Taking Care of Emergencies: Interlock System and GUI Design for ATLAS ITk Strip Endcap Tests

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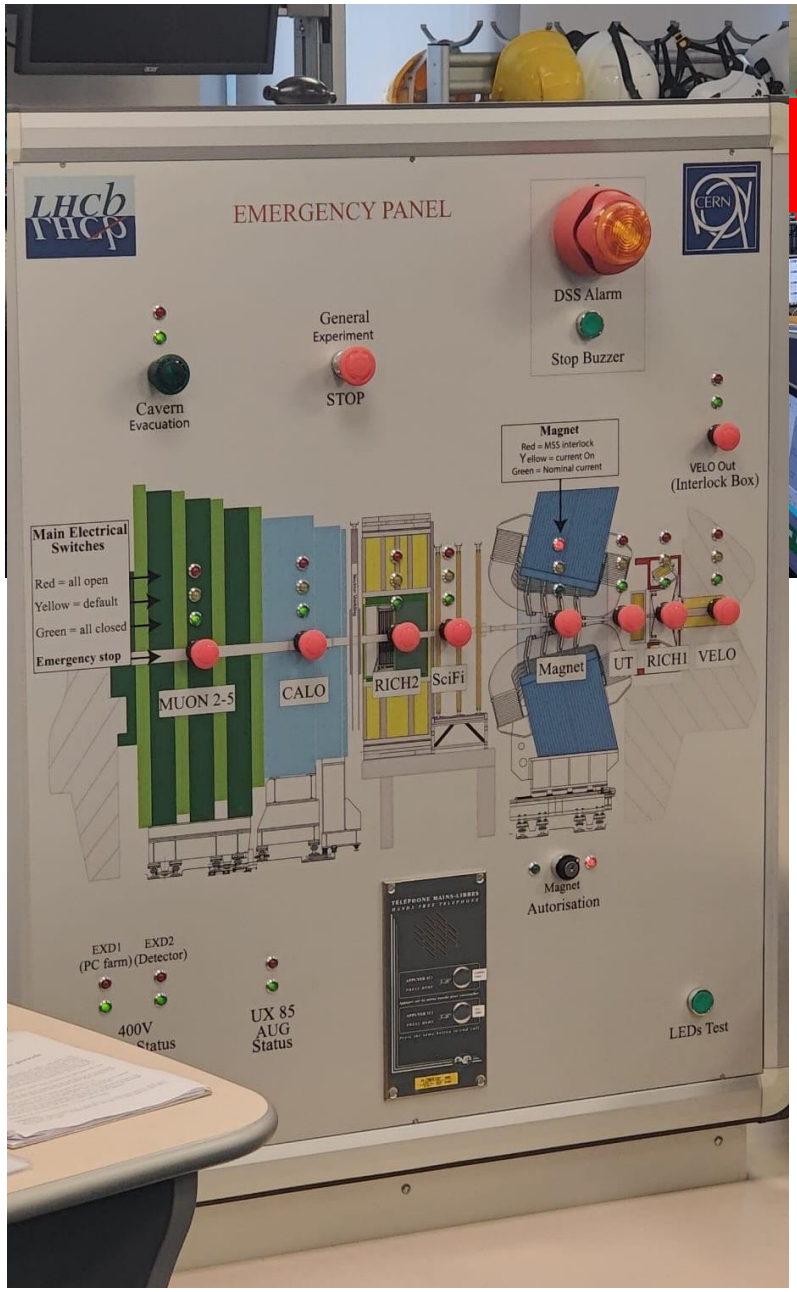
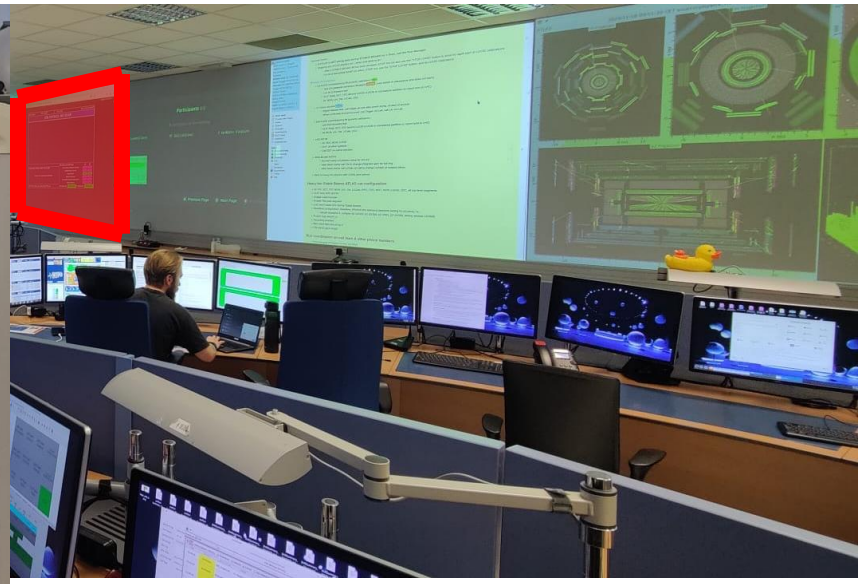
DESY Summer Student Programme 2025

