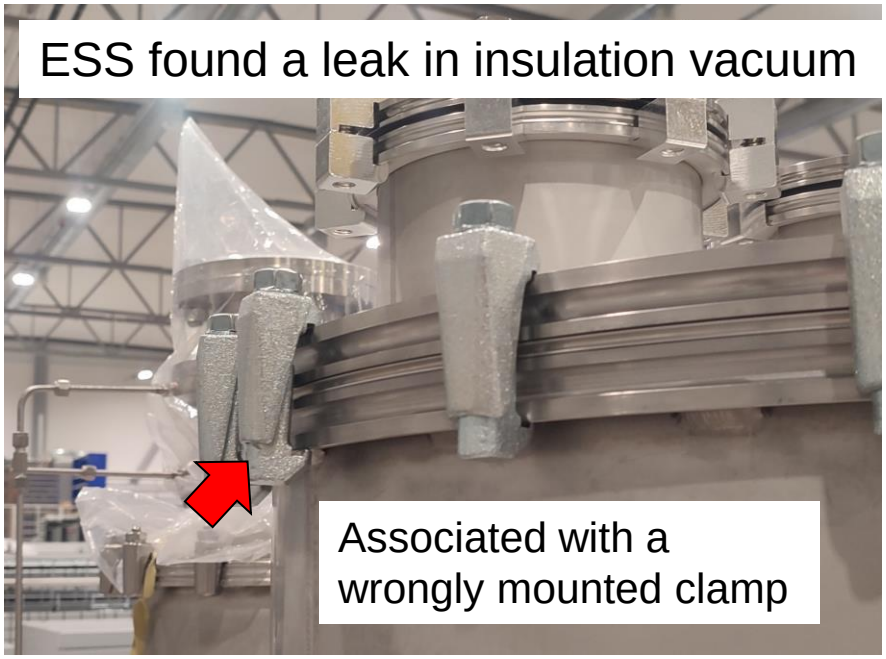
UPPSALA
UNIVERSITET

ESS weekly meeting (2022 W49)

A. Miyazaki et al

Nonconformity reported on CM08 by ESS



IJCLab — Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

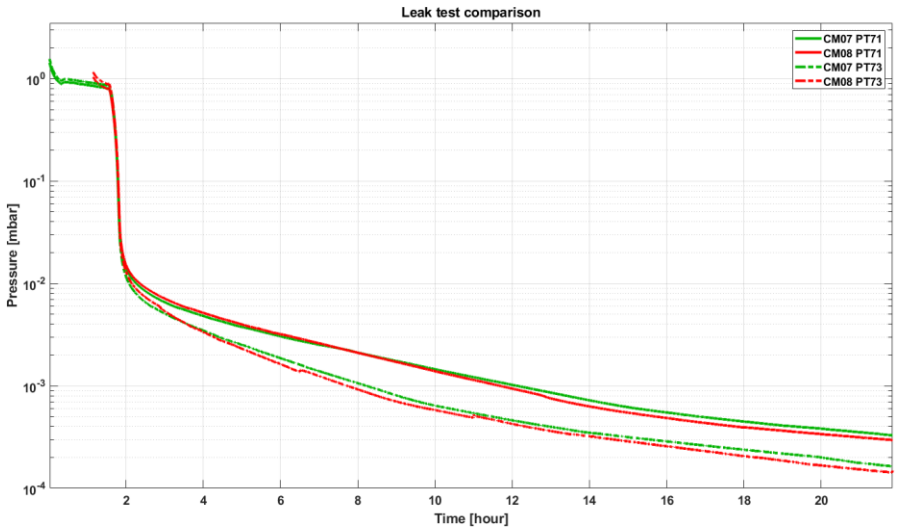
Leak test of the cryomodule

ATRIUM-433618

Date : 29/10/2021

Leak test of CM08 at IJCLAB before shipping				
Name of controllers	*K. Biernacki*		Date	*2021-10-21*
Method	injection			
Données				
Testing elements	Pressure (mbar)	admissible leak rate	measured leak rate (mbar.l/s	Pumping time (hour)
Cryostat	*2,5.10E-2*	Leak rate <	*2,3.10E-10*	*19*
Comments			Conclusion	C
			Visa	Date 2021-10-21

Final Leak test of CM08 at UU				
Name of controllers	*To be completed*		Date	*To be completed*
Method	injection			
Données				
Testing elements	Pressure	admissible leak rate	measured leak rate	Pumping time
Cryostat	*To be completed*	Leak rate <	To be completed	*To be completed*
Comments			Conclu	*To be completed*
			Visa	Date



Vacuum

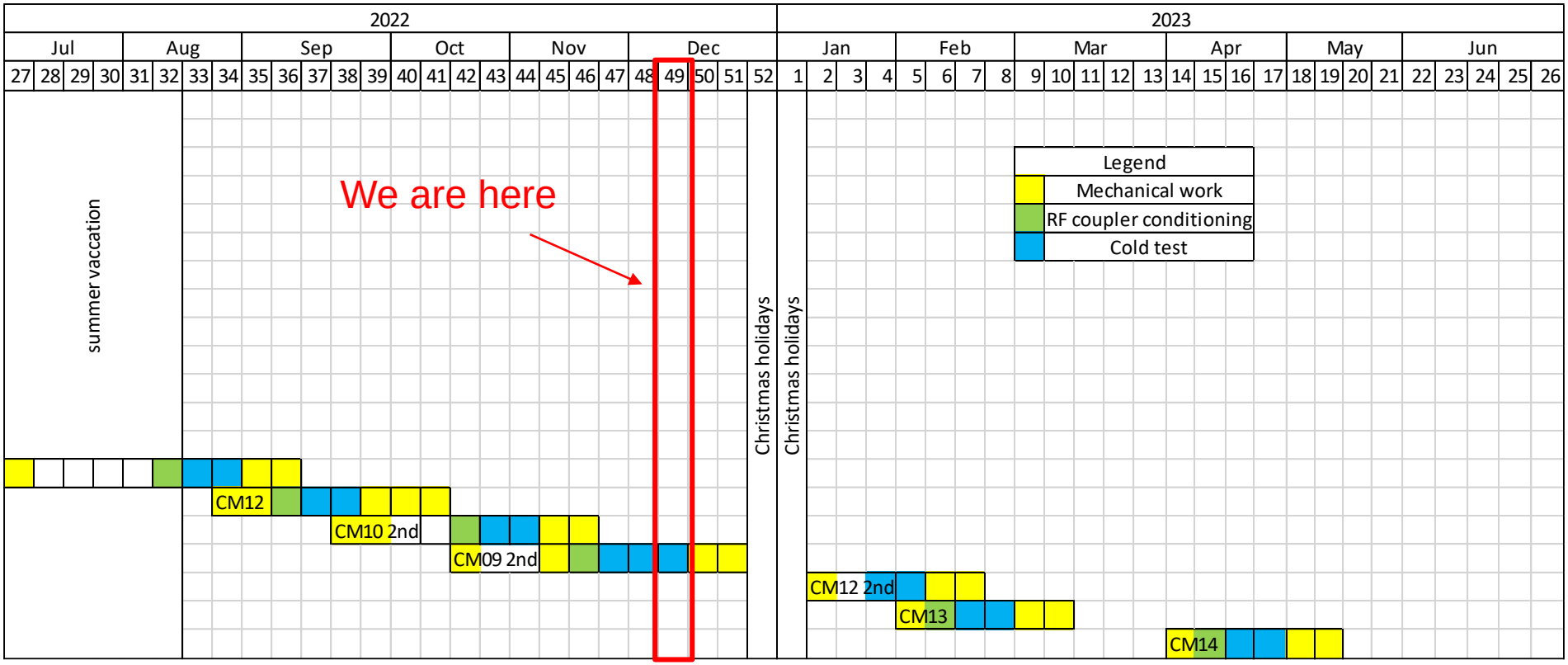
date	2021-12-17	2022-02-26	2022-03-07
Temperature (K)	300	2.06	300
Beam vacuum (mbar)	4.1E-3	1.6E-9	<5.0E-4
Isolating vacuum (mbar)	1000	3.4E-7	1000

- UU do’t perform leak test of insulation vac
- The cryogenic lines inside the bellows between CM and VBox was leaky but fixed

Other two noncomformities in CM08

- Three clamps around the coupler flange were loose
- Plenty of grease in helium gas flanges and O-rings
  - It is there from the beginning
  - UU is aware of this and does not wipe them before or after our test

Global planning



- Cryogenics was unstable (low LHe production rate?)
  - We cannot keep 2 K operation for several days
  - Rest of the tests have been prioritized
- The potential leak signal at A/q=4 was identified when the cavities reached 13 K
  - The ESS LD, RGA, and Penning gauges consistently show the same signal
  - Goal is to answer: **what is the mechanism?** Where is it from? **Is it a problem?**

CM09: progress and planning

week		W48											
date		MON		TUE		WED		THU		FRI		SAT	SUN
		28-nov		29-nov		30-nov		01-dec		02-dec		03-dec	04-dec
		m	a	m	a	m	a	m	a	m	a		
present CM	**CM09**	stand-by operation		4 K filling		ESS's leak detector was connected, background leak rate is being pumped		leak test at cold with ESS' leak detector					

week		W49											
date		MON		TUE		WED		THU		FRI		SAT	SUN
		05-dec		06-dec		07-dec		08-dec		09-dec		10-dec	11-dec
		m	a	m	a	m	a	m	a	m	a		
present CM	**CM09**	4K filling / 2K pumping	stepper motor test	piezo test	static heat load go to standby	4K filling / 2K pumping	MP conditioning / heat load meas			another leak test	start warming up	vent insulation vacuum	warming up

We are here

week		W50											
date		MON		TUE		WED		THU		FRI		SAT	SUN
		12-dec		13-dec		14-dec		15-dec		16-dec		17-dec	18-dec
		m	a	m	a	m	a	m	a	m	a		
present CM	**CM09**	warming up completed	vacuum cryolines disconnected		docking area	N2 filling		out going test		waiting in the box			
next CM	**CM12**												

week		W51											
date		MON		TUE		WED		THU		FRI		SAT	SUN
		19-dec		20-dec		21-dec		22-dec		23-dec		24-dec	25-dec
		m	a	m	a	m	a	m	a	m	a		
present CM	**CM09**	departure to ESS		arrival at ESS		report writing		publish report					
next CM	**CM12**												

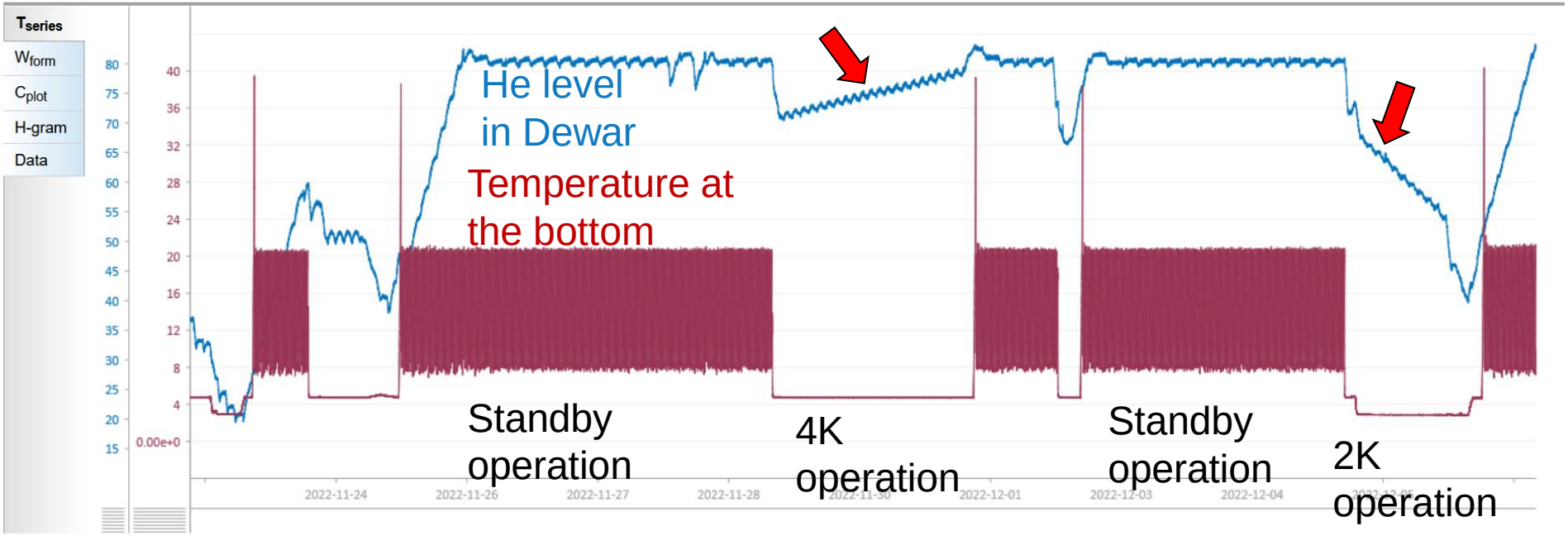
Goal of CM09

Time is limited due to cryogenics

Del	Plot	Name	DBRType	Units	Processing	Scale	Time (local)	Value	Notes
x	☑	Cryo-Dwr:LHe:LI5200-PercOut	DBR_SCALAR_DOUBLE	%	raw	linear	2022-11-25 **11:26:19**	41.22902297973633	
x	☑	CM-CM:TT04:sRdV	DBR_SCALAR_DOUBLE	K	raw	linear	2022-11-25 **11:26:50**	4.821434926618378	

