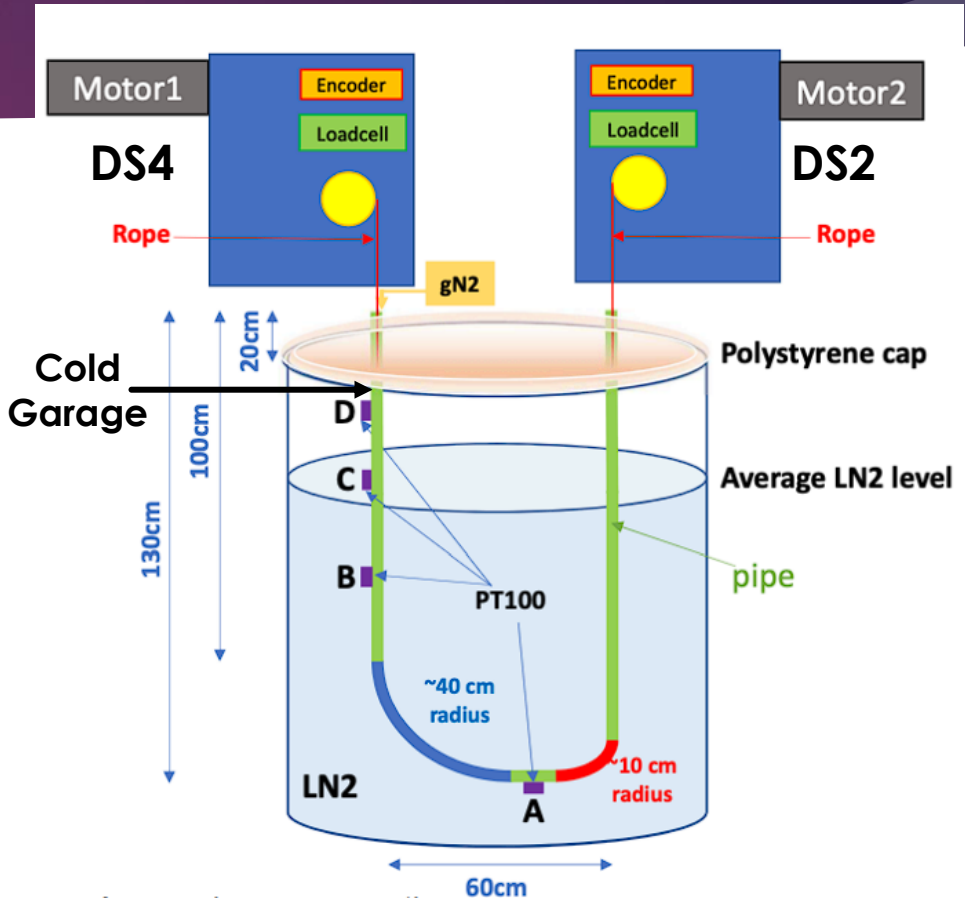
Stress test with LN2

PROGRAM

The goal is to check robustness of the Mock-up

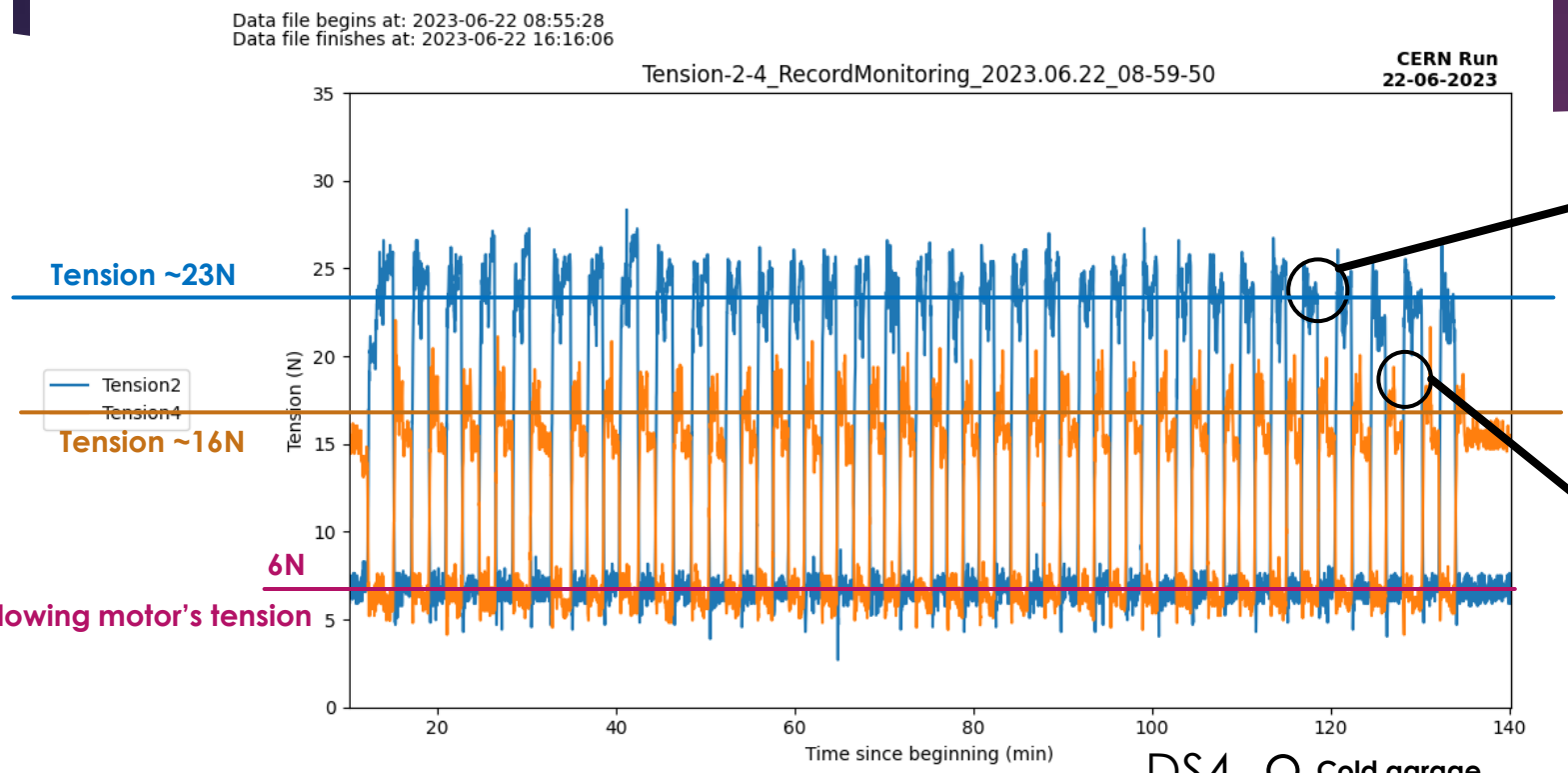
- **Back and forth (b&f) from the cold garage to PT100 A** (2x 