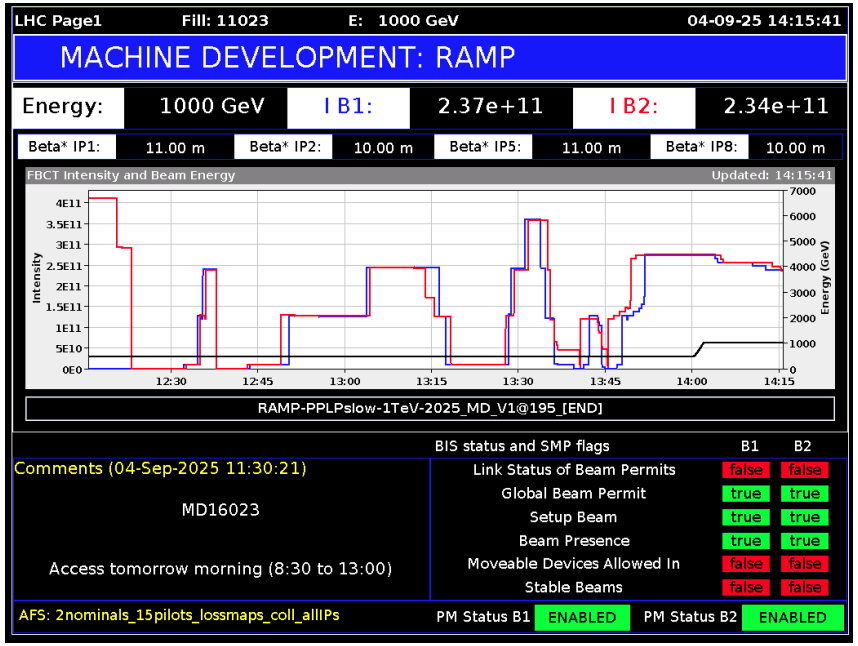
Sep. 8th, 2025, DESY ATLAS Meeting Room

ATLAS Control Room

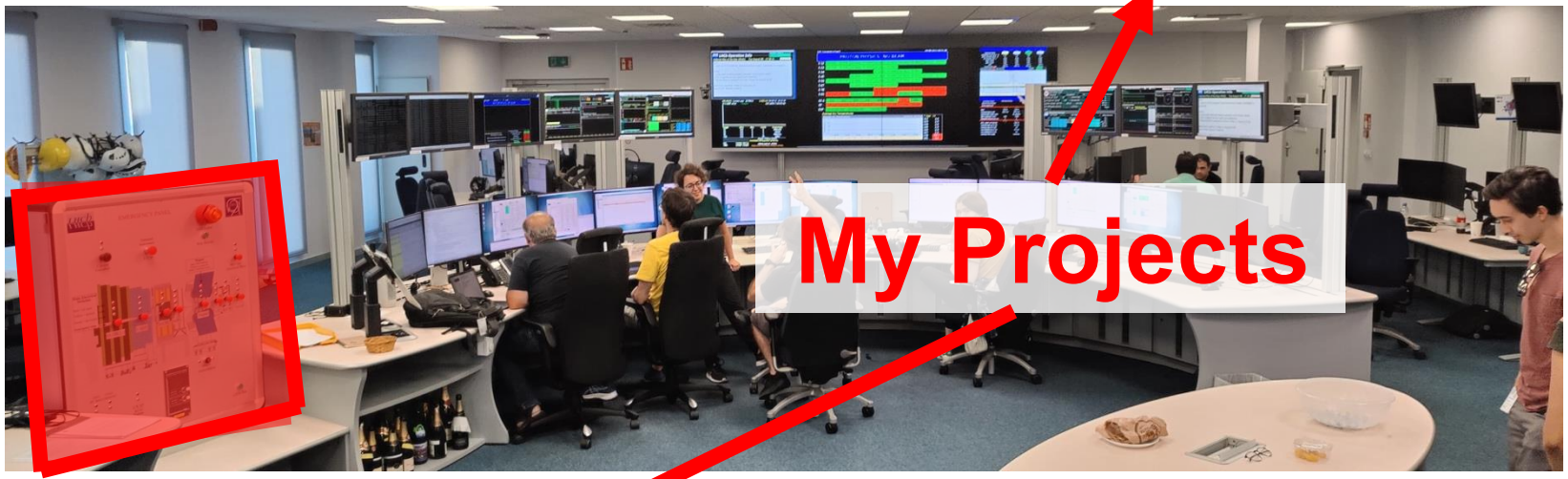
LHCb Control Room





