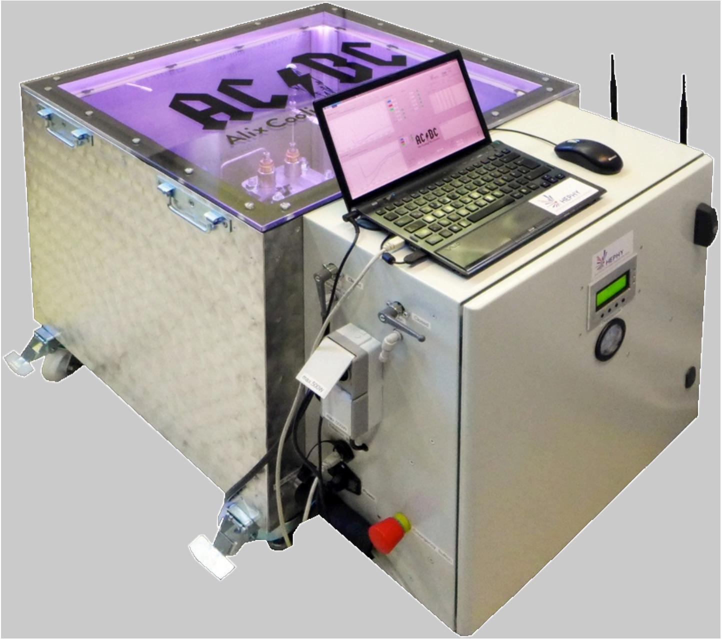
High Energy Accelerator Research Organization



Experience with the open CO2 system @ KEK

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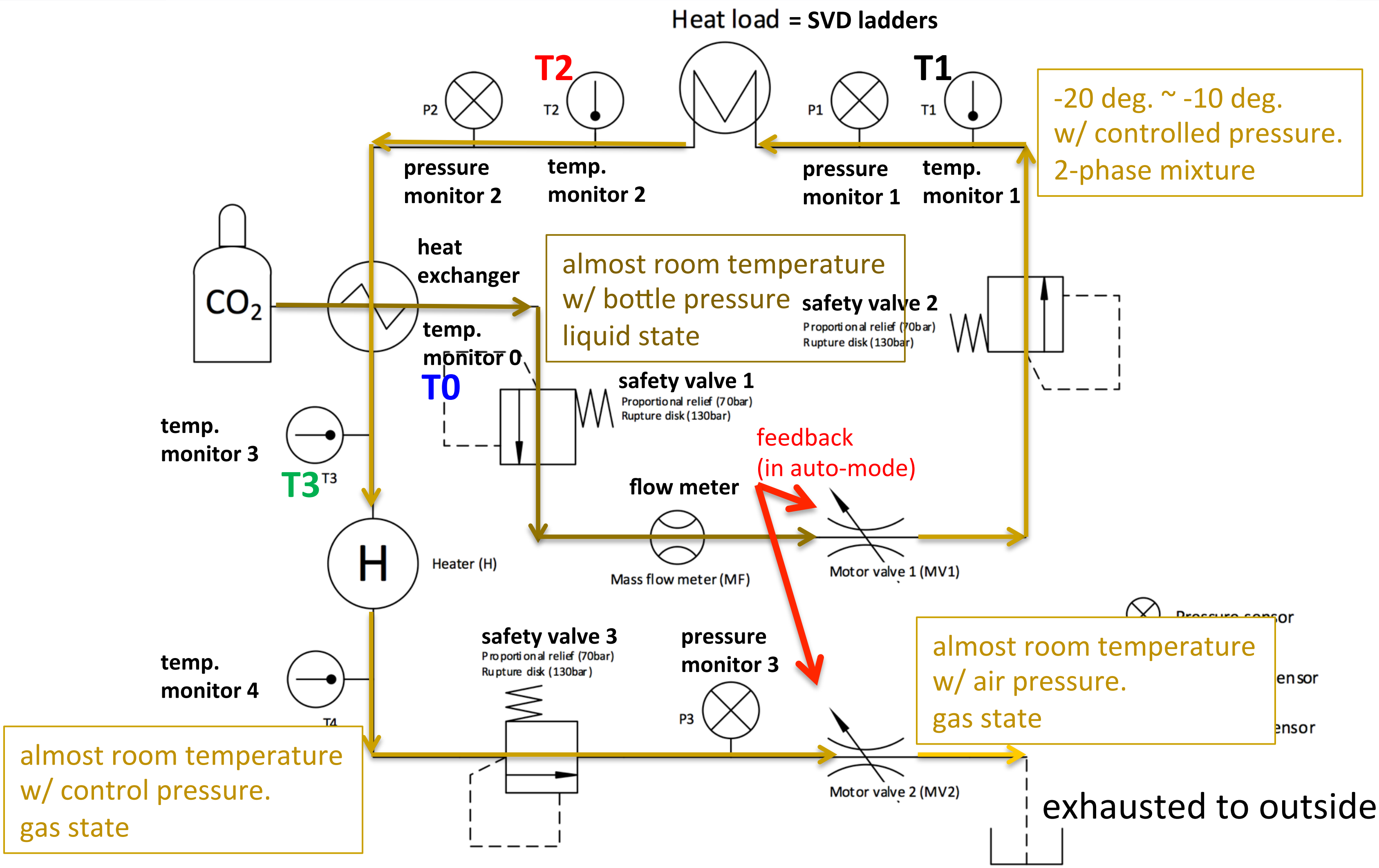
Open CO2 system

- Open CO2 cooling system developed by HEPHY
- O(100W) cooling power
- Li-CO2 is supplied by bottles outside.
- Automatic control of the CO2 flow rate is implemented. But not CO2 temperature (= CO2 pressure) currently.

- Naoya Kambara (Tokyo University of Science) is studying the system at KEK.