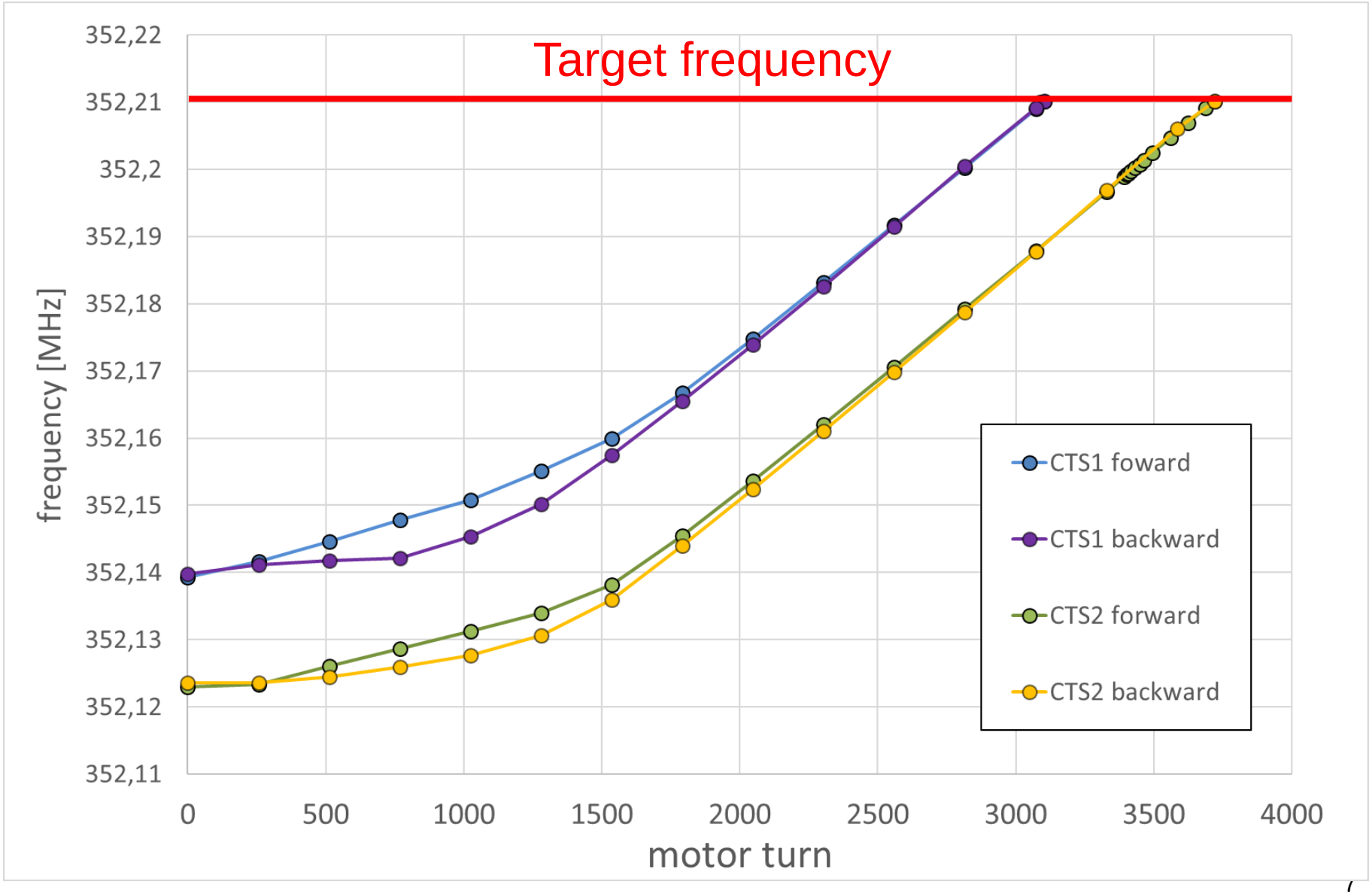
WINDOW SIZE: 1 year | 1 month | 2 w | 1 w | 2.5 d | 1 d | 18 h | 12 h | 8 h | 4 h | 2 h | 1 h | 30 m | 10 m | 5 m | 1 m | 30 s END: 2022-12-07 09 :03 :44 NOW < >

Standby operation



- Liquefaction rate 65 l/h (nominal 116 l/h) without CM load
- The Dewar level increased during stand-by and 4K but significantly dropped during 2K operation
- We do not know by 100% if this is due to heat load or poor liquefaction

CM09_2: CTS1 & 2


Target frequency
352,22
352,21
352,2
352,19
352,18
352,17
352,16
352,15
352,14
352,13
352,12
352,11
frequency [MHz]
0
500
1000
1500
2000
2500
3000
3500
4000
motor turn
CTS1 foward
CTS1 backward
CTS2 forward
CTS2 backward

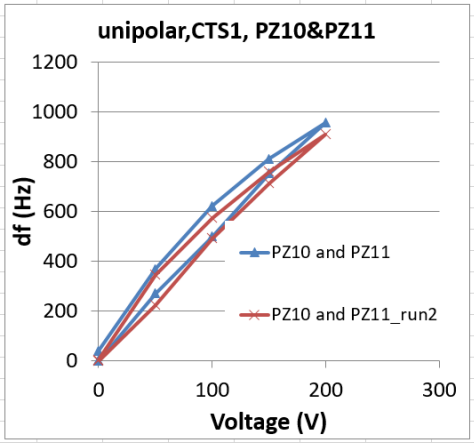
CM09_2: CTS1 piezos

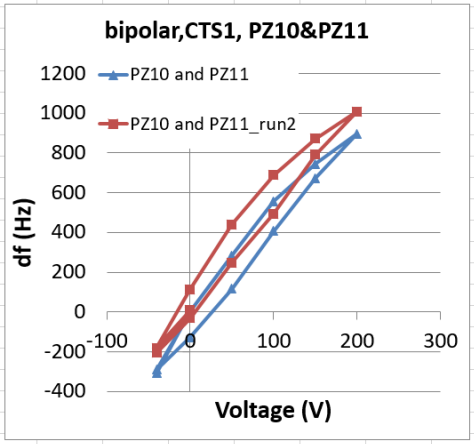
CAV IN BW (Hz)	1951

20221206 TT11=92,7K

both piezos simulaneously

Voltage (V)	Phase (°)	df(Hz)
0	85,83	0
50	98,32	270,755
100	108,93	500,757
150	120,59	753,52
200	130,01	957,724
150	123,32	812,7
100	114,59	623,453
50	102,88	369,606
0	87,74	41,4046
0	86,52	0
50	96,91	225,232
100	109,28	493,386
150	119,51	715,15
200	128,53	910,683
150	121,65	761,54
100	113,05	575,111
50	102,47	345,761
0	86,75	4,98589
0	87,55	0
-40	74,14	-290,7
0	81,7	-126,82
50	92,95	117,06
100	106,31	406,675
150	118,64	673,962
200	128,93	897,026
150	121,96	745,932
100	113,22	556,469
50	100,7	285,063
0	87,76	4,55233
-40	73,35	-307,82
0	82,35	0
-40	72,84	-206,16
0	80,95	-30,349
50	93,82	248,644
100	105,12	493,603
150	118,91	792,54
200	128,93	1009,75
150	122,63	873,181
100	114,16	689,57
50	102,74	442,01
0	87,69	115,759
-40	73,98	-181,44
0	82,78	9,32144
tuning range bp		1215,91
tuning range up		910,683



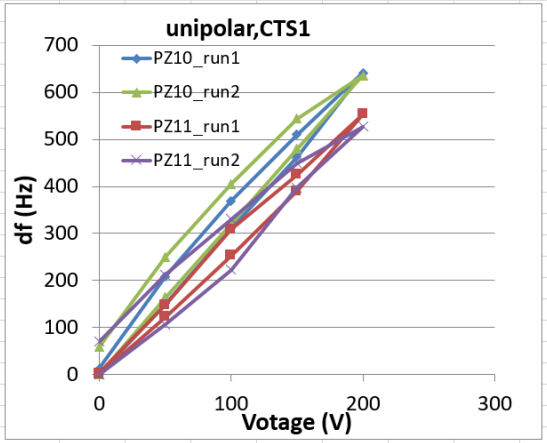


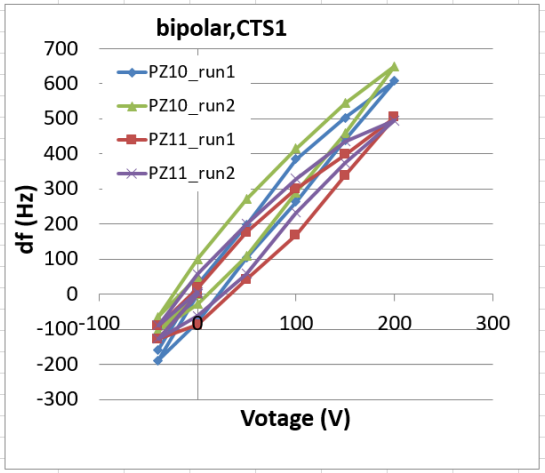
PZ10 only

Voltage (\	Phase (°)	df(Hz)
0	85,75	0
50	92,7	150,661
100	100,1	311,076
150	107,12	463,254
200	115,34	641,445
150	109,31	510,728
100	102,78	369,173
50	95,39	208,974
0	86,29	11,706
0	86,23	0
50	93,81	164,318
100	100,99	319,964
150	108,4	480,596
200	115,58	636,243
150	111,33	544,112
100	104,92	405,158
50	97,8	250,812
0	88,94	58,7468
0	87,89	0
-40	79,17	-189,03
0	84,28	-78,257
50	92,7	104,27
100	100,04	263,385
150	108,2	440,276
200	115,93	607,845
150	111,13	503,792
100	105,65	384,997
50	97,01	197,701
0	89,1	26,2301
-40	80,6	-158,03
0	87,44	0
-40	82,64	-104,05
0	86,16	-27,748
50	92,45	108,606
100	100,8	289,615
150	108,59	458,485
200	117,45	650,55
150	112,58	544,979
100	106,64	416,213
50	99,97	271,623
0	92,06	100,151
-40	84,47	-64,383
0	89,71	49,2086
tuning range bp		754,603
tuning range up		636,243

PZ11 only

Voltage (\	Phase (°)	df(Hz)
0	86,62	0
50	92,27	122,479
100	98,28	252,763
150	104,63	390,417
200	112,18	554,084
150	106,25	425,535
100	100,86	308,692
50	93,46	148,276
0	86,72	2,16778
0	87,77	0
50	92,67	106,221
100	98,05	222,848
150	106,12	397,787
200	112,08	526,987
150	108,53	450,031
100	103,04	331,02
50	97,59	212,876
0	90,99	69,8024
0	89,86	0
-40	83,95	-128,12
0	85,85	-86,928
50	91,77	41,4046
100	97,62	168,22
150	105,46	338,173
200	113,15	504,875
150	108,22	398,004
100	103,72	300,454
50	97,99	176,24
0	90,7	18,2093
-40	85,66	-91,047
0	89,22	0
-40	83,4	-126,16
0	86,34	-62,432
50	91,93	58,7468
100	100	233,686
150	106,45	373,508
200	112,1	495,988
150	109,33	435,94
100	104,43	329,719
50	98,48	200,736
0	91,86	57,2293
-40	85,14	-88,445
0	89,51	6,28656
tuning range bp		622,152
tuning range up		526,987





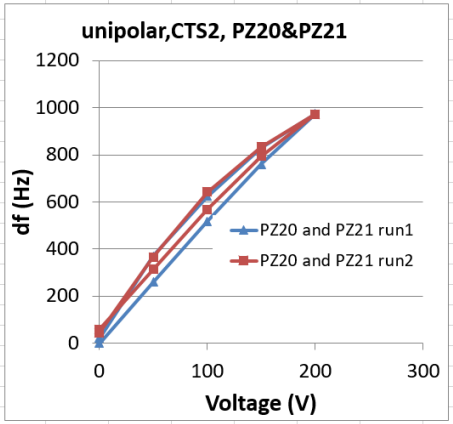
CM09_2: CTS2 piezos

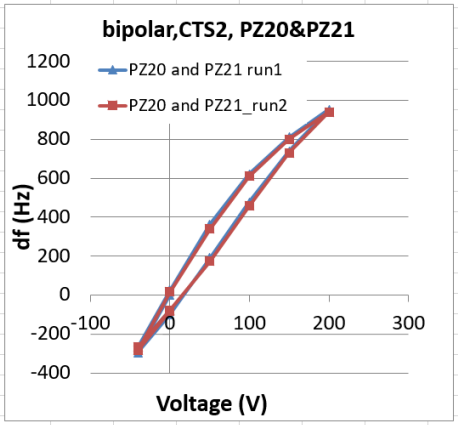
CAV OUT BW (Hz)	1823

20221206 TT21=101,3K

both piezos simulaneously

Voltage (V)	Phase (°)	df(Hz)
0	20,52	0
50	33,38	260,486
100	46,07	517,529
150	58,01	759,381
200	68,62	974,292
150	61,47	829,465
100	51,34	624,276
50	38,82	370,677
0	21,59	21,6734
0	23,45	59,3488
50	36,05	314,569
100	48,57	568,168
150	59,7	793,613
200	68,56	973,077
150	61,73	834,731
100	52,24	642,506
50	38,59	366,018
0	22,71	44,3597
0	22,41	0
-40	7,81	-295,73
0	17,45	-100,47
50	31,82	190,605
100	45,91	476,006
150	58,85	738,112
200	69,51	954,037
150	62,46	811,235
100	53,09	621,44
50	40,32	362,777
0	23,66	25,3194
-40	9,13	-268,99
0	18,61	-76,971
-40	9,14	-268,79
0	18,59	-77,376
50	30,99	173,793
100	45,01	457,776
150	58,45	730,01
200	68,86	940,871
150	61,86	799,082
100	52,55	610,502
50	39,15	339,078
0	23,25	17,0147
-40	8,29	-286,01
0	18,35	-82,238
tuning range bp		1226,88
tuning range up		928,717