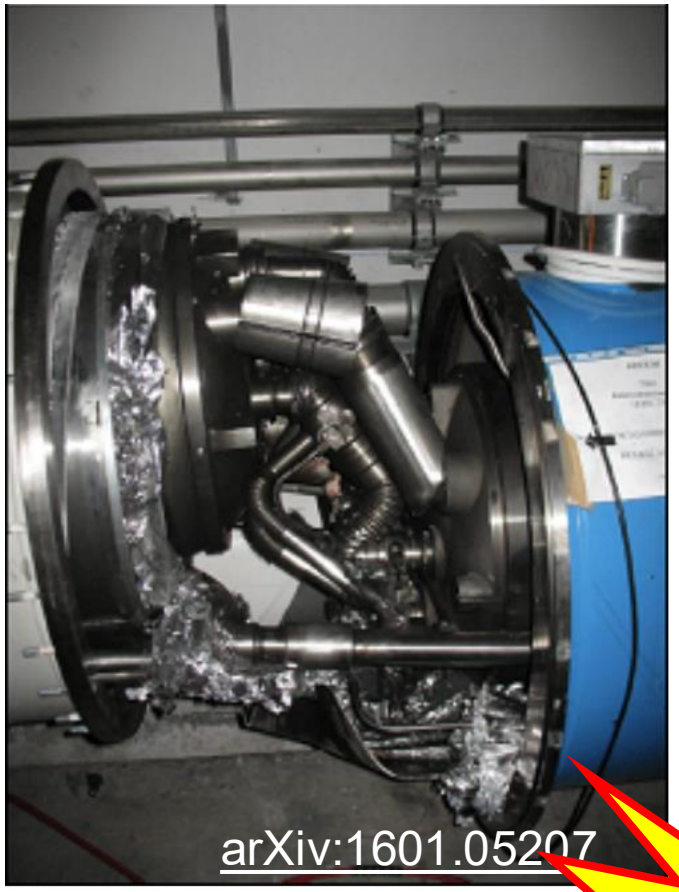


Real-Time Monitoring GUI



Emergency Panel with Emergency Buttons

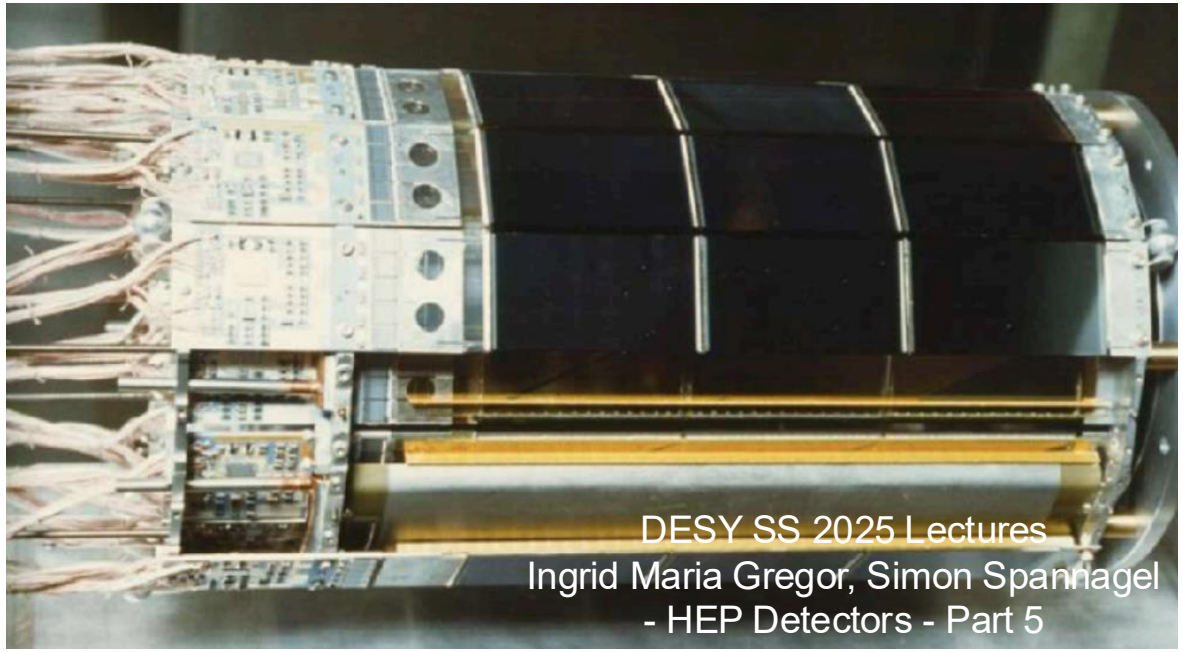
Catastrophic Consequences…



LHC 2008
"Quench"