System Flow Diagram



CO2 cooling system setup at KEK B1

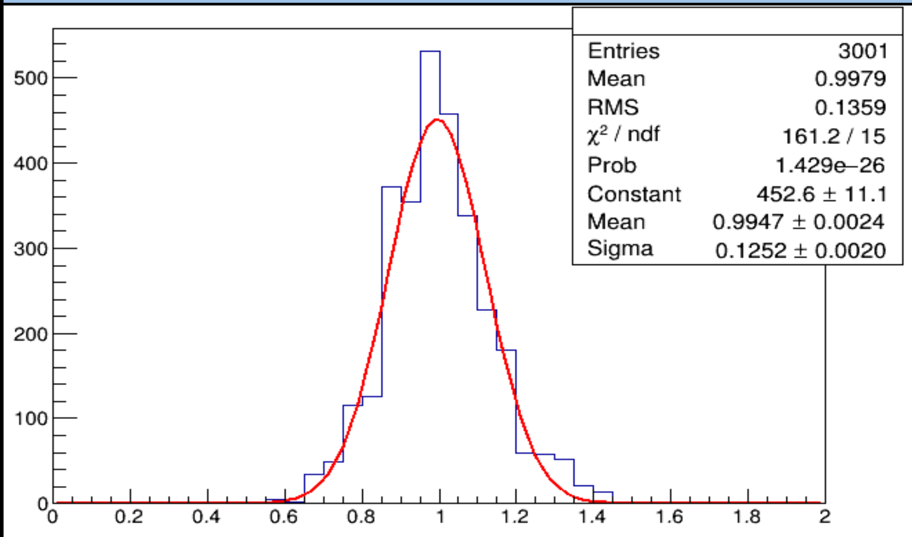
- **From 1 CO2 bottle, about 20kg CO2 is available for the CO2 system**
  - (actual amount of CO2 inside the bottle is 30kg).
- **Currently, once one CO2 bottle gets empty, we have to switch off the CO2 cooling system, connect to another bottle, and then restart the CO2 system.**
- **In future, we will implement switching valves, which enable us continuous switching the bottles without stop of the system.**

Requirements on the open CO2 system

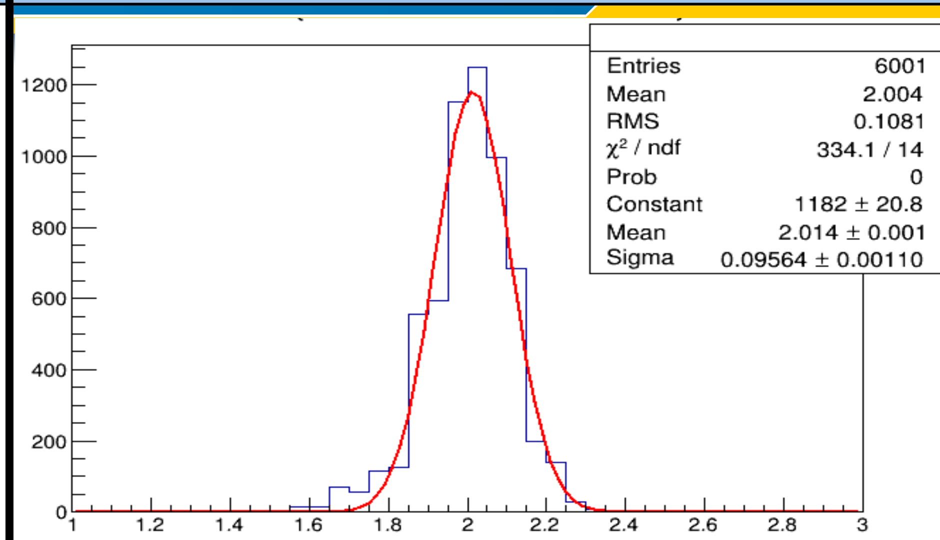
- **Role of the open CO2 system**
  - **Cooling test during SVD ladder mount.** (highest priority)
    - Test thermal conductance between endmounts/bridges and Endrings.
    - Test thermal conductance between ORIGAMI cooling pipes and APV25 chips (through Keratherms).
  - Test SVD ladder performance under the cooling down (secondary priority)
    - Mechanical deformation study under the cooling
      - DESY is also performing this study with dummy ladders, but check it with a real ladder (class-C) is preferable.
    - Possibly, study of S/N ratio improvement (Maybe w/ class-B- ladder).
- **Requirements**
  - 100W cooling capability
    - Total power dissipation from ORIGAMI APV25s in half L6 ladders (the largest unit in the cooling test):
      8[ladders] x 30[APV25s/ladder] x 0.4[W/APV25] = 96[W]
  - Stabilities in temperature and CO2 flow control
  - Reasonable CO2 gas consumption
  - Reasonable test time

Stability of Flow Rate (Deviations in Flow Rate)