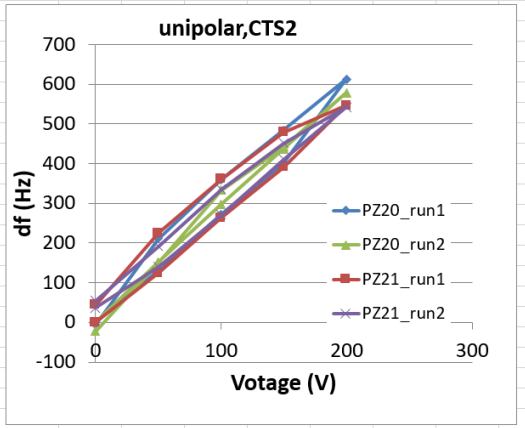


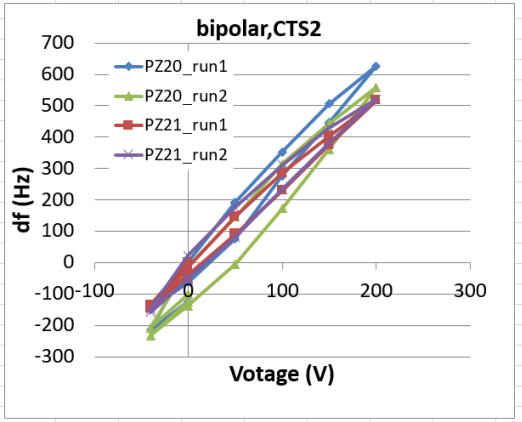
PZ20 only

Voltage (\	Phase (°)	df(Hz)
0	22,12	0
50	28,59	131,053
100	35,54	271,83
150	41,9	400,655
200	52,37	612,731
150	46,04	484,513
100	39,88	359,739
50	32,53	210,86
0	21,85	-5,469
0	22,16	0,81022
50	29,64	152,322
100	36,84	298,162
150	43,71	437,317
200	50,71	579,106
150	43,98	442,786
100	38,6	333,812
50	29,57	150,904
0	21,04	-21,876
0	19,6	0
-40	12,47	-144,42
0	16,48	-63,197
50	23,37	76,3634
100	33,28	277,096
150	41,66	446,838
200	50,54	626,707
150	44,57	505,781
100	36,99	352,244
50	29,14	193,238
0	19,64	0,81022
-40	8,97	-215,32
0	13,47	-124,17
-40	8,14	-232,13
0	12,81	-137,54
50	19,33	-5,469
100	28,13	172,78
150	37,4	360,549
200	47,16	558,243
150	41,49	443,394
100	35,17	315,379
50	26,76	145,03
0	19	-12,153
-40	9,28	-209,04
0	14,6	-101,28
tuning range bp		858,836
tuning range up		600,982

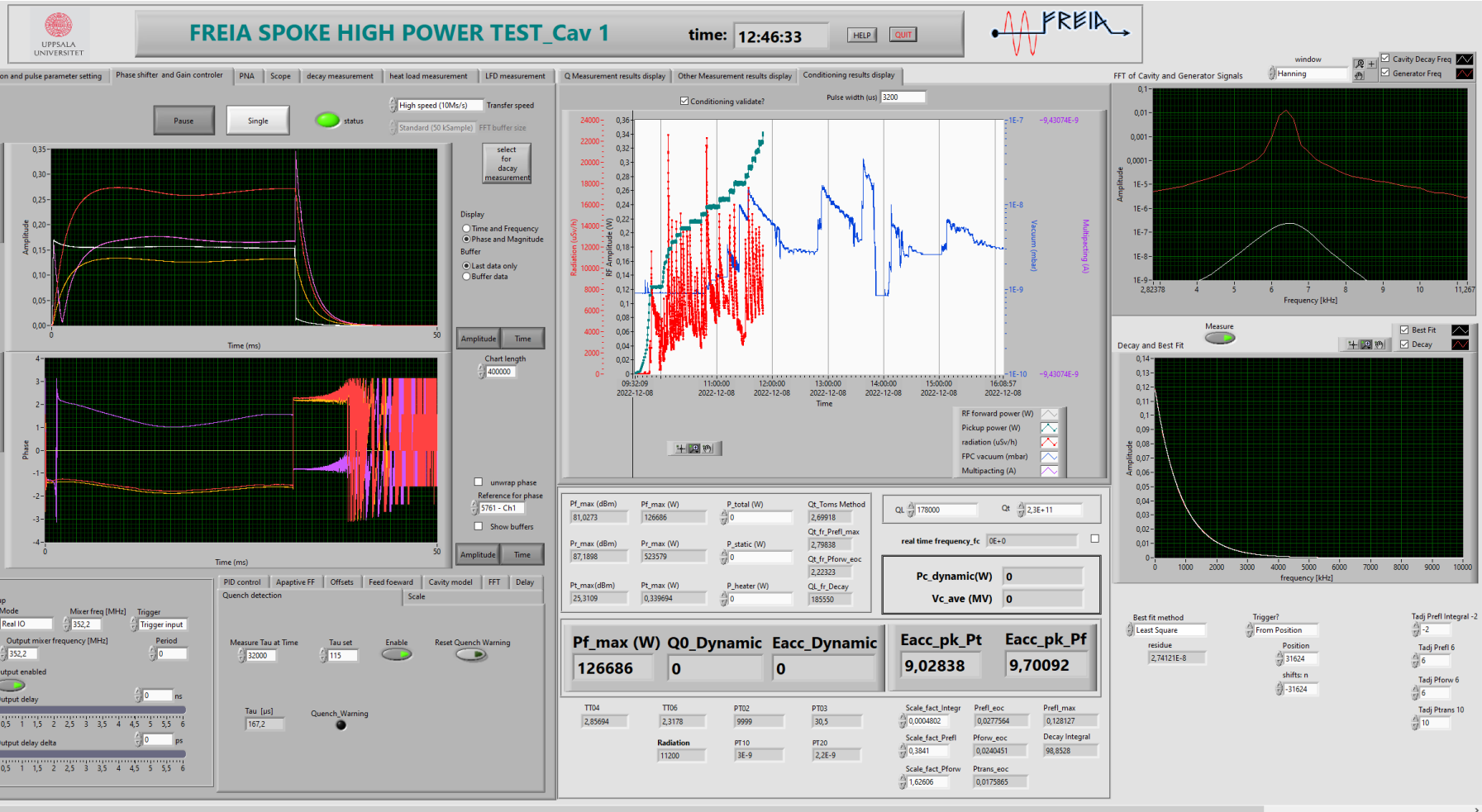
PZ21 only

Voltage (\	Phase (°)	df(Hz)
0	21,84	0
50	27,98	124,369
100	34,87	263,93
150	41,13	390,73
200	48,85	547,103
150	45,47	478,639
100	39,65	360,751
50	32,96	225,242
0	24,04	44,5622
0	23,64	36,46
50	28,76	140,168
100	35,23	271,222
150	42,1	410,378
200	48,62	542,444
150	44,11	451,091
100	38,41	335,635
50	31,31	191,82
0	24,53	54,4874
0	24,31	0
-40	17,66	-134,7
0	22,39	-38,891
50	28,83	91,5551
100	35,62	229,09
150	42,82	374,93
200	49,85	517,327
150	44,22	403,288
100	38,41	285,603
50	31,58	147,258
0	23,61	-14,179
-40	17,11	-145,84
0	21,7	-52,867
-40	16,48	-158,6
0	21,85	-49,829
50	28,38	82,4401
100	35,84	233,547
150	43,14	381,412
200	50,02	520,77
150	45,53	429,823
100	39,63	310,315
50	33,02	176,426
0	25,38	21,6734
-40	16,94	-149,28
0	21,49	-57,121
tuning range bp		675,928
tuning range up		487,956