superconducting magnet temperature > operating temperature

Temperature monitoring



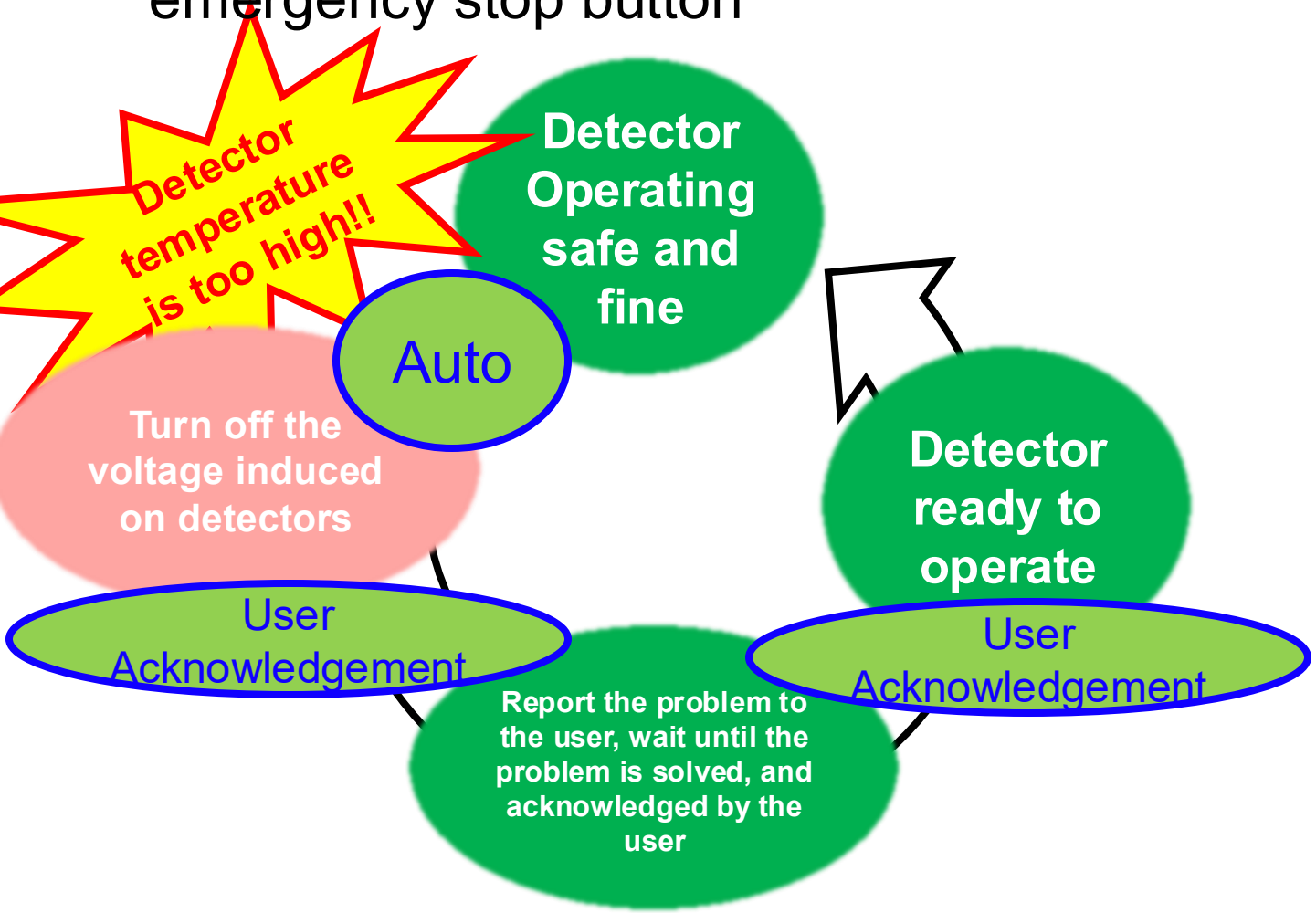
OPAL MVD 1994

Detector temperature too high, most modules failed or partially damaged.