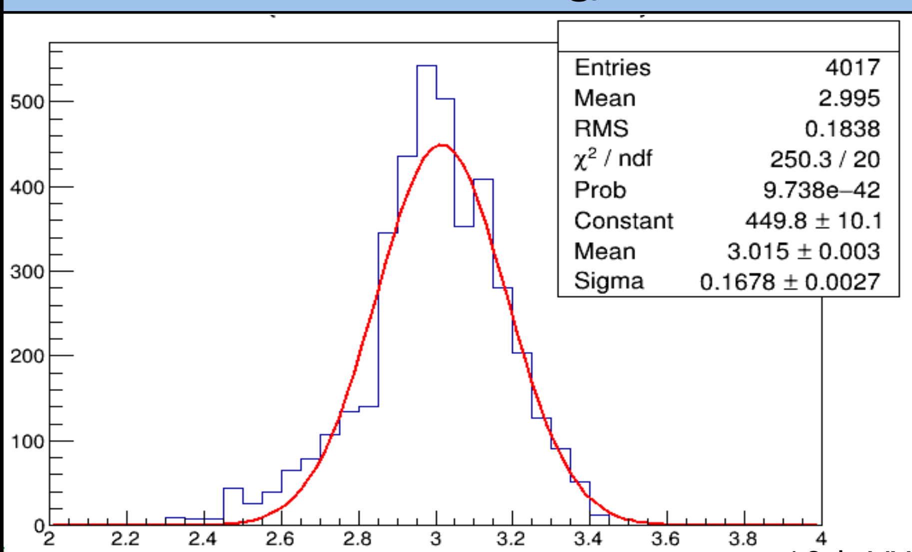
flow rate: 1.0 g/s



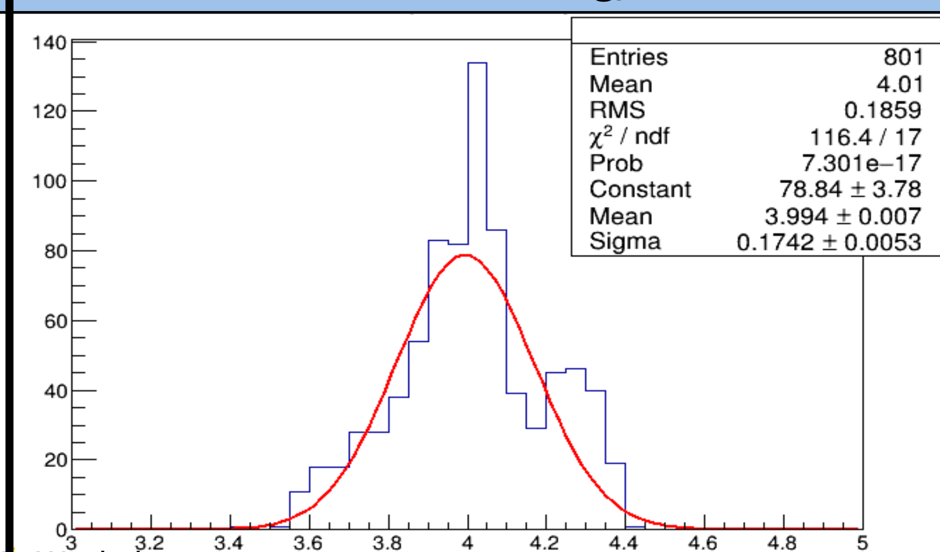
flow rate 2.0 g/s



flow rate: 3.0 g/s



flow rate: 4.0 g/s

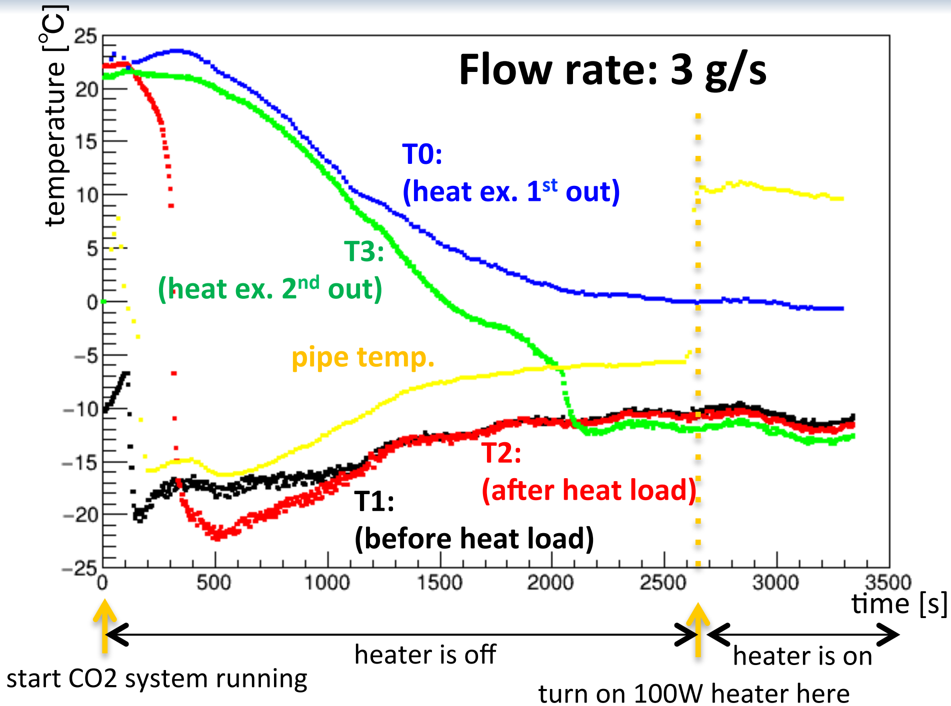


The system was operated in automatic mode.

Cooling Capability Test (Setup)

- **Voltage supply applies a load on the test pipe directly.**
  - Pipe: SUS304, OD: 1.6mm, ID: 1.4mm
  - Voltage supply: max. 20V, max. 20A (max. 400W)
- **The resistance of the pipe limit the power up to about 260W.**
- **Monitor pipe temperature with a sensor on the pipe.**

Cooling Capability Test (Results)

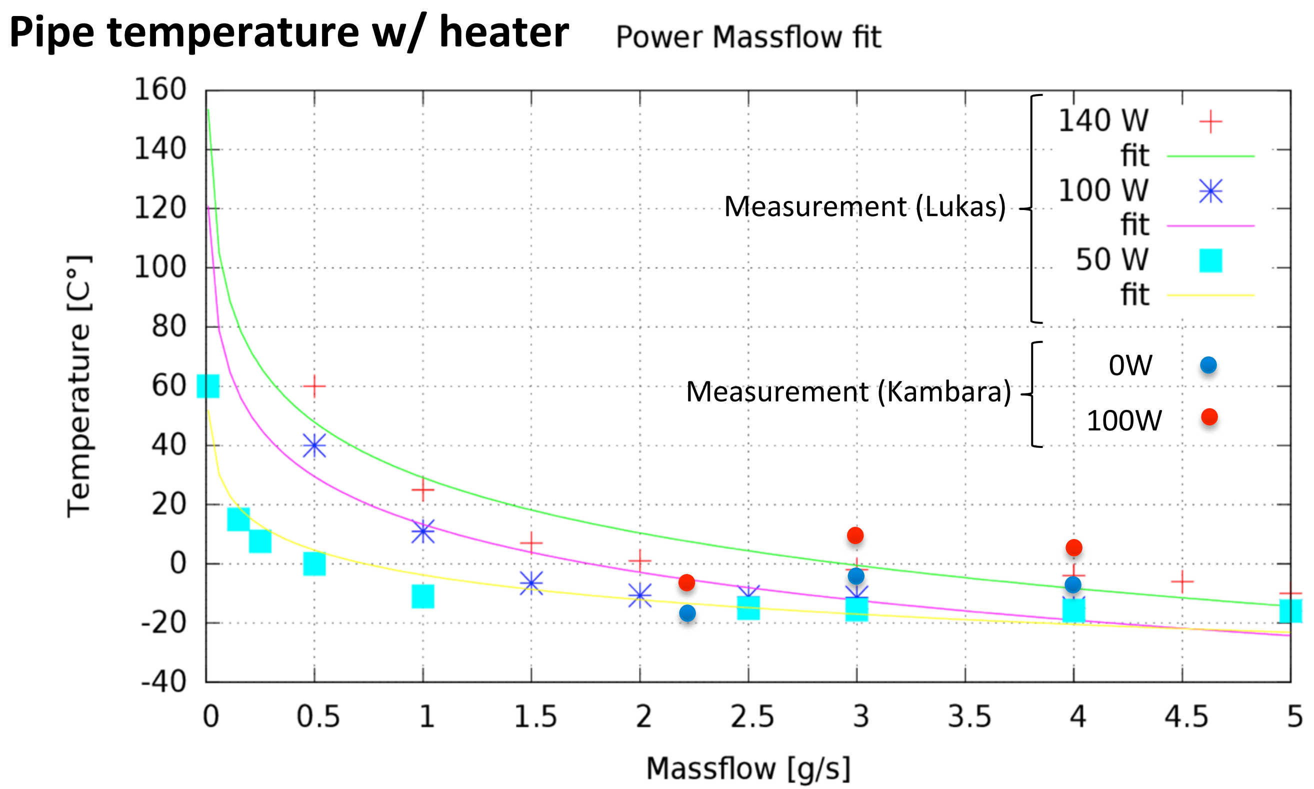


Resulting pipe temperatures

flow rate [g/s]	pipe temp. [°C] w/o load	pipe temp. [°C] w/ 100W load
2.2	-17 … -16	-7 … -6
3.0	-5 … -4	10 … 11
4.0	-7 … -6	6 … 7