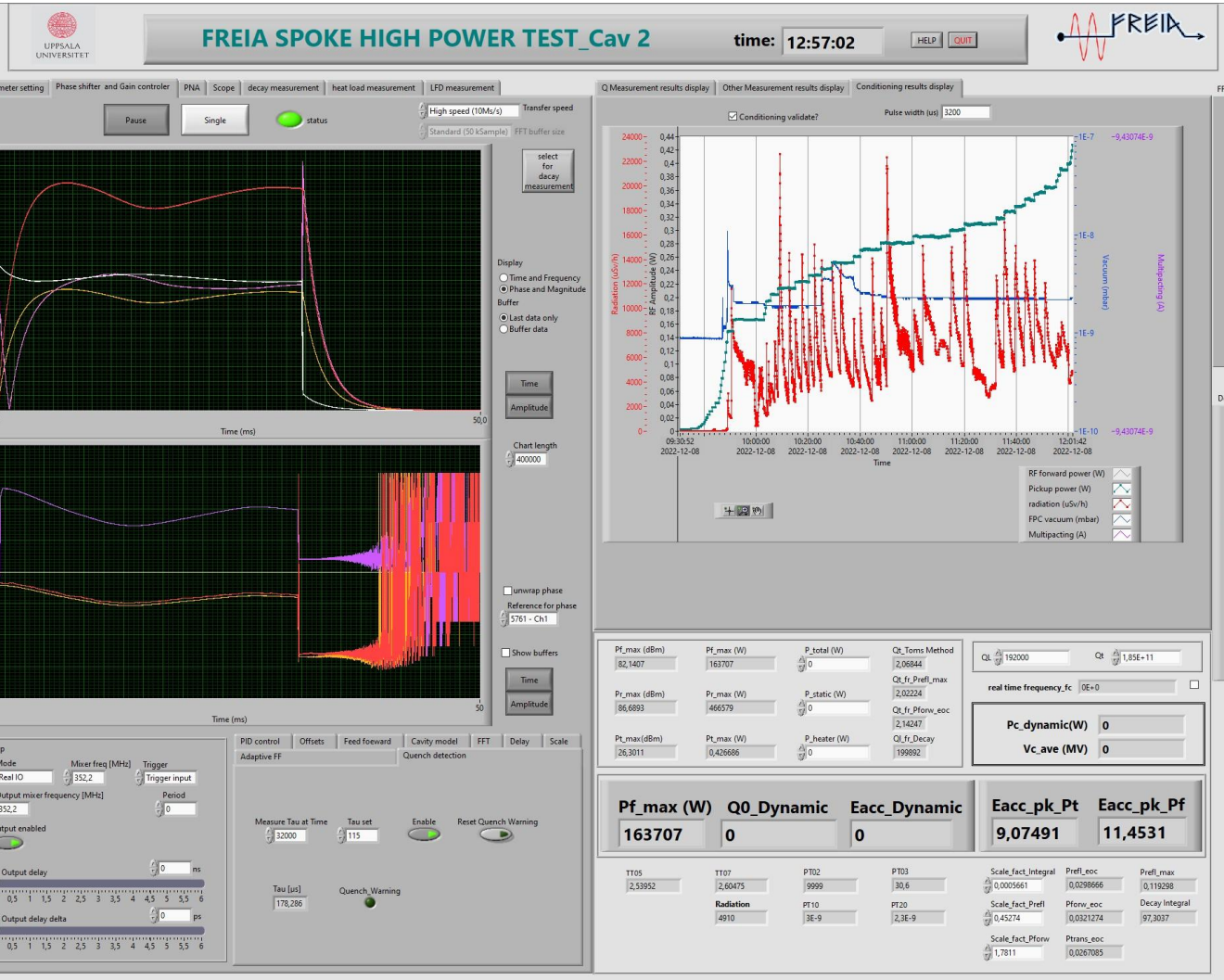




CM09_2: CAVIN reached 9 MV/m

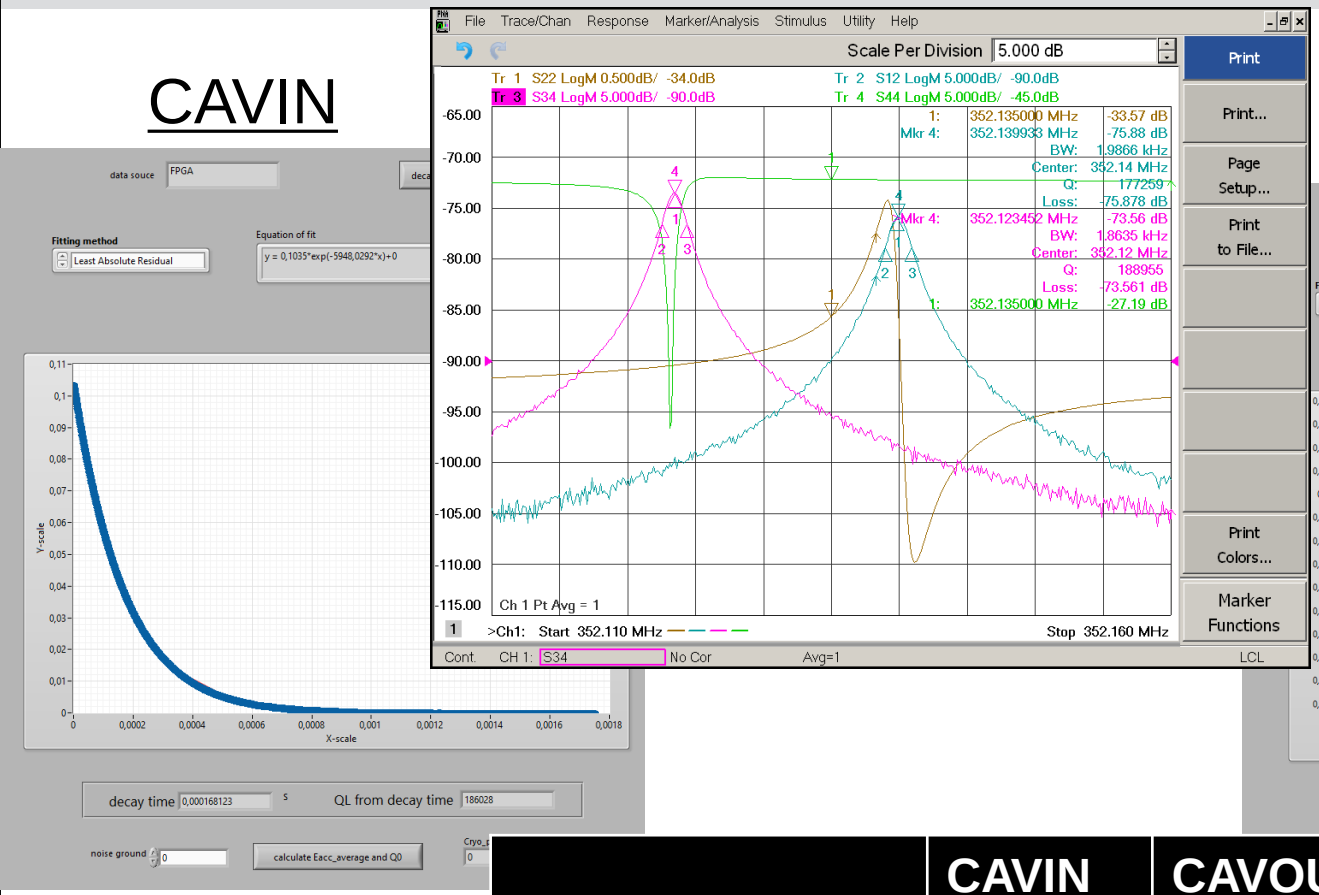


CM09_2: CAVOUT reached 9 MV/m

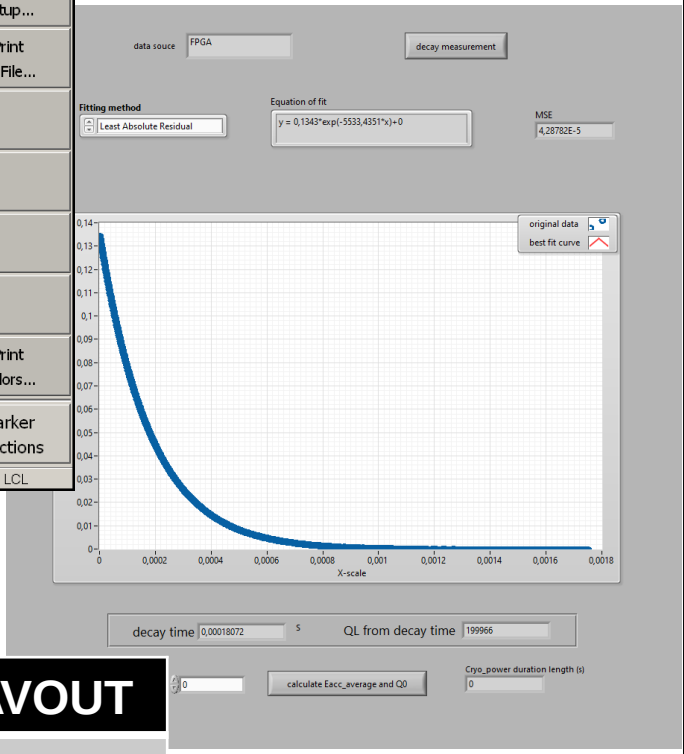


CM09_2: field decay

CAVIN



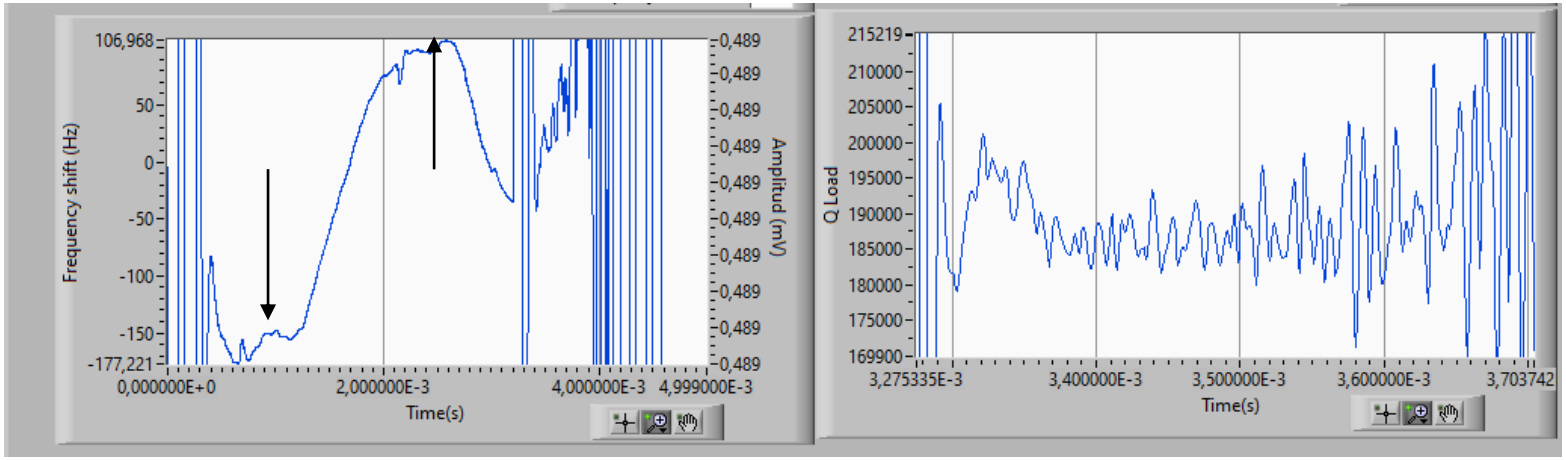
CAVOUT



	CAVIN	CAVOUT
f (warm) [MHz]	351.574	351.559
f (2K) [MHz]	352.140	352.123
QL from VNA (2K)	1.77e5	1.90e5
QL from decay	1.86e4	2.00e5

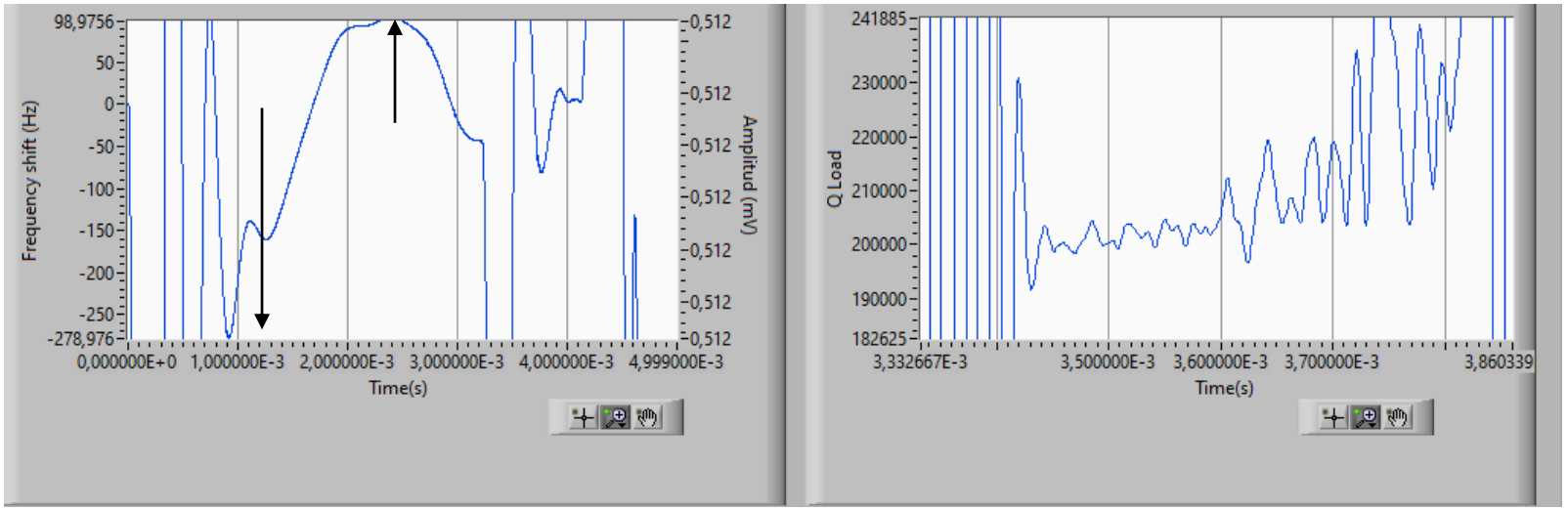
CM09_2: Lorentz force detuning at 9MV/m

CAVIN



|Δf|=284 Hz

CAVOUT

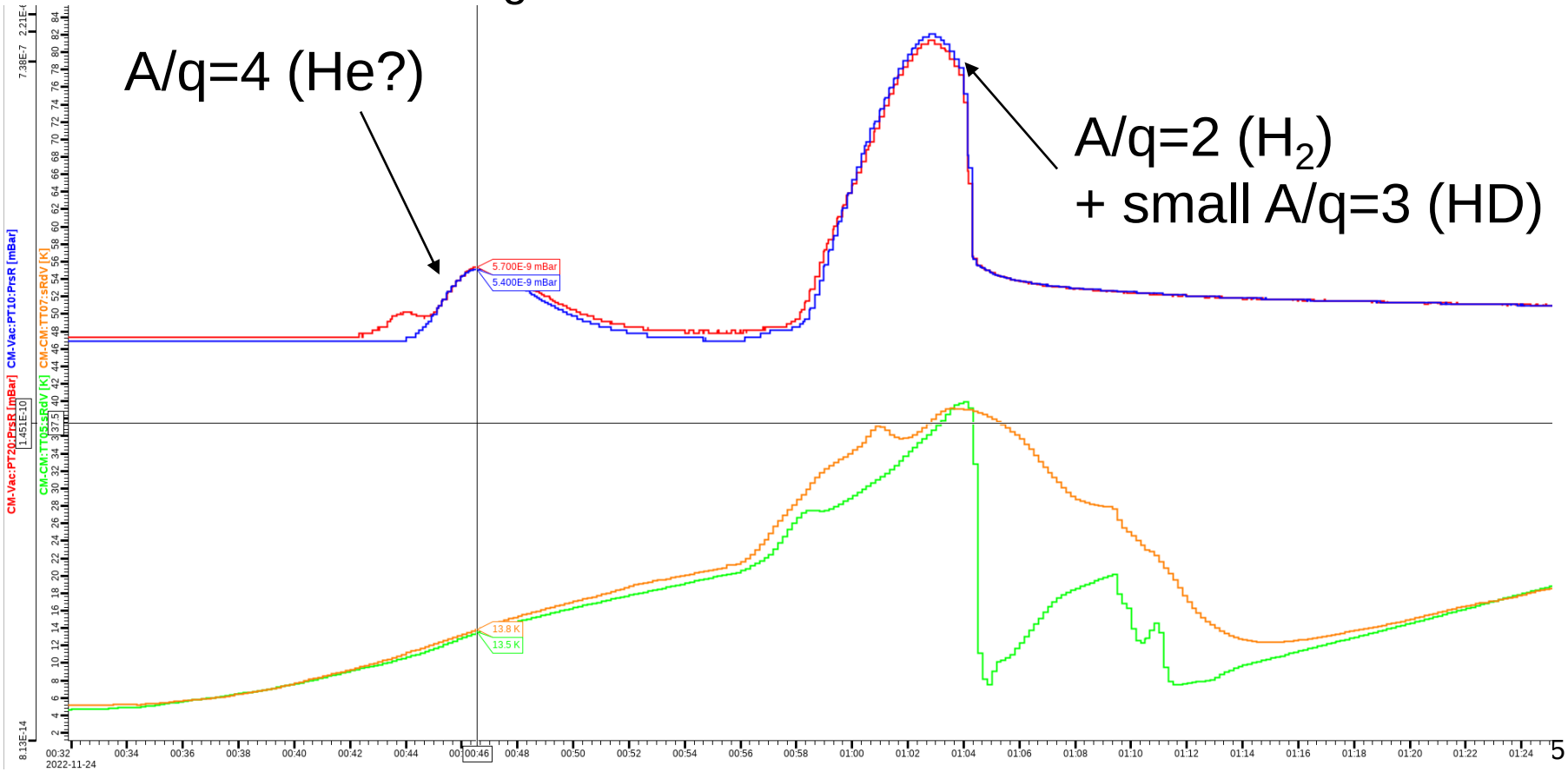


|Δf|=337 Hz

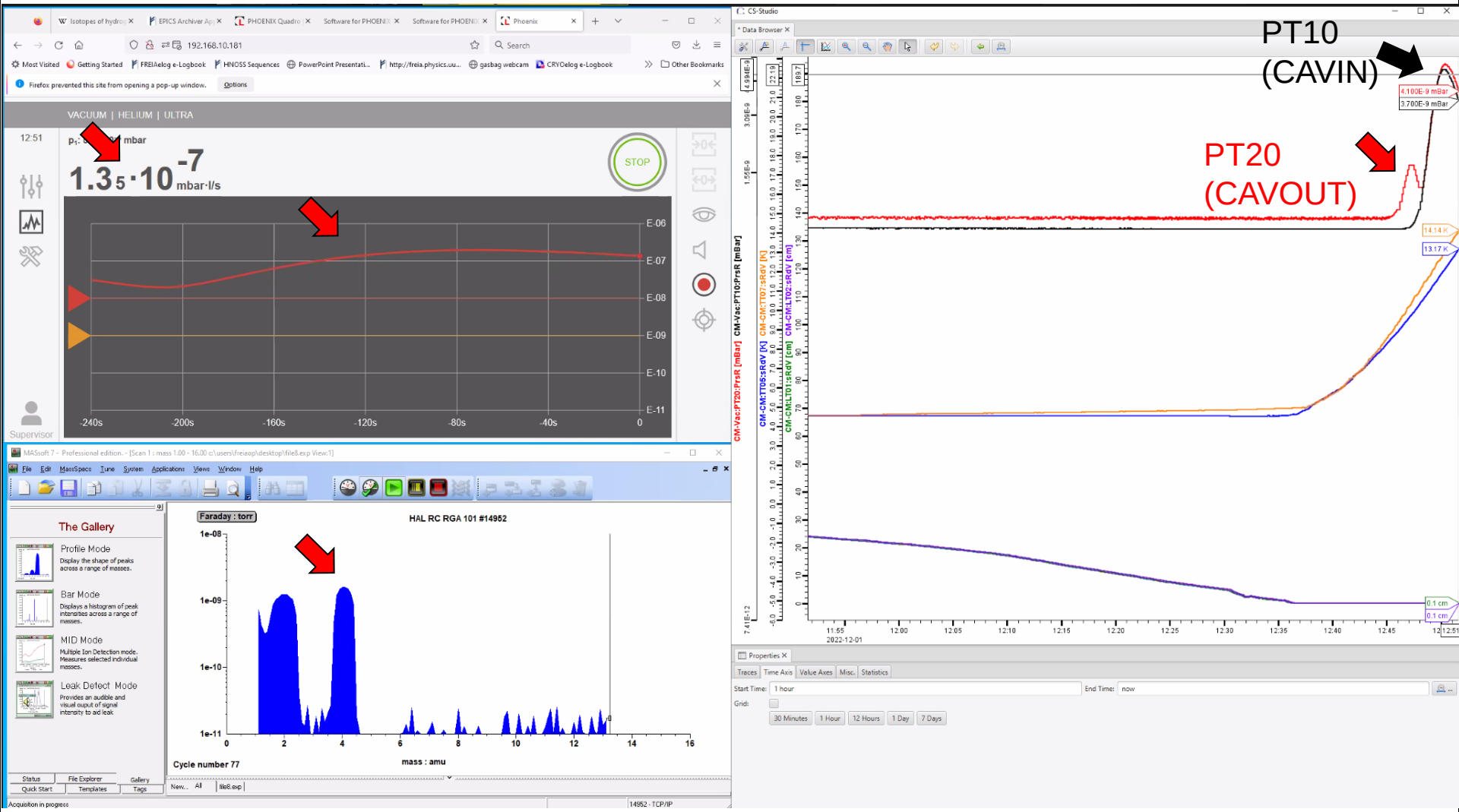
Helium signal in CM09

CM09_2: Reminder 1/2

- Liquefaction rate was not sufficient to keep the LHe level in the Dewar
- Decided to go to the standby
  - Of course, LN2 line was frozen ☹ (thanks, Rocio!!)
- Then, we observed the famous signal of potential leak!
- RGA was not running but the behavior is the same as others