Interlock which could have prevented was disabled

Interlock System

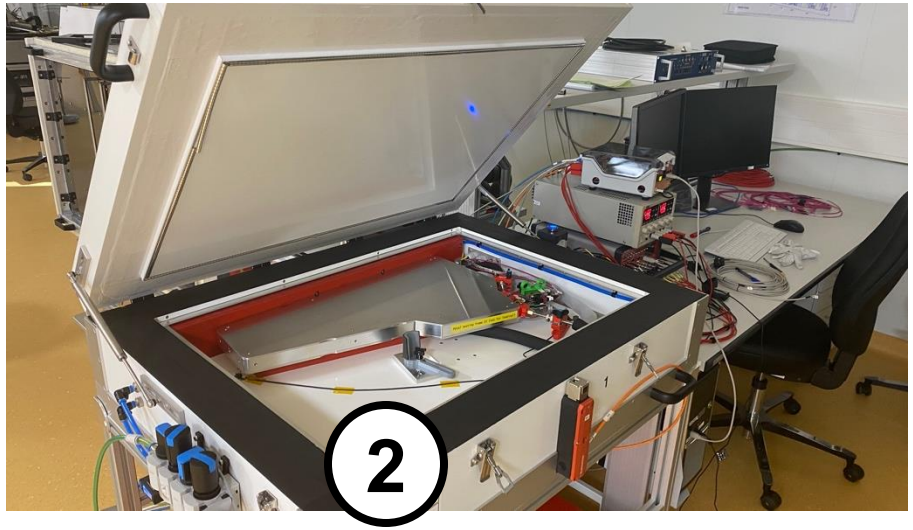
- **State machine which automatically stops the detector under pre-defined emergency conditions, and then wait for the acknowledgement by the user**
- A preliminary/precautious measure to avoid taking the risk of pressing the emergency stop button



Emergency stop button:
Final lifeline to stop the detector, when the interlock malfunctions or cannot take care of the emergency situation properly.

My Projects

Petal CB Test

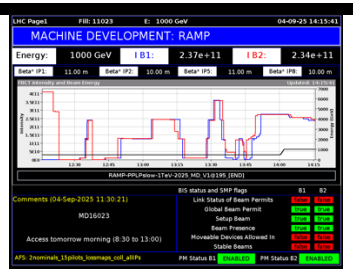


1

2

Interlock System & Emergency Stop Button
Design/Test for Safe Operation of CB Testing

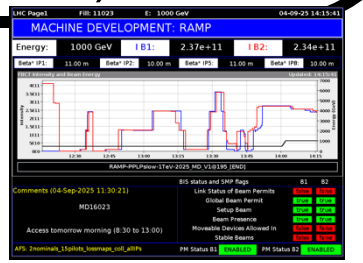
Real-Time Monitoring GUI
Implementation
(Temperature, humidity, Dew Point, **STATES**)



Thermal Enclosure Dry-Out Test

2’

Real-Time Monitoring GUI
Implementation
(Temperature, humidity, Dew Point)