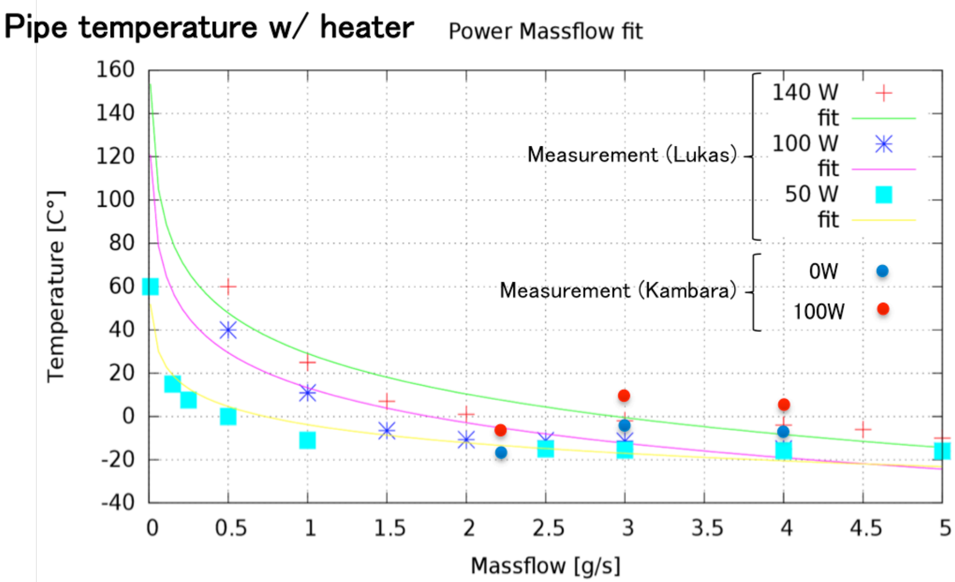
- **We tested flow rates of 4 g/s, 3 g/s, and 2.2 g/s under a heat load of 100W.**
- **In any flow rates, there are no difference in T1 and T2.**
  - → Still cooling power was remaining after the heat load.
- **But pipe temperatures become lower for higher mass flow.**

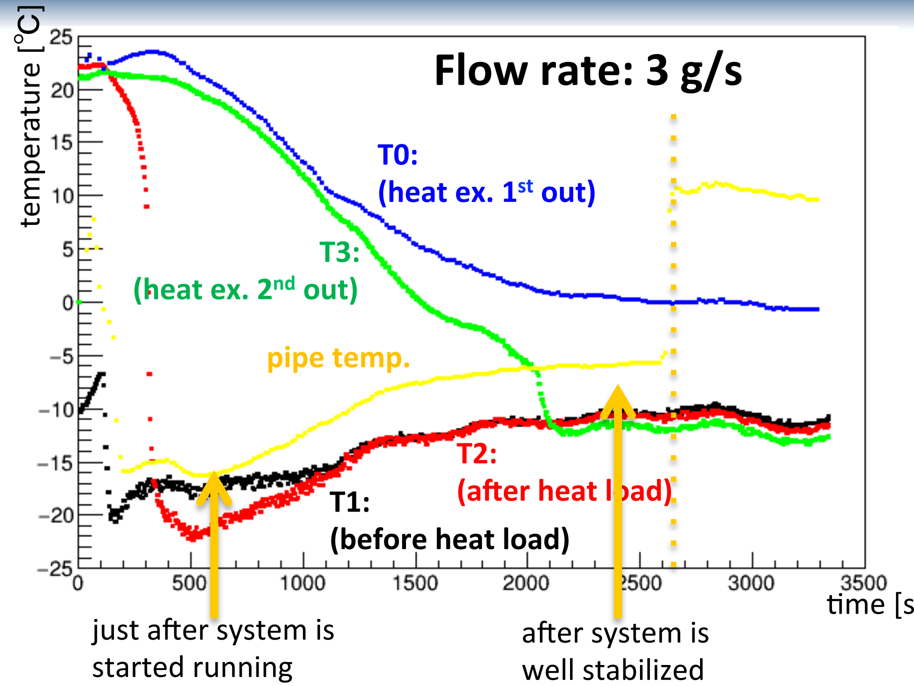
Comparison the results with before shipment



- **Results in 2.2 g/s shows good consistency with Lukas's measurement and a enough cooling power for 100W load.**
- **But, Results in 3 g/s and 4 g/s are higher temperature than Lukas's measurement and our 2.2 g/s result.**
  - They looks inconsistent with our 2.2 g/s result.