CM09_2: Reminder 2/2 helium confirmed



The leak detector is CAVIN side and RGA is at CAVOUT side

List of facts and hypothesis

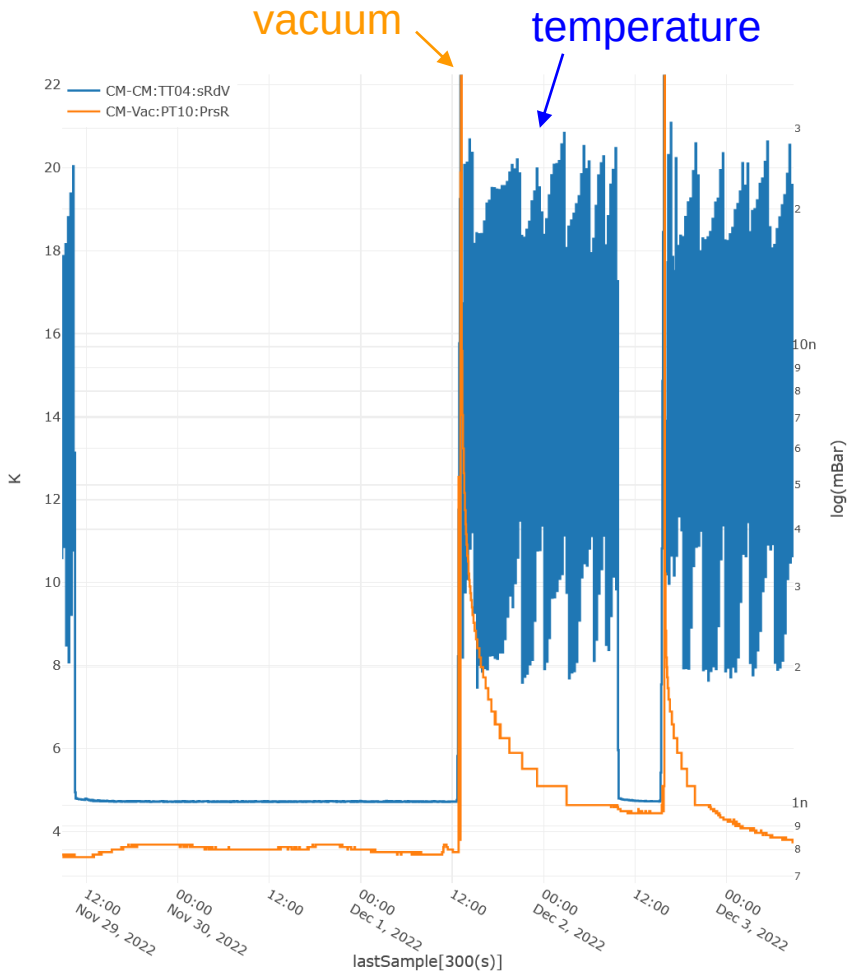
- A helium signal (A/q=4) appears when cavities reach 13 K
  - Penning gauge observes increase in total vacuum
  - RGA observes A/q=4 signal
  - The leak detector observes the helium

Let's check this point

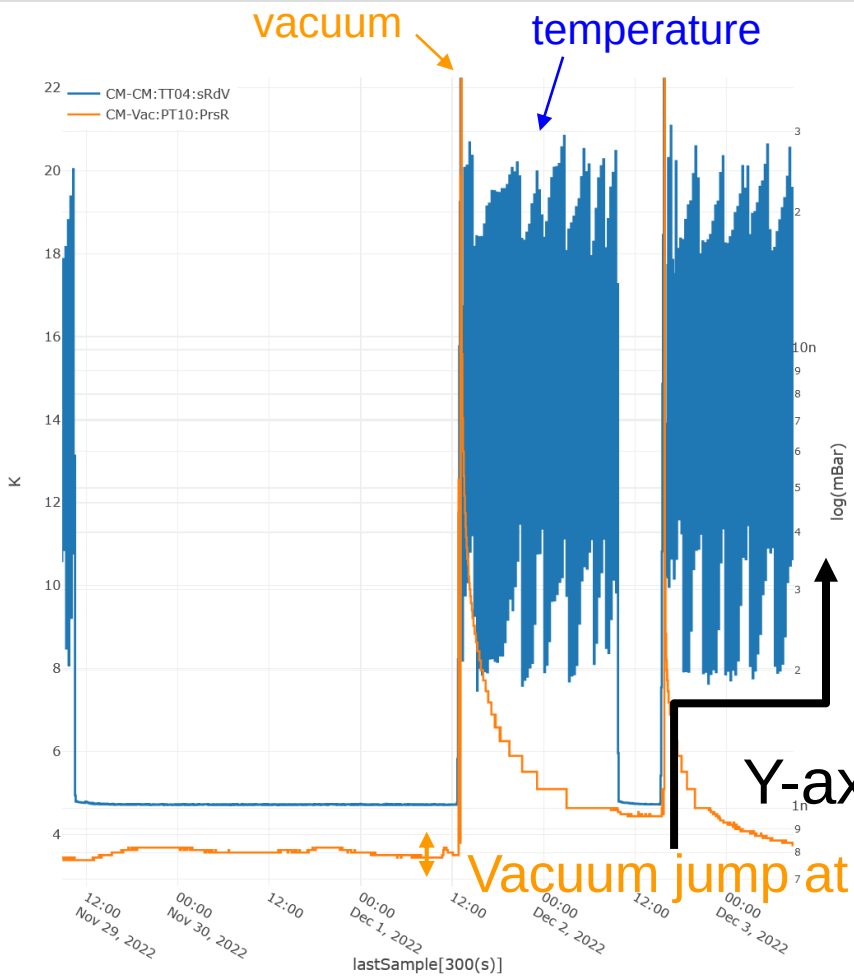
- The signal level is increased if the cavities are with LHe for longer time
  - Thermal cycles (10-50K) without having LHe does not show signal
- The signal appears at a thermal cycle after 2 K operation or 4 K operation without going down to 2 K
  - Superfluid is not a necessary condition

- Hypothesis
  - There is a leak between the beam vacuum and the helium circuit and the leaky helium is accumulated in the cavity
  - The leak is not necessarily at the 2 K boundary and can be again at the supercritical helium line of the coupler's double-wall tube
  - CM12 and CM10 probably have the same issue → how about others?

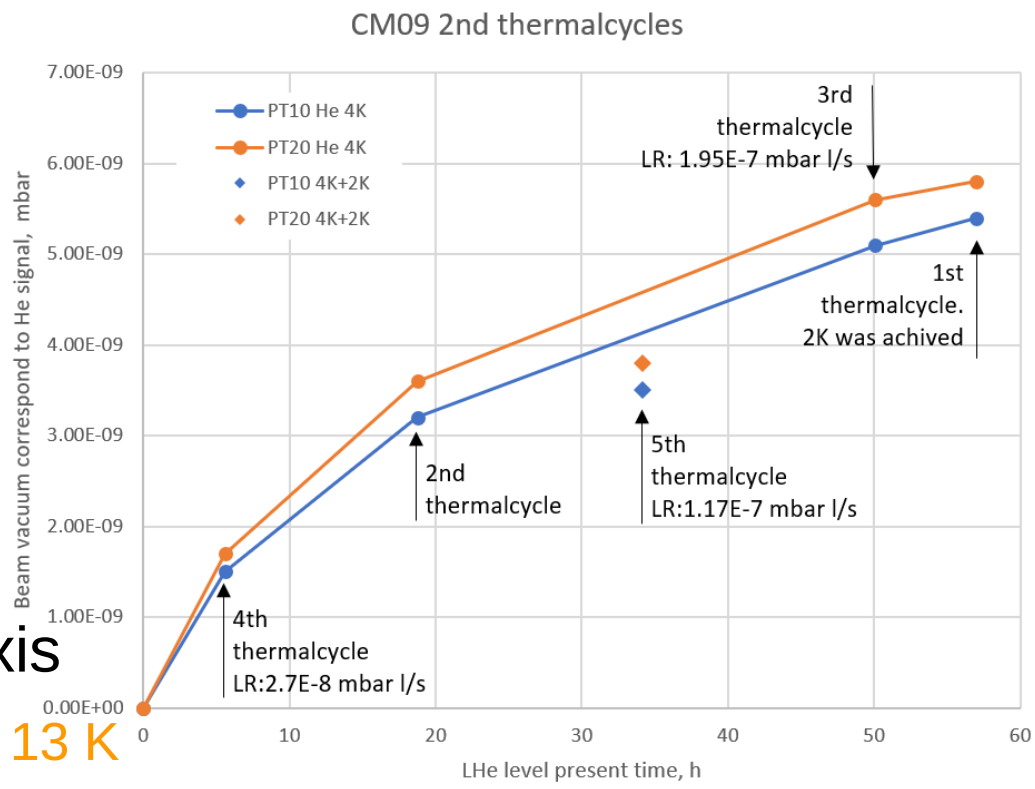
CM09_2: helium signal (13K) vs time at cold



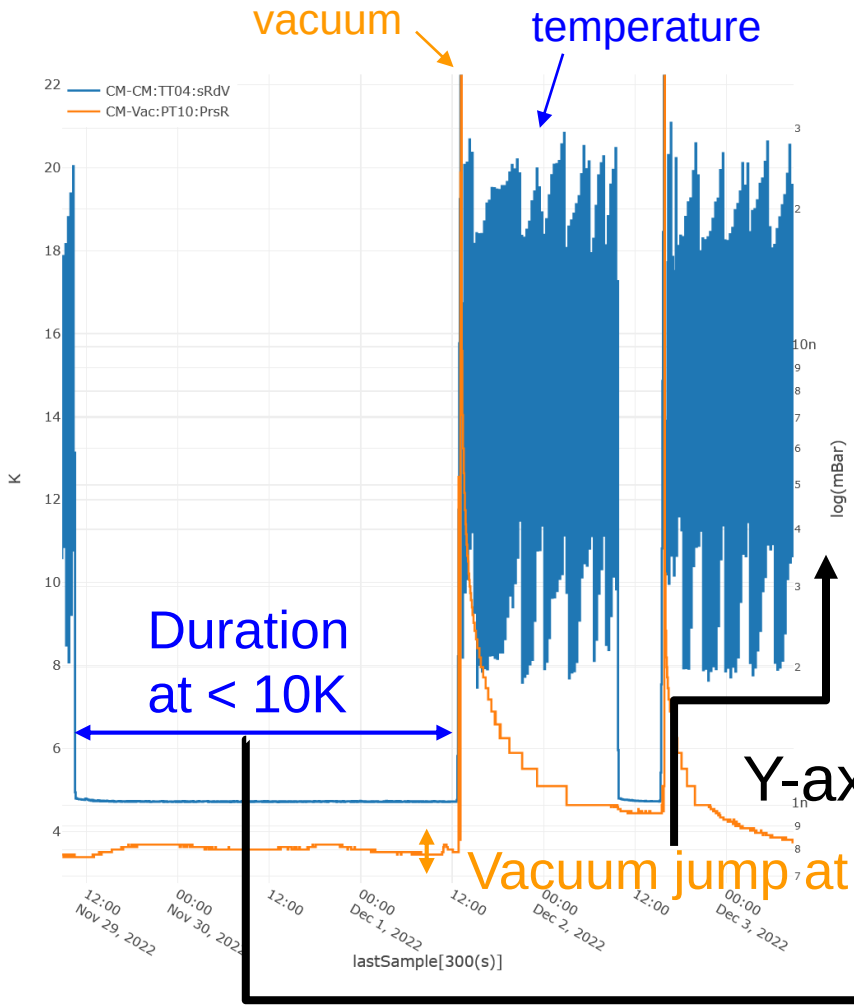
CM09_2: helium signal (13K) vs time at cold