1,3m) with a ~1min stop at the edges (~1 cm/s)

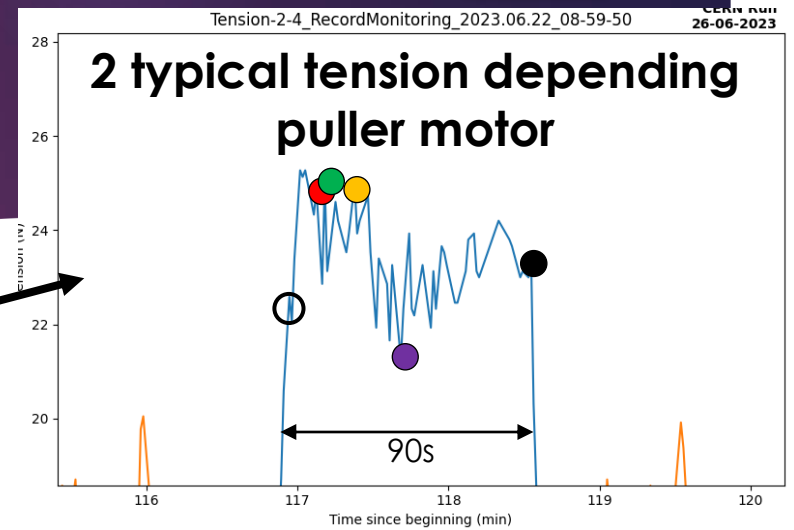
- **35 b&f/day (~3h) for 8 days**
  In DS20K, 8 sources so 4b&f and 20m tube
  → 280 b&f → **70x DS20k**
  → ~740m → **5x DS20k**