Reasons of the inconsistency



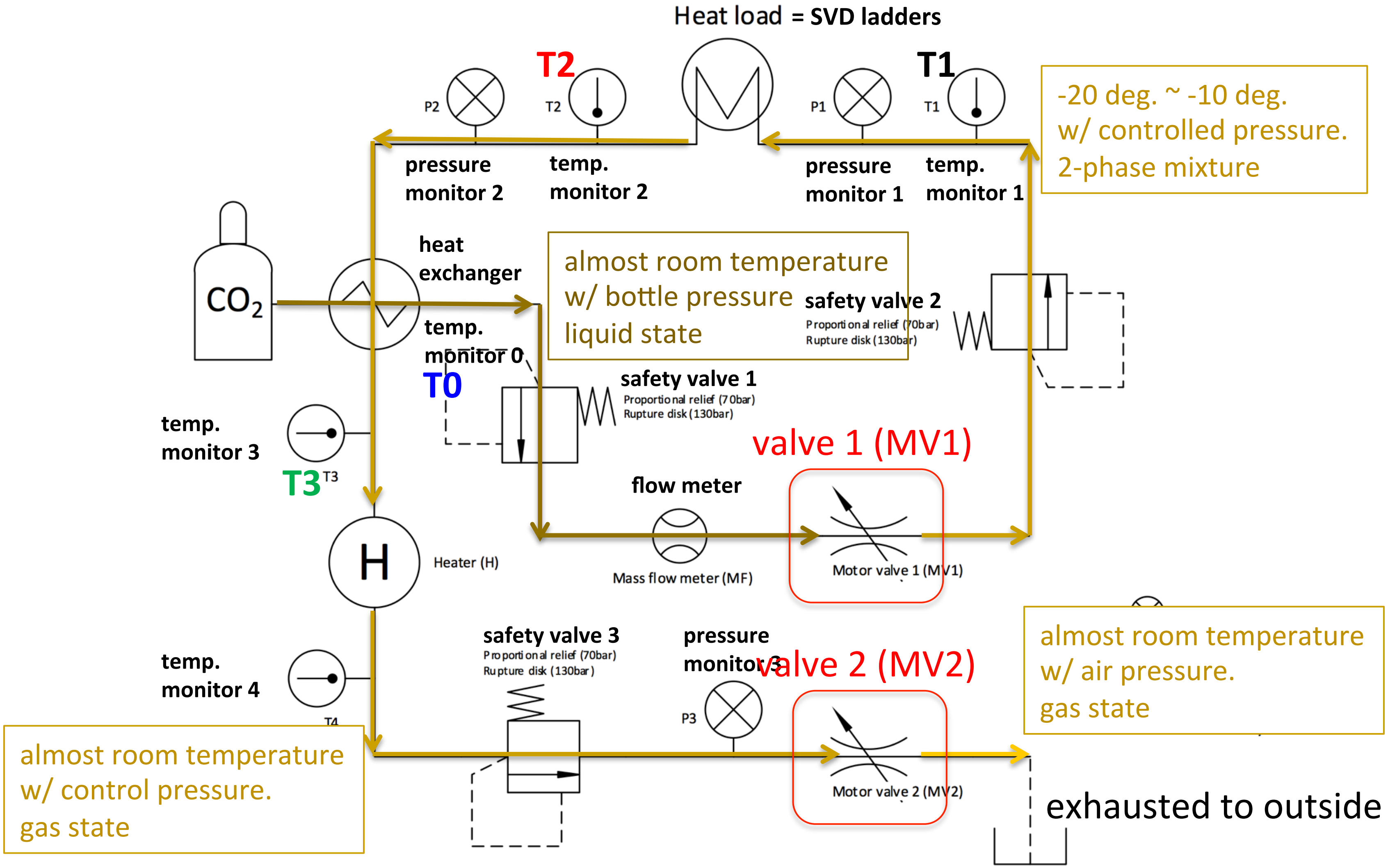


- **We saw large drift in the pipe temperatures during CO2 system operation.**
  - The CO2 temperature is getting higher during the operation. About 10 degrees difference was observed between the beginning and later.
  - 2.2g/s measurement: done earlier, 3.0g/s, 4.0g/s measurement: done later
  - → Need to control the CO2 temperature T1 (= pressure P1) as well as the flow rate.
- **Also thermal isolation form is not tightly surrounded on the pipe.**
  - → We will improve the the form attachment.

Control of CO_2 Temperature

- **Drift in CO_2 temperature (= pressure) during operation**
  - Because the current system doesn't control CO_2 temperature, the temperature changes during operation.
  - We have to be very careful for the temperature drift, otherwise we loose reproducibility of the cooling test results.
  - If the system gets stabilized and we don't change the valve settings, the temperature seems stable. But, the system stabilization takes about 1000s (about 17min.) and consumes 4 kg CO_2 in 4 g/s flow rate.
- **And in the current automatic mode, the stabilized temperature is about -10 degrees, but not less than that.**
  - Do we need to use -20 degrees?
  - Preferable, because it is worth to check mechanical performance of ladders under -20 degrees or lower with the open CO_2 system.
  - In this case, a solution for -20 degrees is manual-mode operation, but stability is not guaranteed.
    - Even turning on heat load can change the CO_2 temperature in manual mode.
- **Can we control the CO_2 temperature?**