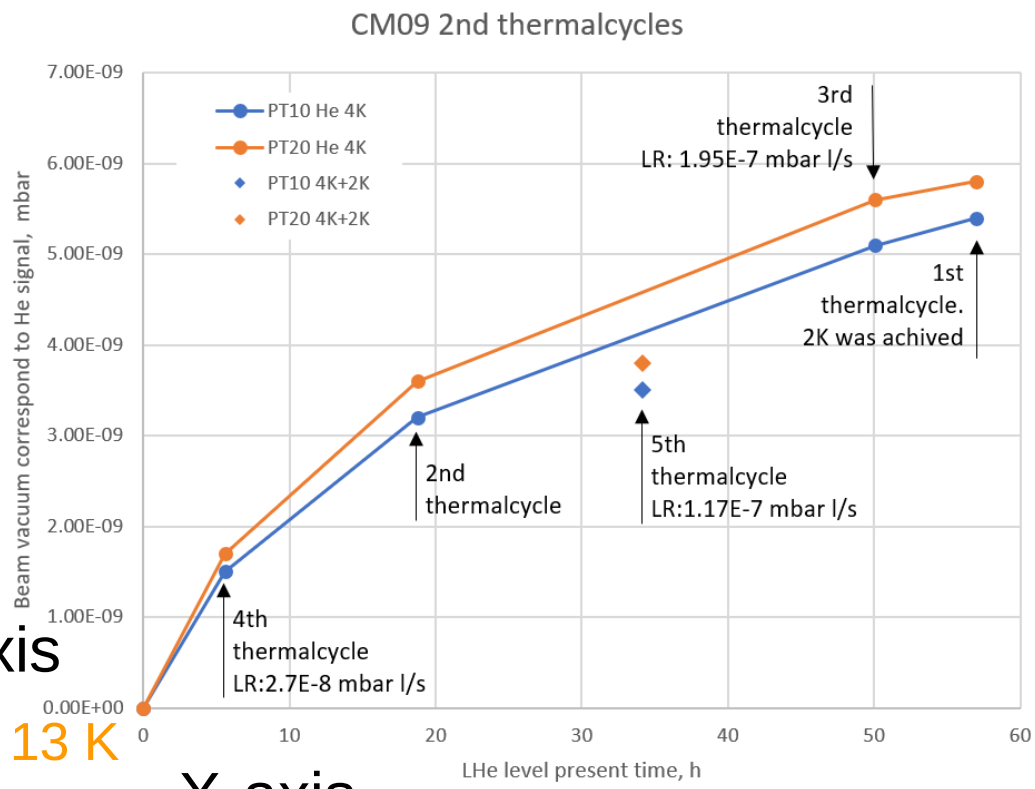
Mysha's idea



CM09_2: helium signal (13K) vs time at cold



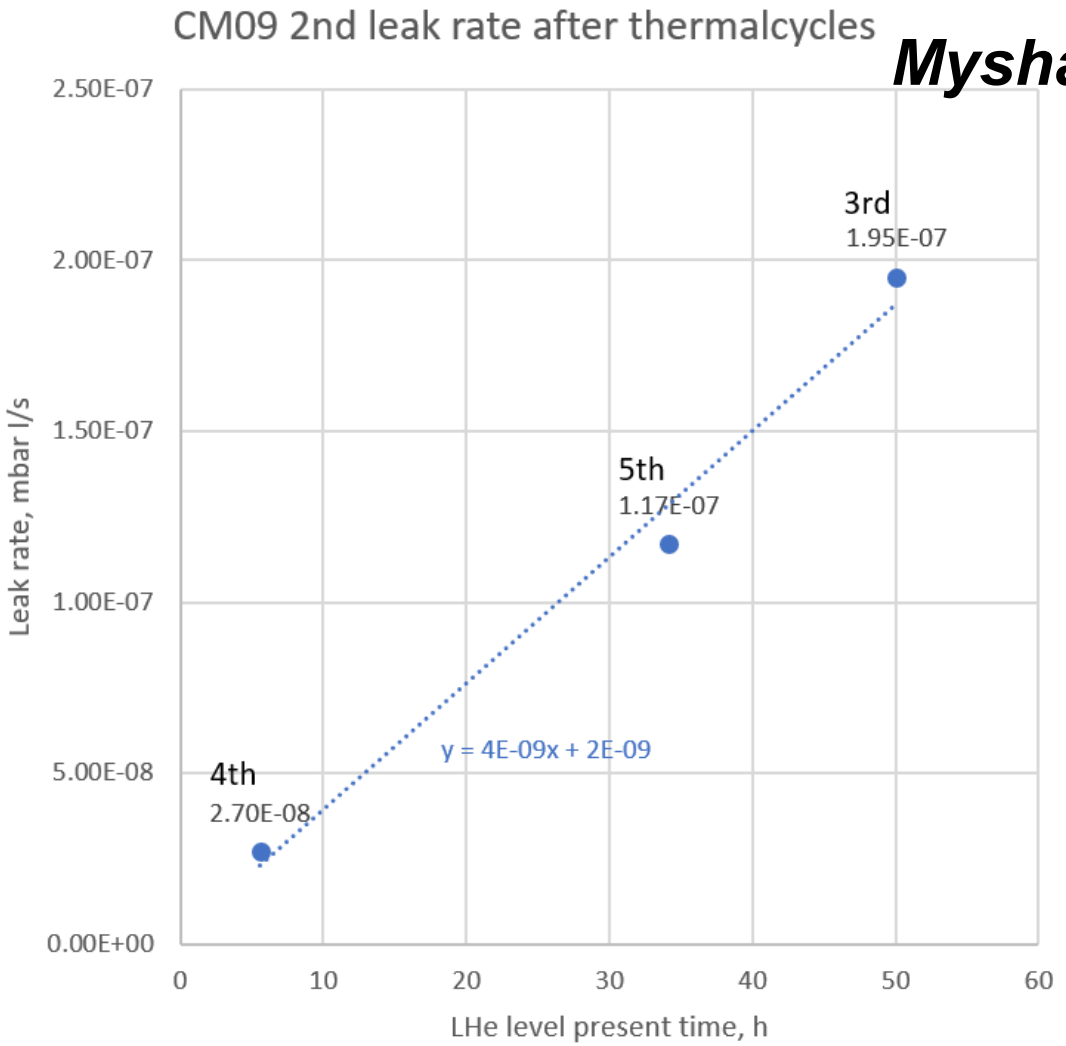
Mysha's idea



The helium signal at 13 K is correlated to how long the cavities are at cold

CM09_2: Leak detector signal vs time at cold

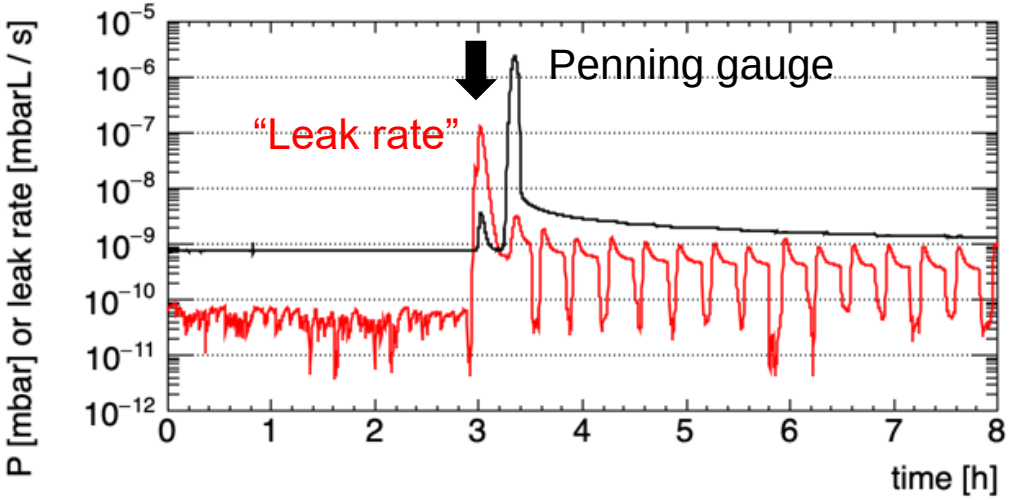
LD's signal instead of total vacuum →

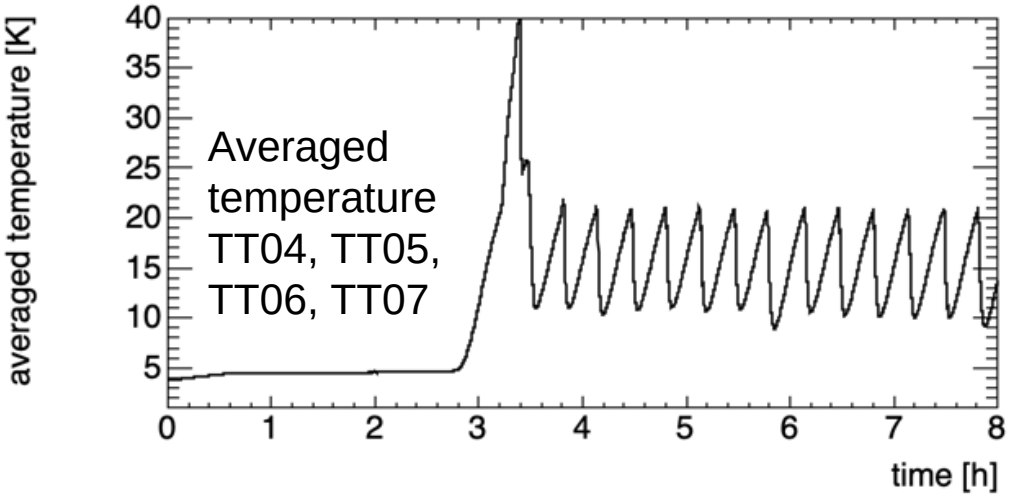


Correlation between helium signal vs time at cold is confirmed

Note: "leak rate" is misleading → helium signal in $nRT/\Delta t = PV/\Delta t$ [mbar*L/s]

CM09_2: leak detector during thermal cycles

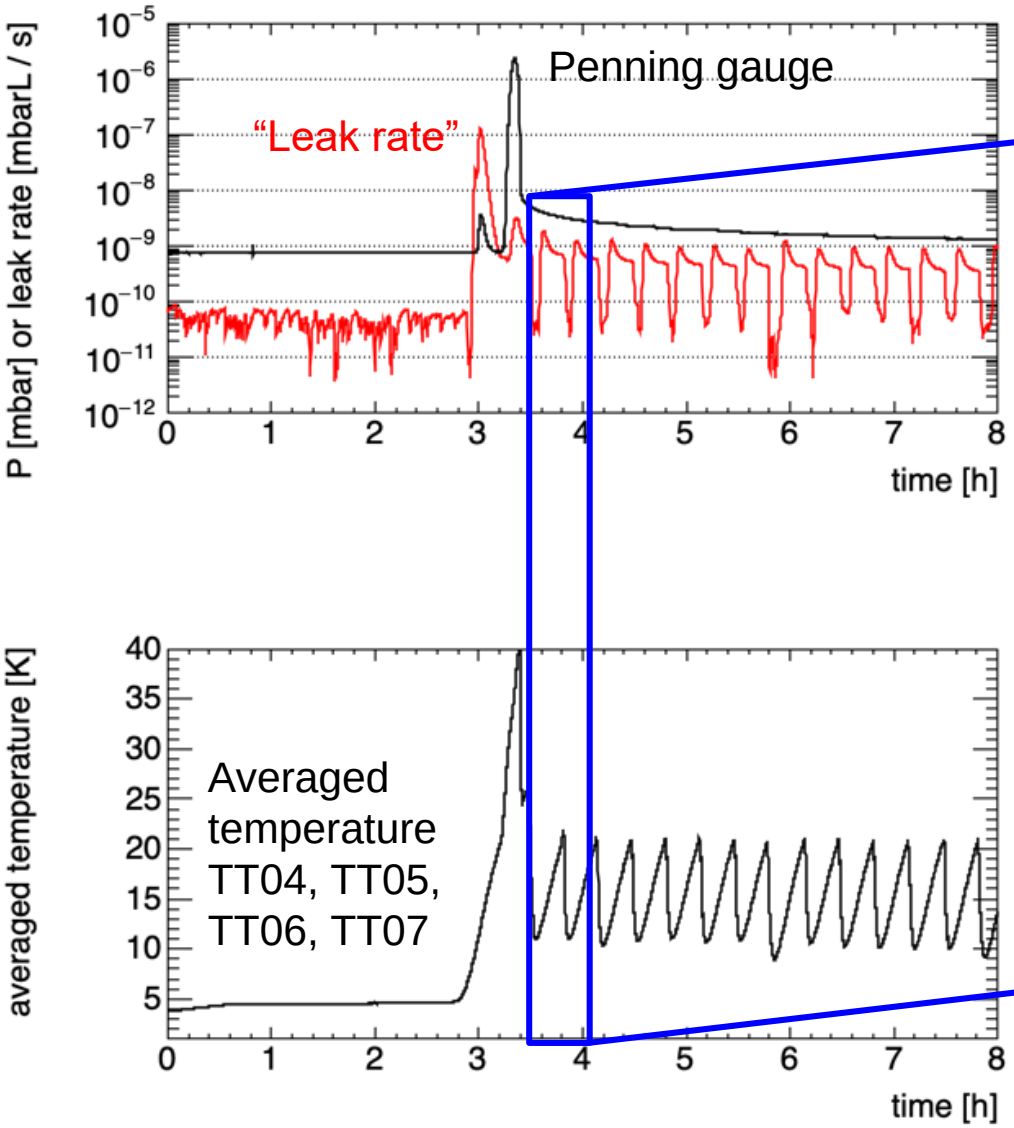




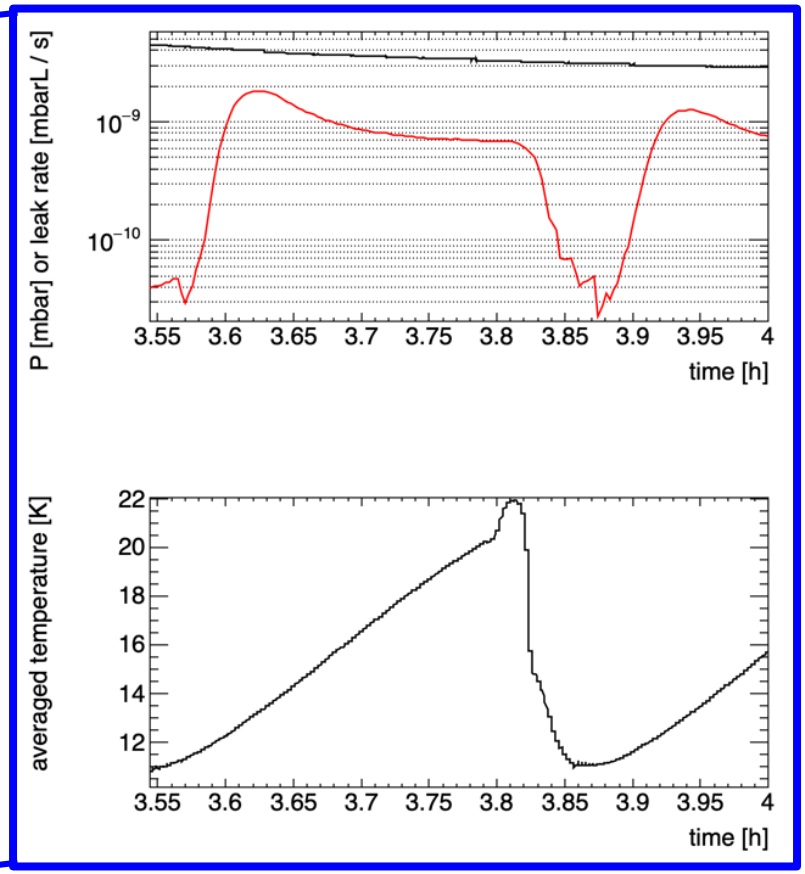
Mysha's idea

Penning gauge observes the He signal only in the 1st cycle but the leak detector is so sensitive that it can observe smaller signal every cycle