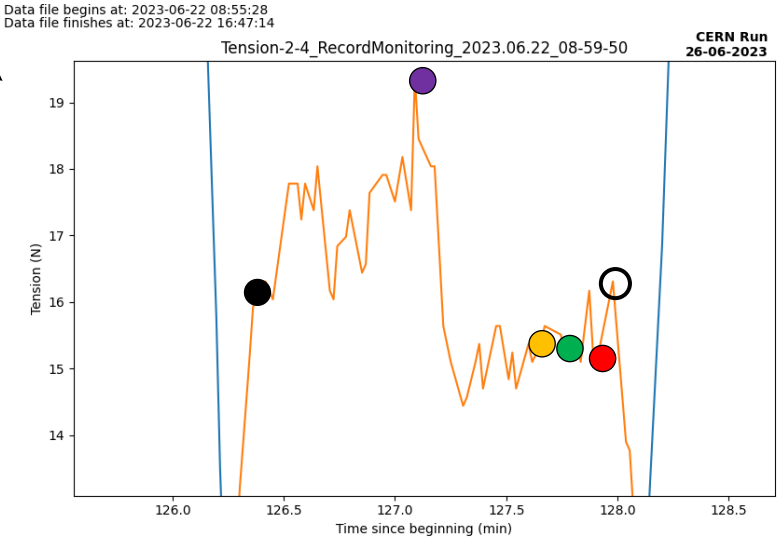
Stress test with LN2

TYPICAL RUN

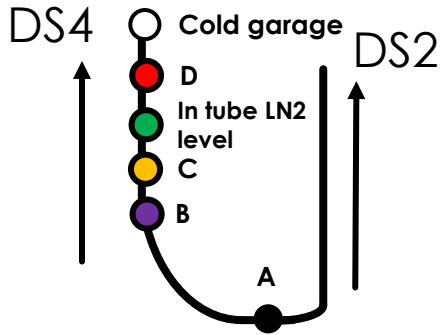




Typical tension for DS2



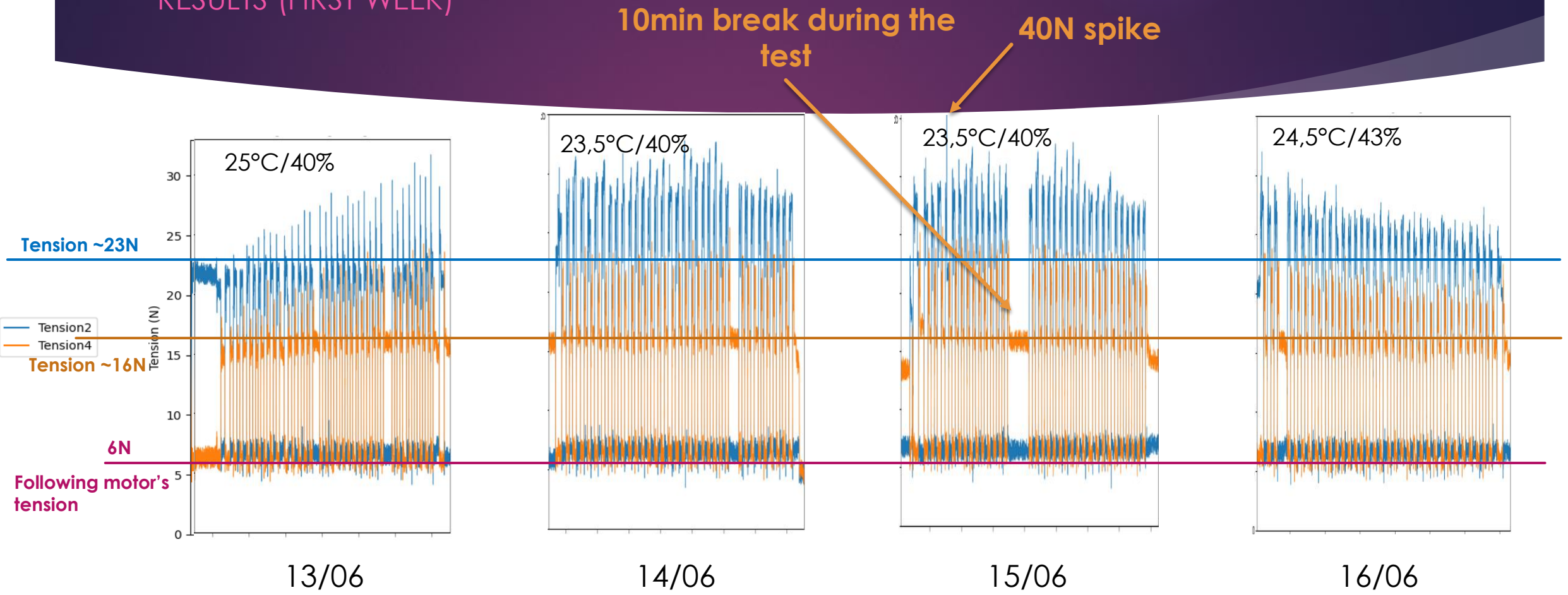
Typical tension for DS4