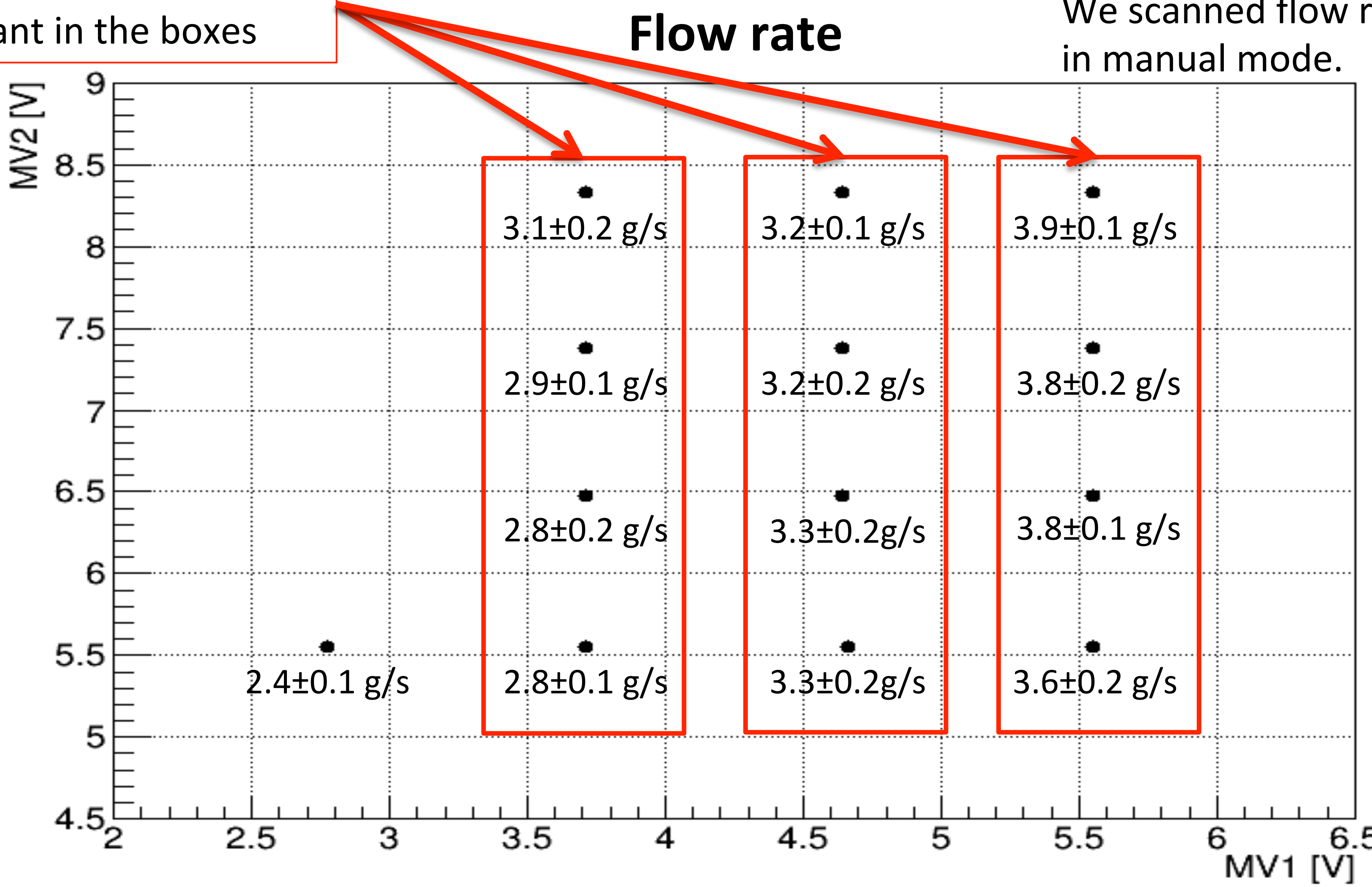
CO2 Temperature Control Scheme



Flow rates in MV1-MV2 map

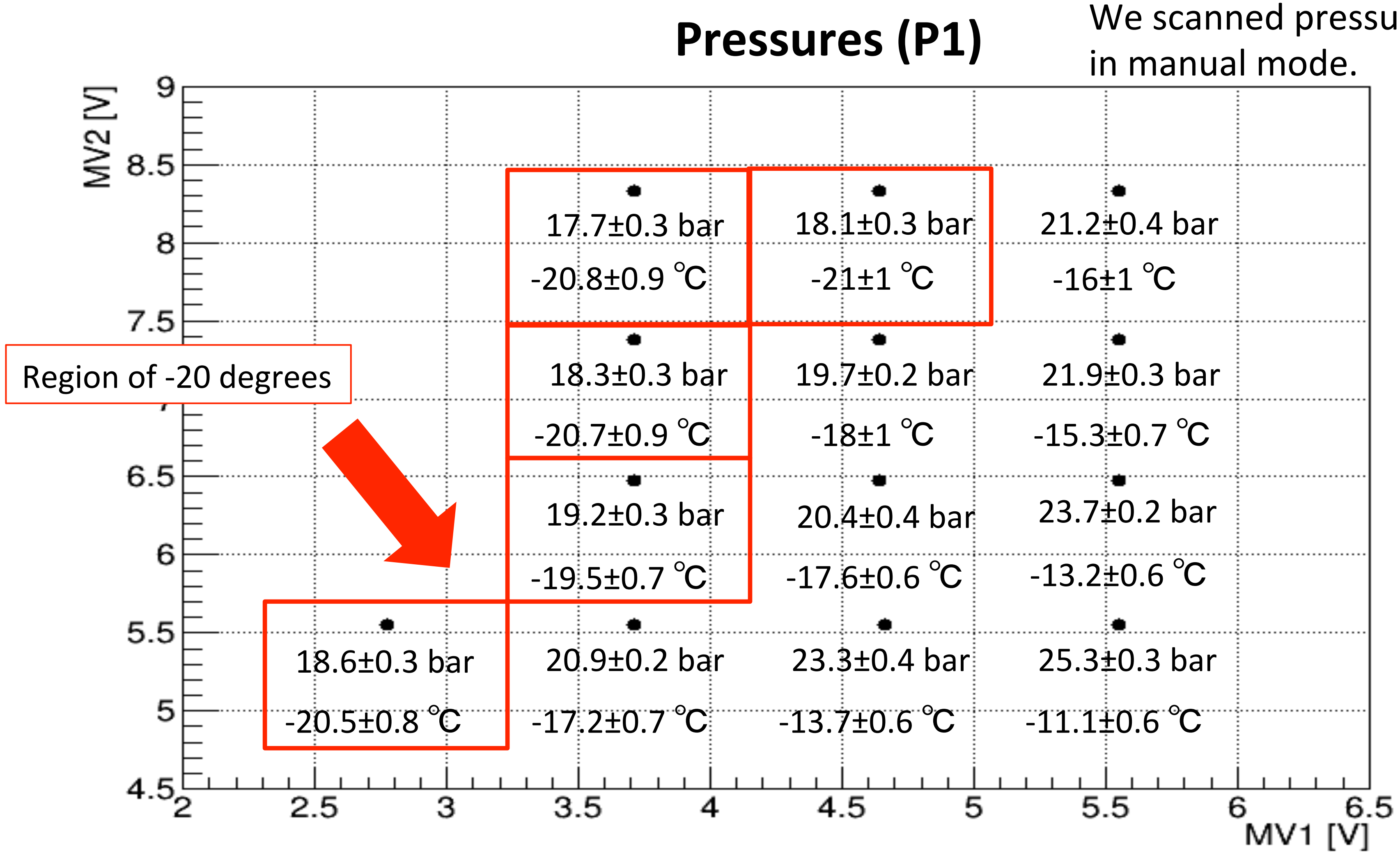
Flow rates are almost constant in the boxes

We scanned flow rates in manual mode.



Pressure in MV1-MV2 map

We scanned pressures in manual mode.