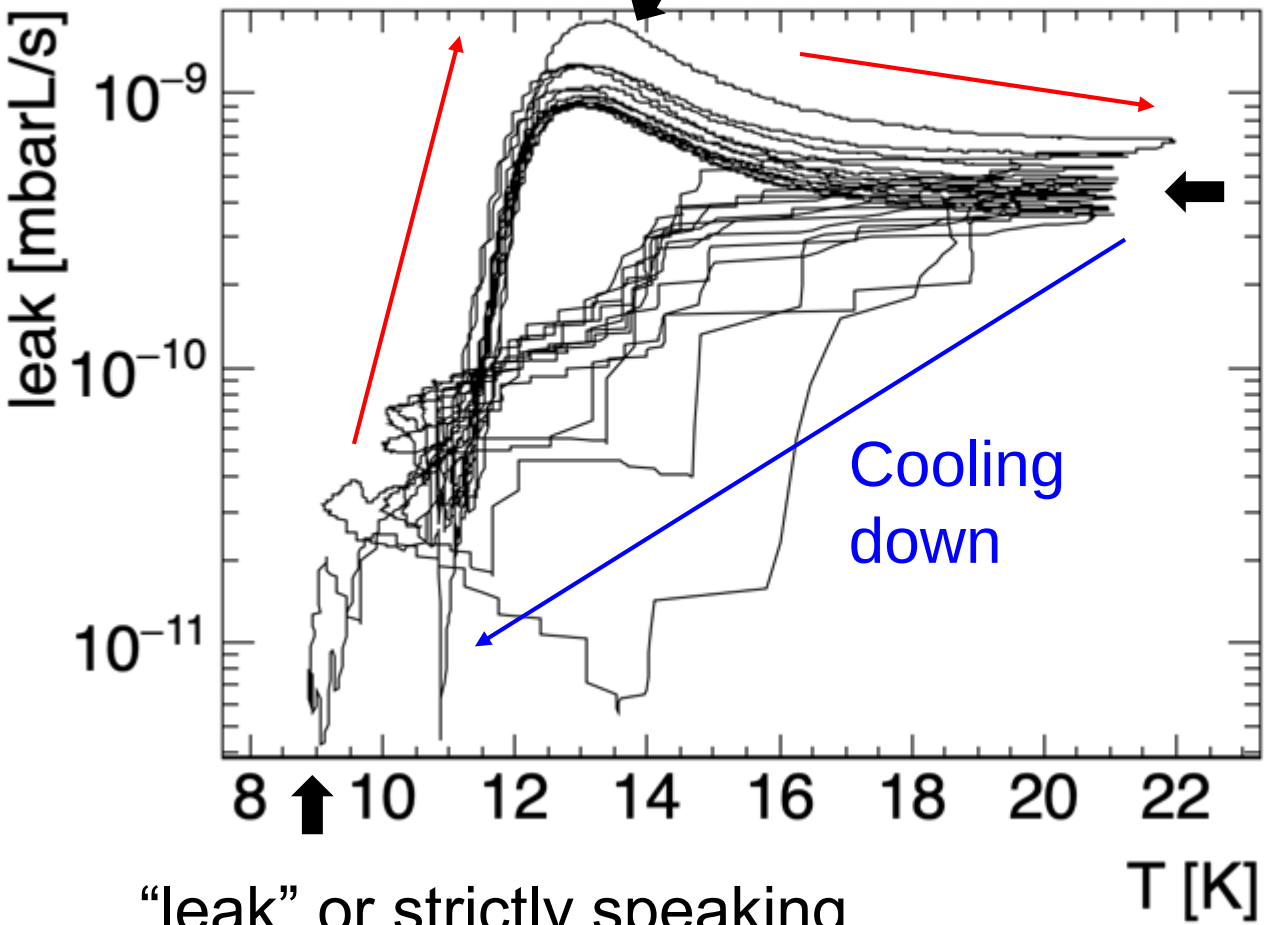
CM09_2: leak detector during thermal cycles



Enlarged one cycle



CM09_2: correlation of “leak” vs temperature



Saturate at 5e-10 mbar*L/s

“leak” or strictly speaking ***helium signal*** disappears

→ Helium seems like desorbed by cavities at very cold temperature

Literature search (thanks to Artur)

High sensitivity He desorption leak detection method

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M. G. Rao

SENSITIVE HELIUM LEAK DETECTION IN CRYOGENIC VACUUM SYSTEMS

1996

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The reliable operation of the accelerator depends on the continued leak tightness of each and every indium seal in superfluid He over the lifetime of the machine with repeated thermal cyclings. In order to achieve this goal, careful assembly procedures and stringent He leak checks of the cavity pairs need to be carried out.[3] The leak rate of the individual components and the bagged cavity pair assembly is specified to be $<2\times10^{-10}$ atm cm^3 s^{-1} at 293 K. Further, the integral leak rate of the cavity pair at 2 K is specified to be $<2\times10^{-8}$ atm cm^3 s^{-1} at 293 K based on the formation of one helium monolayer/year on the cavity pair internal surface. Conventional leak detection techniques are not appropriate to leak check these cavity pairs at superfluid helium temperature, since He will be adsorbed onto the cavity surfaces.

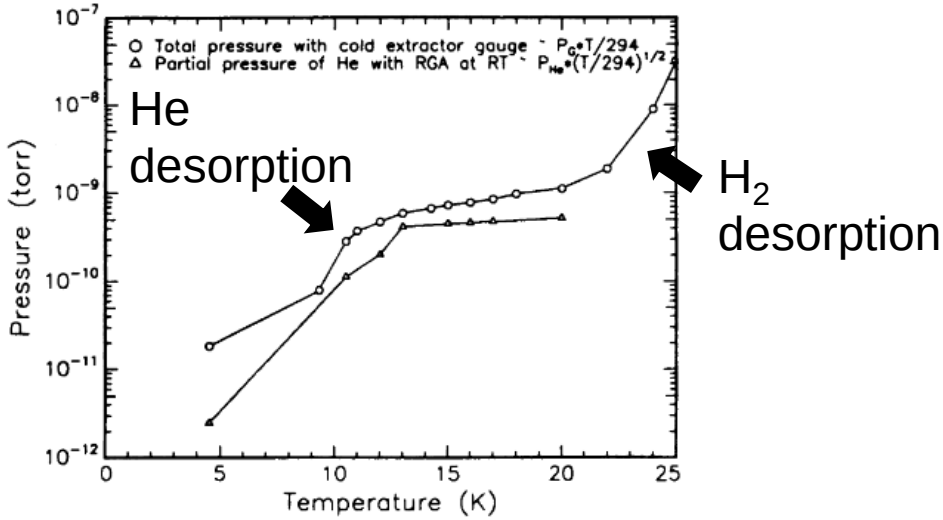
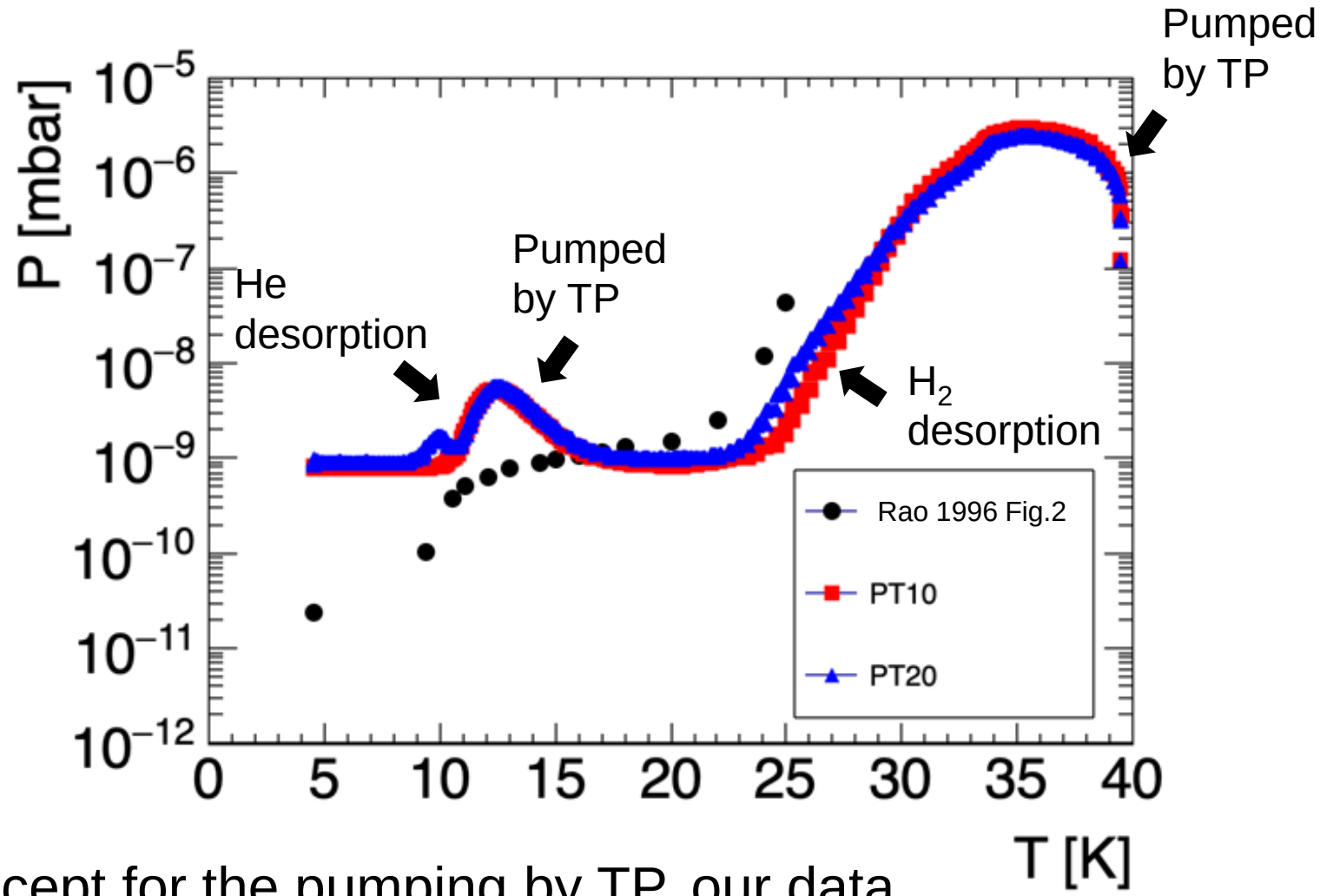


Figure 2. The corrected cold extractor gauge and RGA readings as a function of temperature.