- **DS2 tension around 24N, no visible impact of tube geometry**
- **DS4 tension lower, and reflects the tube geometry**

Stress test with LN2

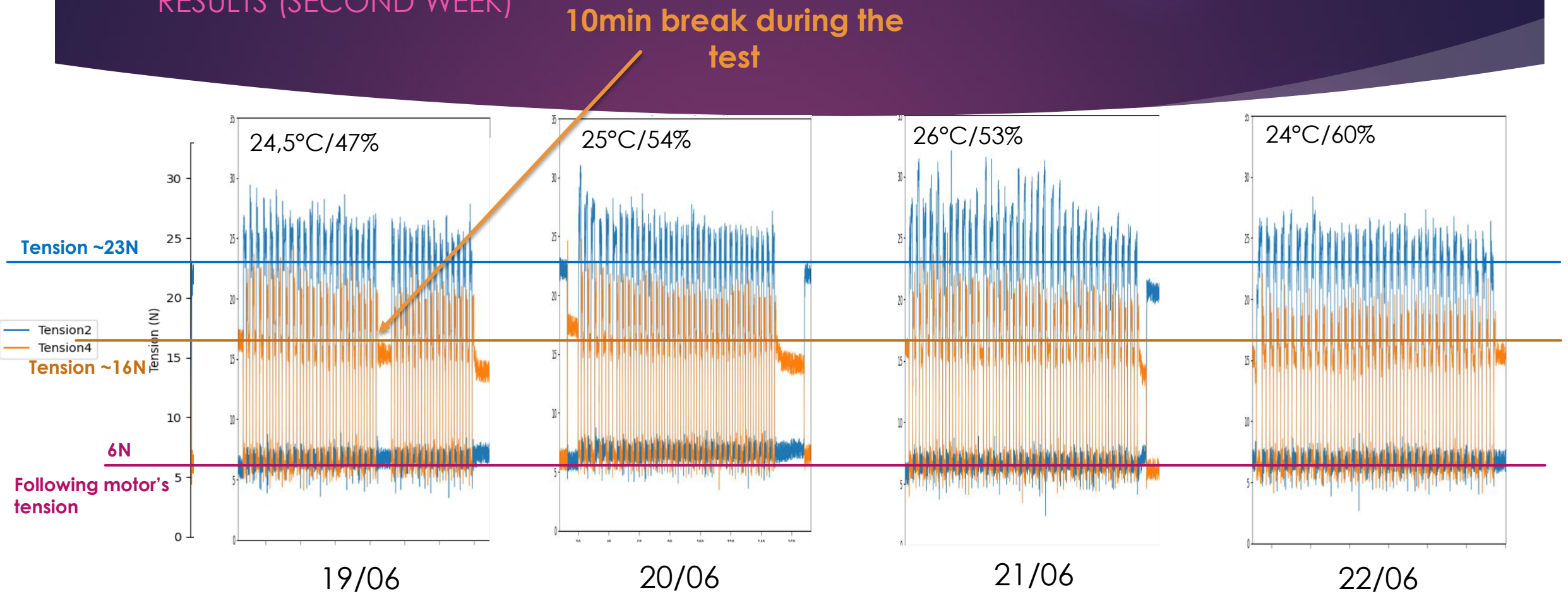
RESULTS (FIRST WEEK)