Solution for CO_2 temperature control

- **In manual mode, we can control the CO_2 temperature.**
    - The first valve (MV1) controls flow rate.
    - The second valve (MV2) controls pressure (= temperature).
  - However, this manual operation doesn't have good stability.
    - We have to keep checking the temperature monitor to adjust the valve frequently, especially in the beginning of operation.
    - Even if we apply heat load, this changes the temperature and we need to change the valve setting again.
- **Ideally, temperature control in automatic mode is rather preferable and useful**
  - as well as we are controlling flow rate.
  - But, maybe, need more development time…

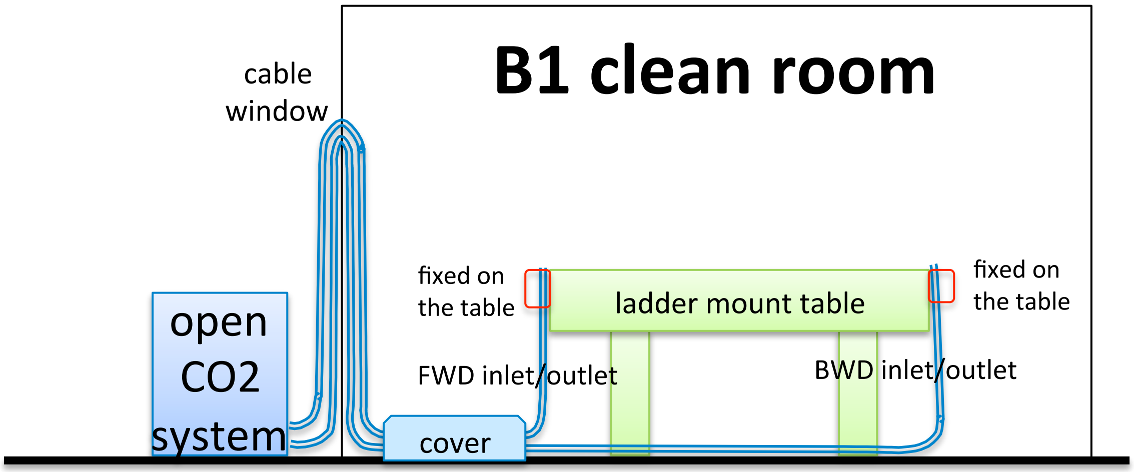
Time and CO_2 consumption

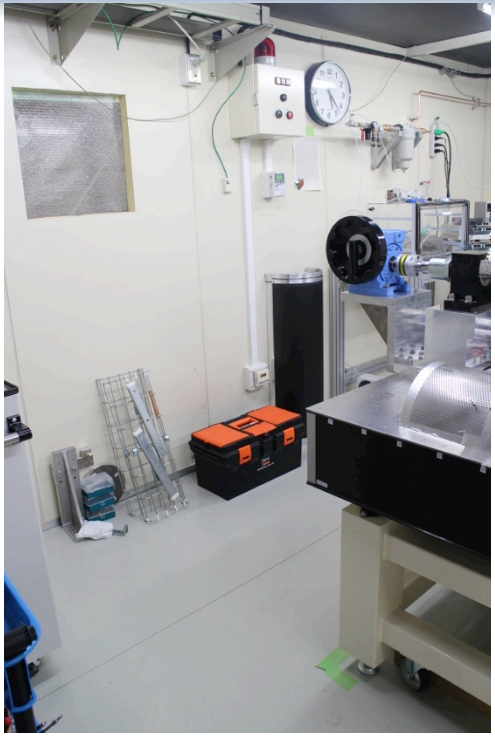
- **CO_2 consumption until the temperature gets stabilized:**
  - 2.0 g/s: 14 kg
  - 3.0 g/s: 6 kg
  - 4.0 g/s: 4 kg
- **Larger flow rate looks better to minimize the CO_2 consumption until the stabilization.**
- **In the current automatic mode, if we change the flow rate after the stabilization, the temperature gets unstable again.**
  - Change from 4.0 g/s to 2.0 g/s after the stabilization to save CO_2 is not good option due to this phenomena.
- **So far, keep running in automatic mode of 4.0 g/s flow rate is the best operation considering the test time and CO_2 consumption.**

flow rate [g/s]	time [s]	CO_2 consumption [kg]
1.0		(more than 5kg)
2.0	7000	14
3.0	2000	6
4.0	1000	4

cf. 20kg CO_2 are available from 1 bottle.

Future open CO2 system setup in clean room





- All the cooling pipes will be laid on the floor in order to prevent dew drop from the roof.
- FWD and BWD cooling lines are selected on the open CO2 system side.
- All the necessary parts are under quotation now. They will be set up by the end of Oct.

Safety interlock system

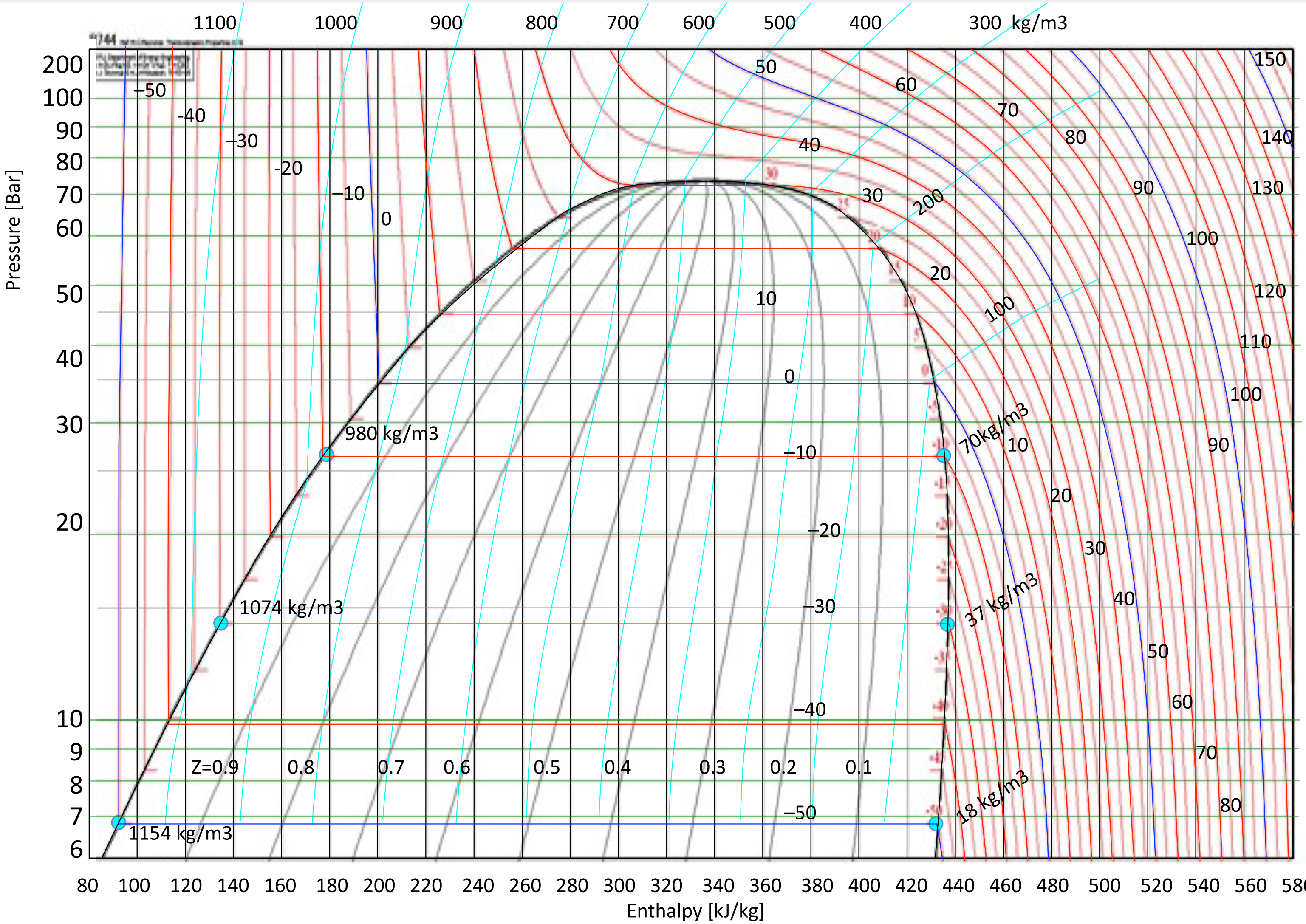
- **We had a small accident:**
  - CO2 system was turned off while the heater to the dummy load was kept on.
  - Fortunately, before smoke or fire, we notice it with a bad smell from the load.
  - The same accident happened when Lukas tested the system.
- **Possible solutions:**
  - Interlock signal from the temperature sensor on the load.
    - We will implement it soon.
  - Interlock signal from the open CO2 system
    - Currently, there is no such output from the system, which indicates whether the system is running properly or not.
    - It is good that the system has such output for safety purpose, and this makes the system simple.