LARGER SCALE

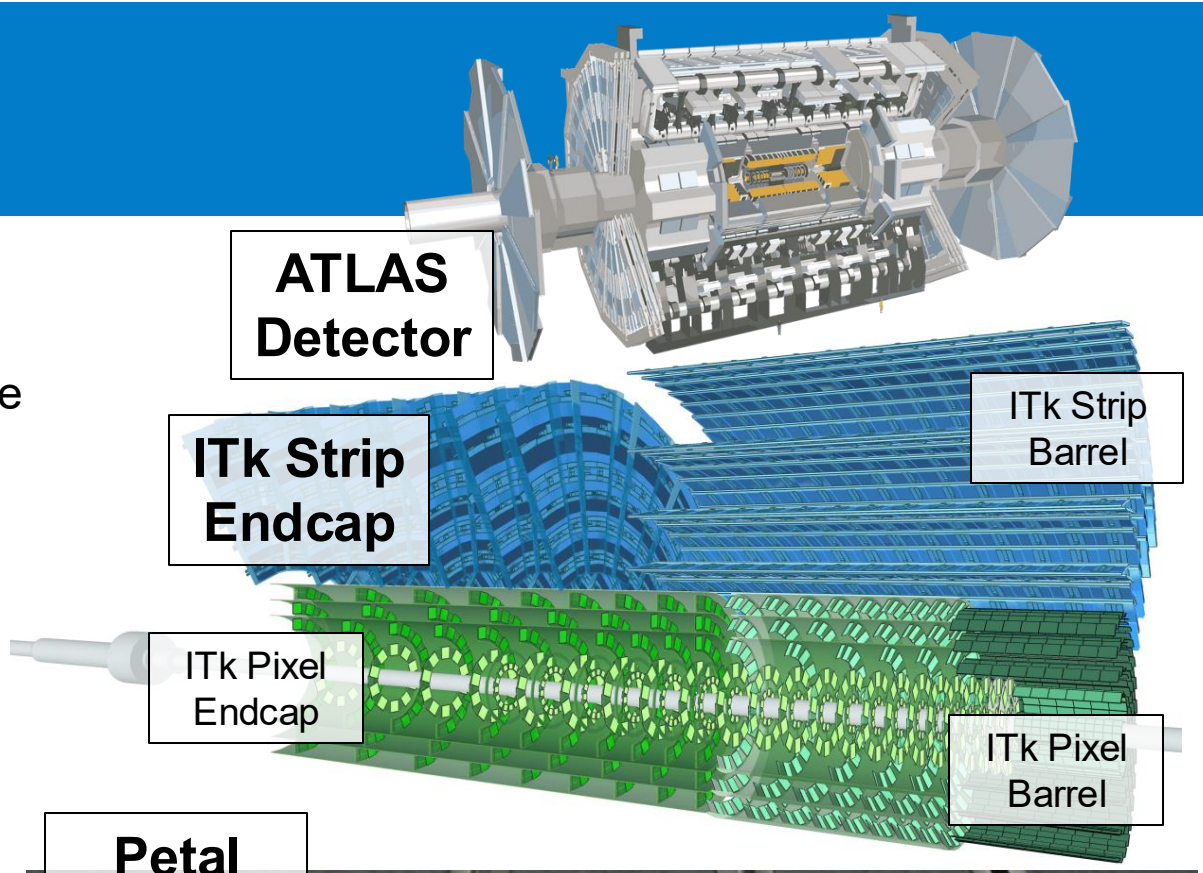
1. Interlock System & Emergency Stop Button
Design/Test for Safe Operation of CB Testing

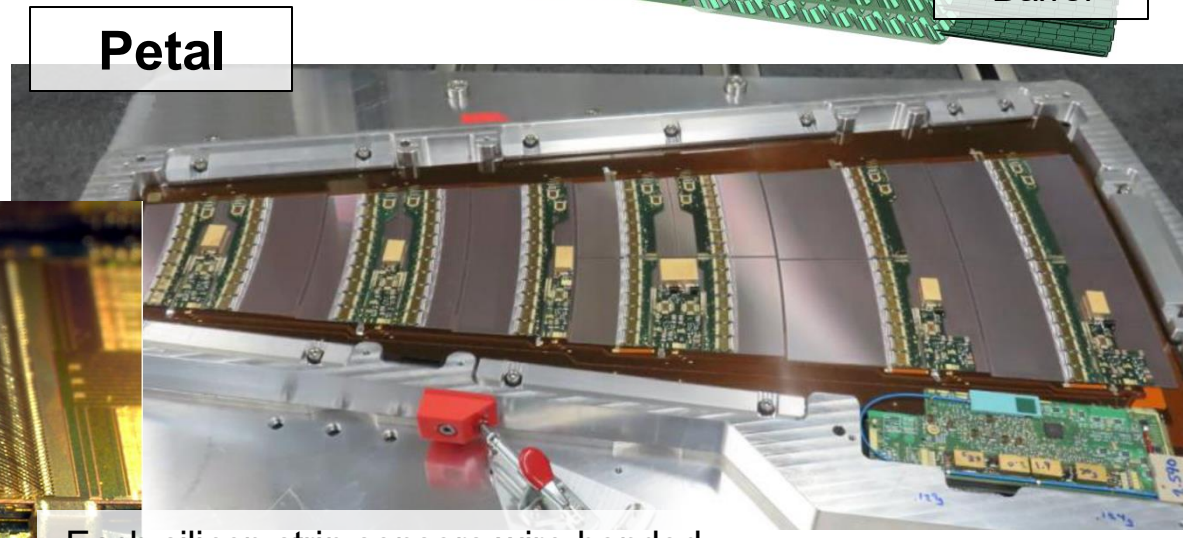
ATLAS ITk Strip Endcap

- In HL-LHC, the innermost layer of the ATLAS detector, “inner detector” upgraded to “**inner tracker (ITk)**”, development since 2011
- **ITk strip endcap** composed of 6 disks on each side
- Each disk composed of 32 **petals**