DS2 tension : two days at 25-30N at worst

Stress test with LN2

RESULTS (SECOND WEEK)



The tension is stable

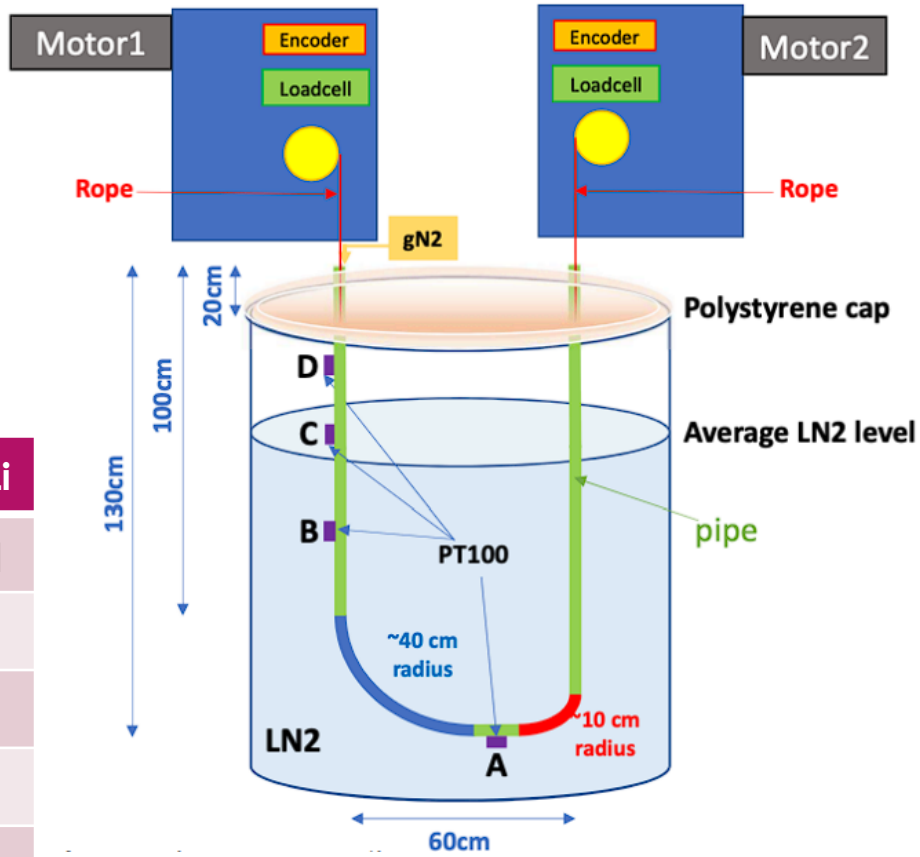
Long stay test with LN2

PROGRAM FOR THE TEST

The goal is to check **how the motors react when the source is left for a long time** at a PT100 step.