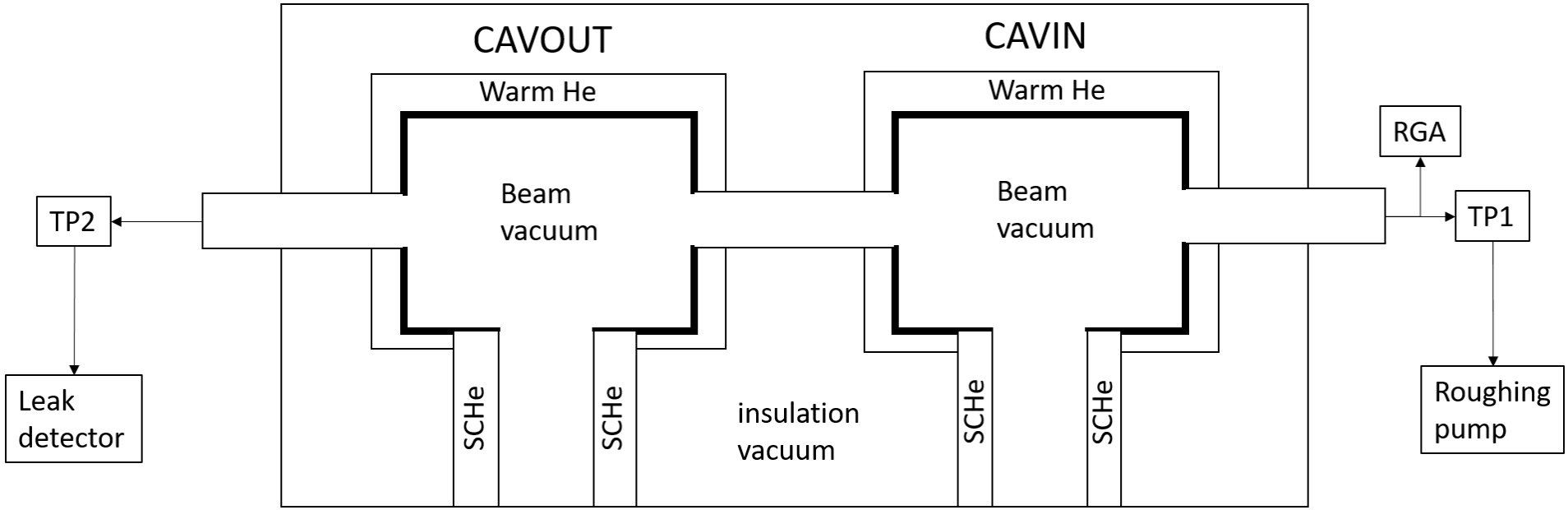
onto the He peak at 4 amu). The He is expected to be completely desorbed at a temperature of ~10 K for an

CM09_2: comparison to Rao 1996



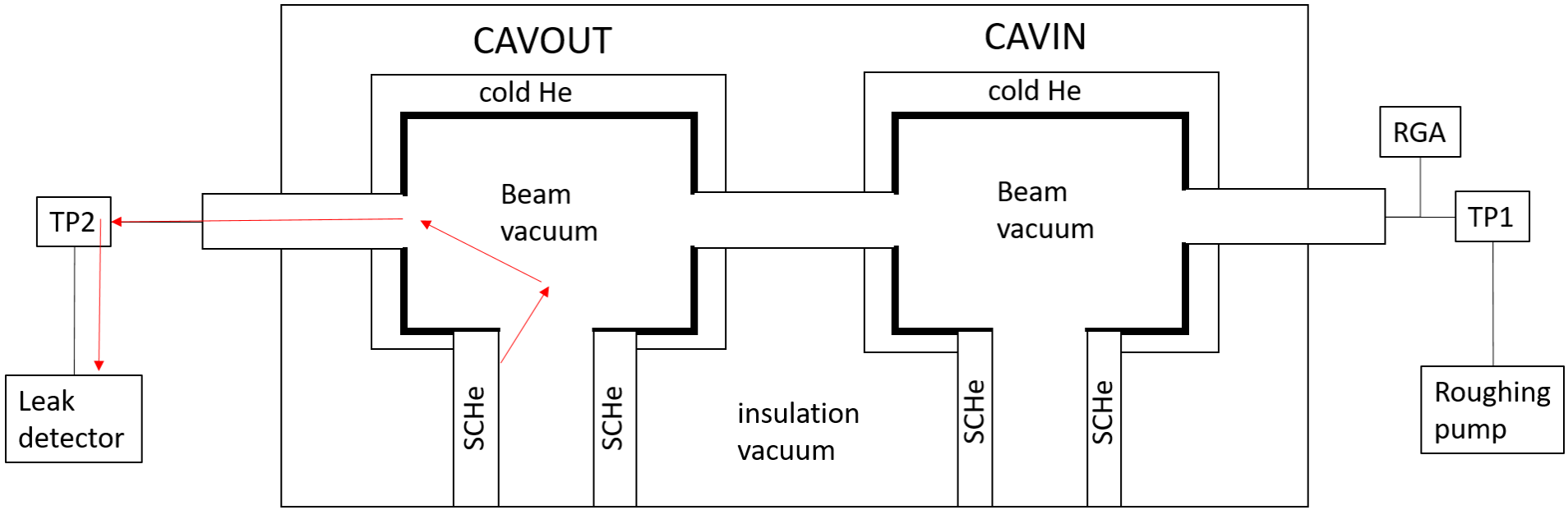
Except for the pumping by TP, our data surprisingly reproduces the results in 1996!

What happens in fact?



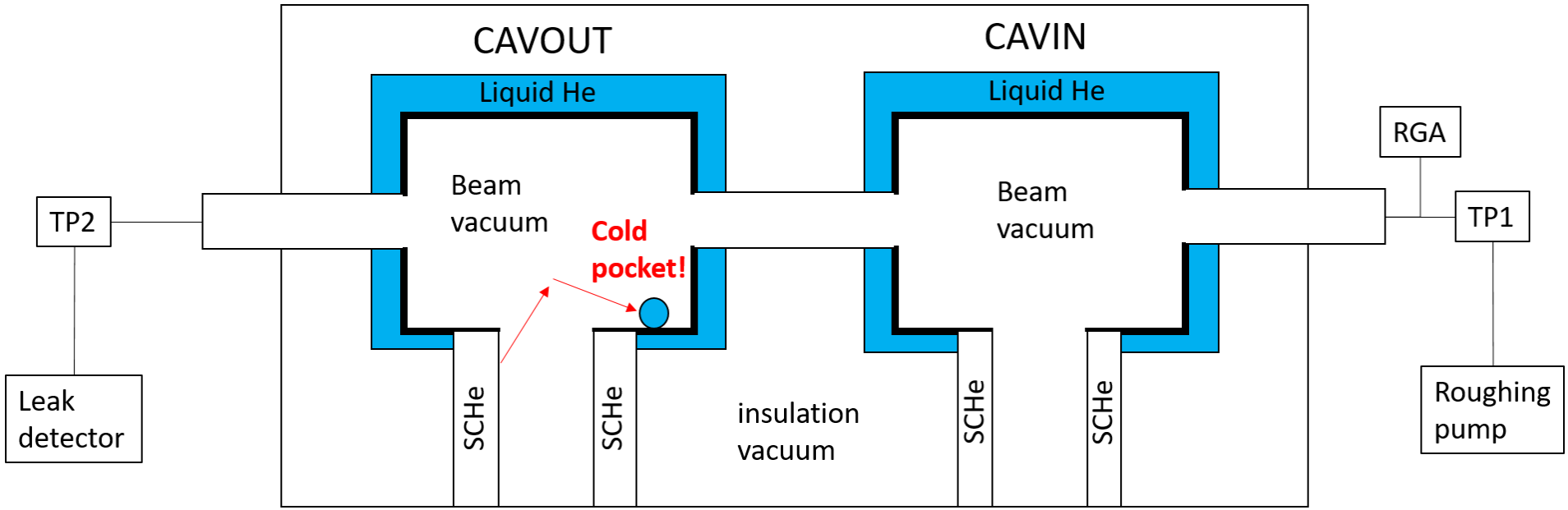
At warm leak was not detected or does not exist or invisibly small

At intermediate temperature 10K < T < 300 K



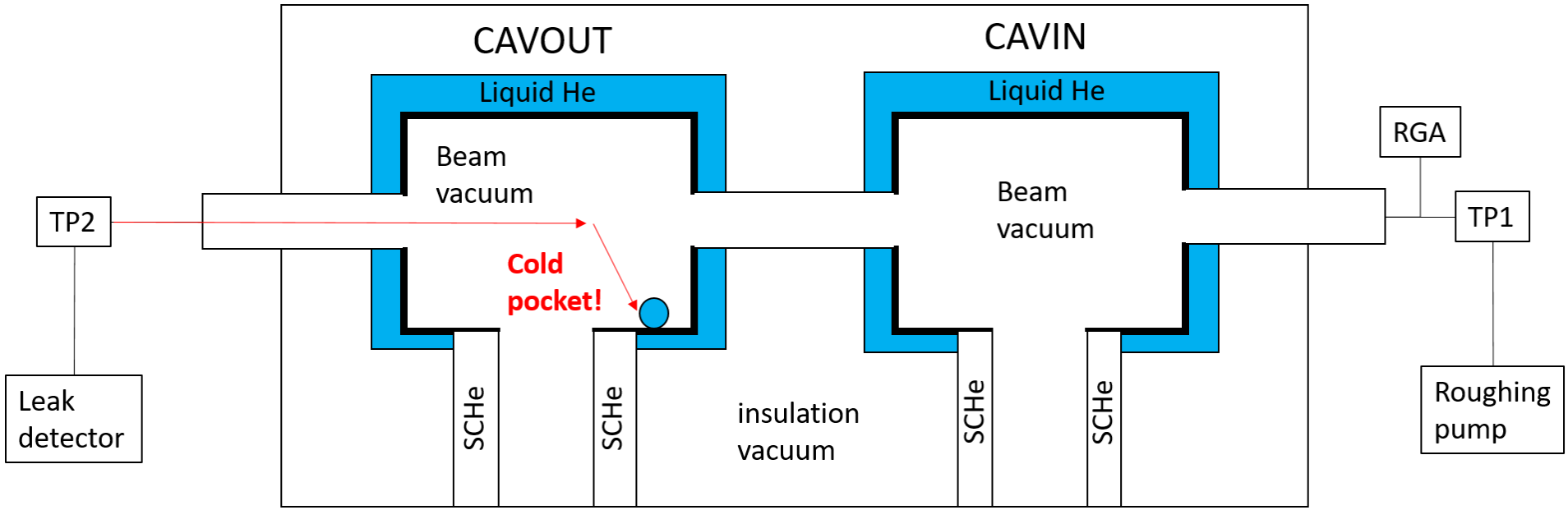
- Thermal contraction may open up a very small hole
- A very small leak increases the “background” leak rate to 5e-10 mbar*l/s

Below 10K: helium desorption happens



No gas helium signal is observable in RGA, LD and even by Penning gauge until the amount of helium reaches some equilibrium value

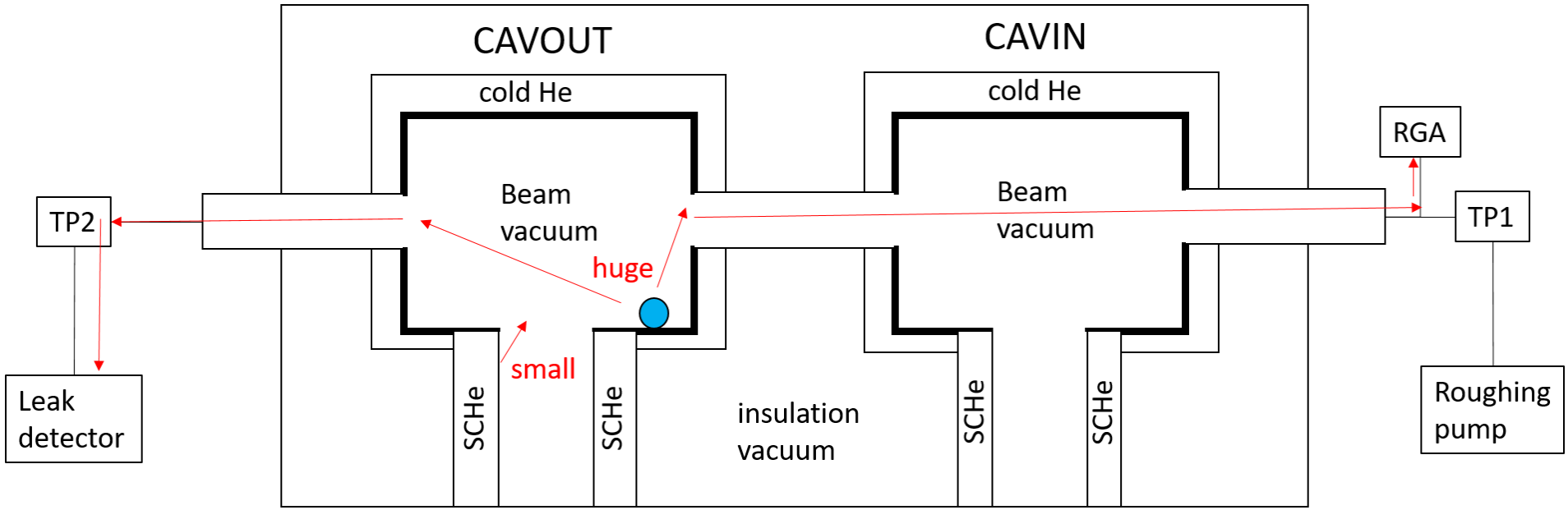
Another scenario: back stream from TP



- The helium absorption and desorption are probably the right interpretation of this phenomenon
- However, the source of helium may still be from outside

→ We are closing the angle valves during the tests below 10 K

Warming up after being below 10 K



- The accumulated liquid helium eventually desorbed when the measured temperature reaches 13 K (not on the cavity)
- The detectors see the helium signal but NOT the leak itself

If it is a leak somewhere inside the module

- **Is such a small leak really a problem?**
- From the saturation of helium signal above 15K monitored by the leak detector, the leak rate would be around 5e-10 mbar*L/s
  - Another way is to calculate it from the amount of accumulated helium over some period:

$$\text{Leak rate} = \frac{P}{t}\left[V_{RT} + (T_{RT}/T_C)^{1/2} V_C\right],$$

  - We reach 5e-9 mbar after 1 day and cavity volume may be of the order of 1 m^3 → 5e-11 mbar*L/s

<u>If helium is accumulated for 1 year</u>

$$nRT \sim PV = 5 \times 10^{-10} \times 365 \times 24 \times 60 \times 60$$
$$\sim 1.6 \text{ Pa} * \text{L}$$

$$\rightarrow n \sim 1.6/(8314 \text{ LPaK}^{-1}\text{mol}^{-1} \times 10 \text{ K})$$
$$= 1.9 \times 10^{-5} \text{ mol } (1.2 \times 10^{19} \text{ atoms})$$

Helium is 4 g/mol → 77 μg accumulated

One helium atom occupies 1Å × 1Å
→ $n \times 10^{-10} \times 10^{-10} = 0.12 \text{ m}^2$
Are will be covered by helium monolayer → Maybe nothing?

atm cm^3 s^{-1} = mbar L s^{-1}

The reliable operation of the accelerator depends on the continued leak tightness of each and every indium seal in superfluid [illegible] th repeated ther[illegible] care-ful assembly procedures and stringent He leak checks of the cavity pairs need to be carried out.[3] The leak rate of the individual components and the bagged cavity pair assembly is specified to be $<2\times10^{-10}$ atm cm^3 s^{-1} at 293 K. Further, the integral leak rate of the cavity pair at 2 K is specified to be $<2\times10^{-8}$ atm cm^3 s^{-1} at 293 K based on the formation of one helium monolayer/year on the cavity pair internal surface. Conventional leak detection techniques are not appropriate to leak check these cavity pairs at superfluid helium temperature, since He will be adsorbed onto the cavity surfaces.