Summary

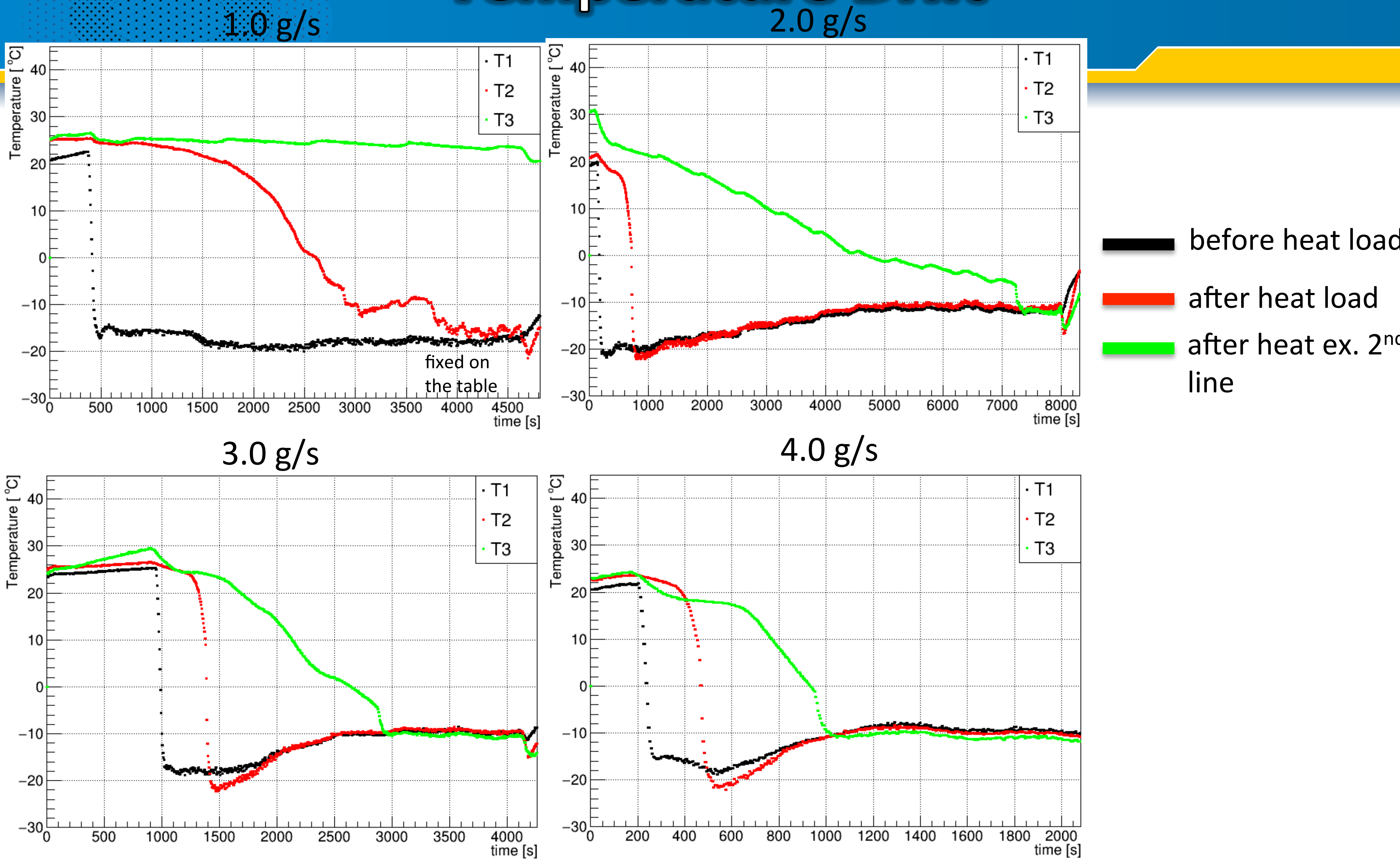
- **Cooling capability**
  - Even flow rate of 2.2 g/s shows excellent cooling performance.
- **Stability in automatic-mode operation.**
  - Flow rate: excellent stability
  - Temperature: At least needs 17min. and 4 kg CO2 until the stabilization. Moreover, we cannot achieve -20 degrees.
    - Temperature control as well as flow rate control would be preferable.
- **Flow rate during the test**
  - 4.0 g/s seems the best considering the test time and CO2 consumption.
- **System setup in B1**
  - Now ongoing. Setup will finish by the end of Oct.
- **Interlock system**
  - We will implement an interlock system based on temperature sensors.

backup

CO2 phase diagramf



Temperature Drift



Equilibrium temperature is about -10 degrees for all flow rates.