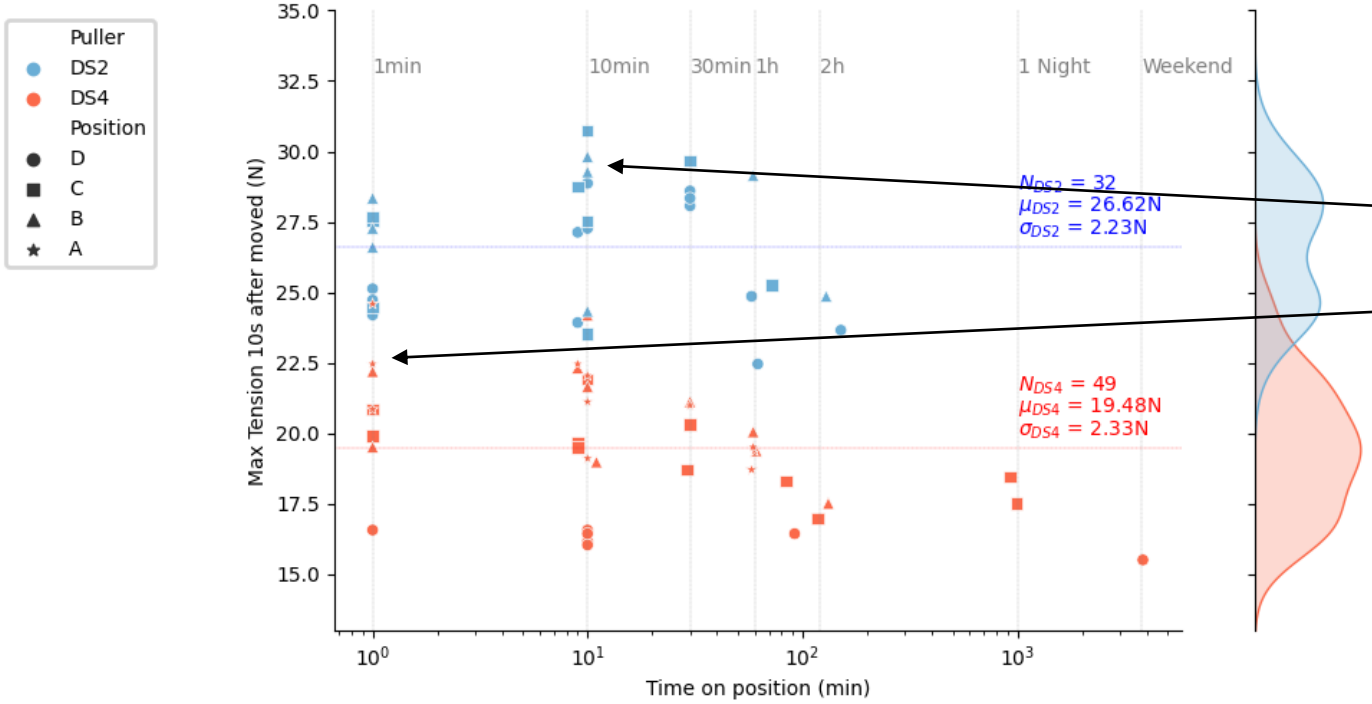
We left the source at different spots for different periods of time (1min, 10min, 30min, 1h, 2h, a night, a weekend)

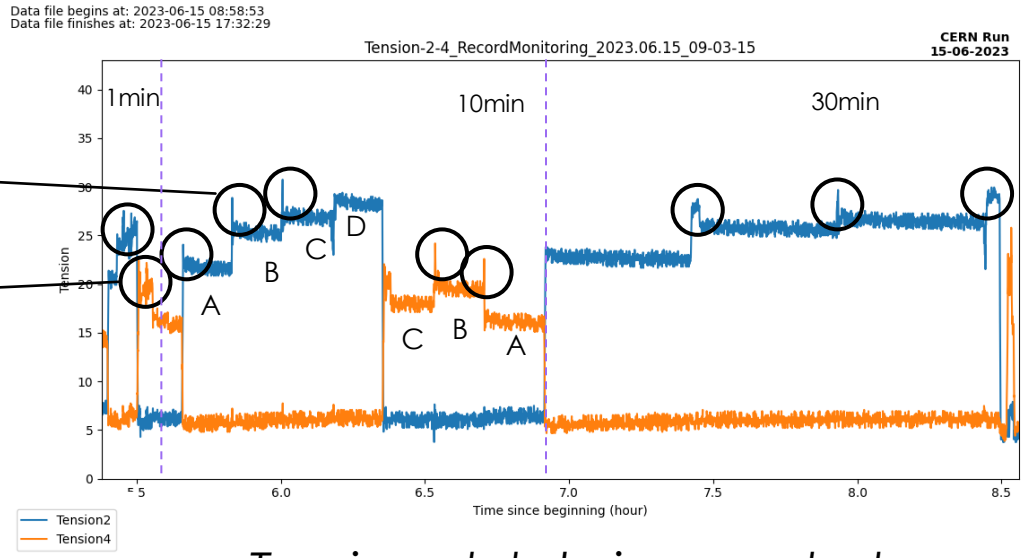
Source	^{57}Co	^{133}Ba	^{22}Na	^{137}Cs	^{60}Co	AmBe	AmC	AmLi
Energy (keV)	122	356	511	662	1173	[0.2, 12]	[2, 7]	[0, 2]
Activity (side) (kBq)	18	1,9	0,36	2,2	0,36	0,14	0,15	-
Activity (bottom) (kBq)	100	5	0,67	4,6	0,6	0,18	0,18	-
Duration of calibration (h)	3,84	18,72	23,52	36	74,4	200	200	-
Time on each spot	**12'**	**1h50'**	**2h20**	**3h45'**	**8h**	**22h**	**22h**	**-**



Long stay test with LN2

TENSION AFTER STOP



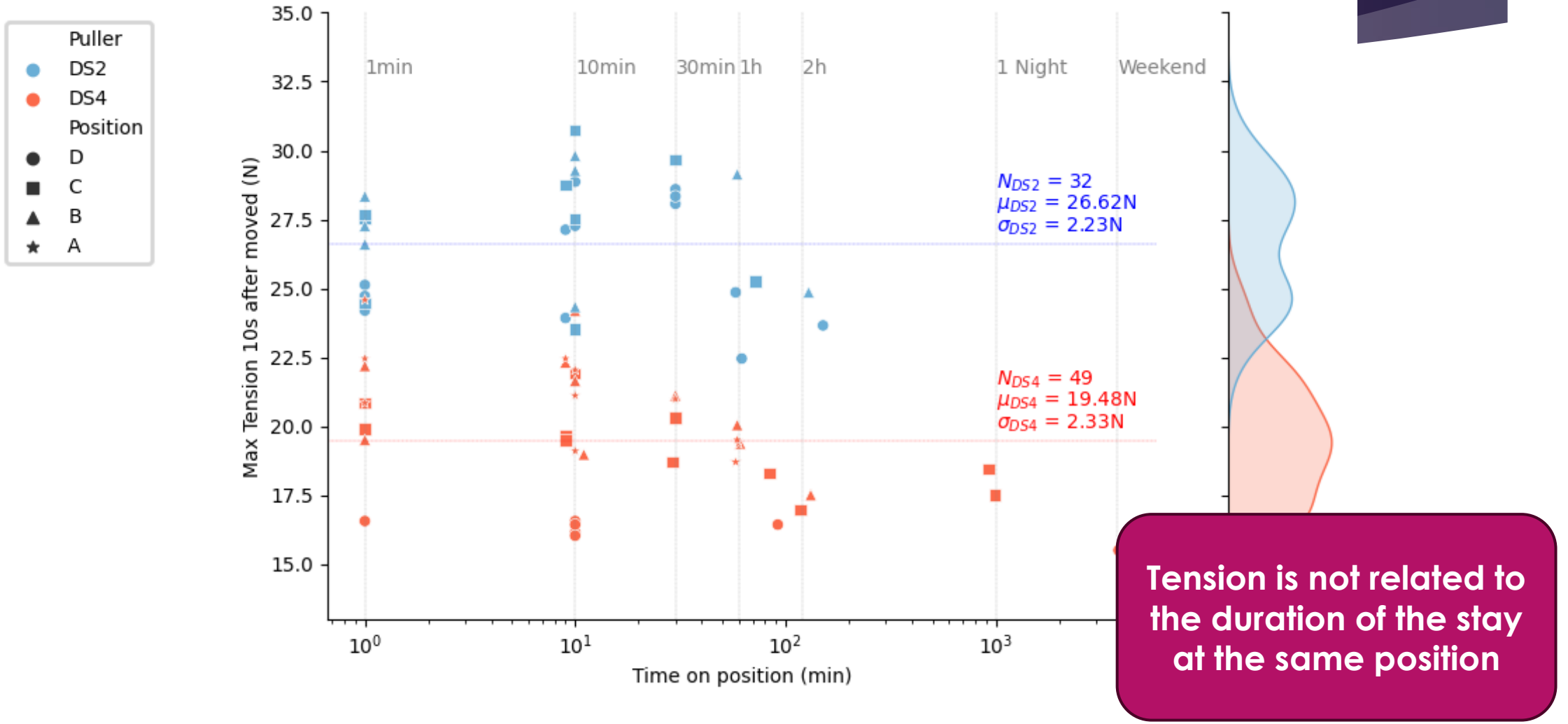


Tension plot during one test

When the source is moved from its staying position, extract maximal tension 10s after the start of the move

Long stay test with LN2

TENSION AFTER STOP



Tension is not related to the duration of the stay at the same position