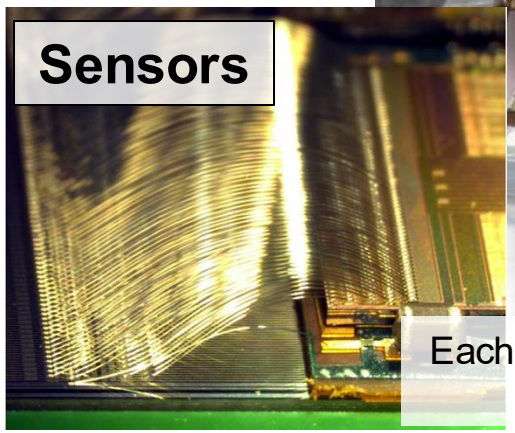
Petal ColdBox (CB) test in DESY:
Thorough threshold scan, noise analysis, and calibration of strip sensors on petals

Thermal Enclosure test in DESY:
Same test with 16 petals loaded in a thermal enclosure



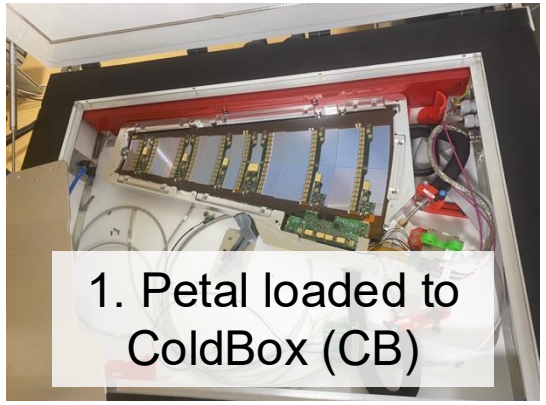


- 500V induced on strip sensors
- **HV (High Voltage)** must be slowly ramped down, otherwise damage the sensors
- HV switch controlled by on-detector **LV (Low Voltage)** switch
- Safe operation **temperature**: $-35℃$

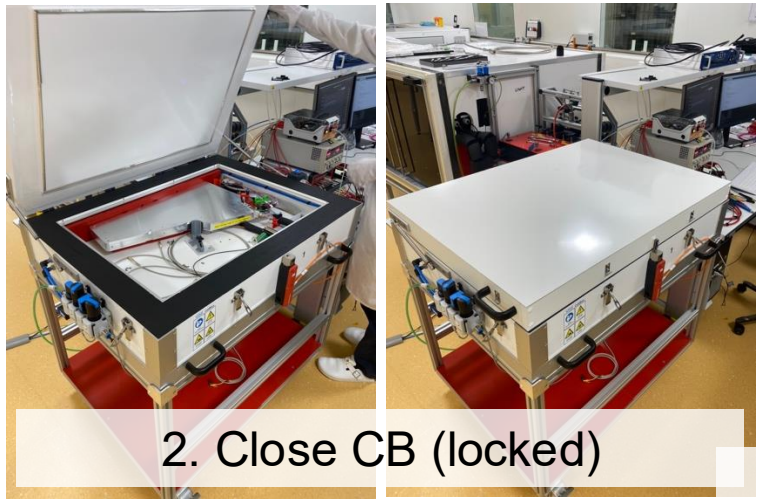


Each silicon strip sensors wire-bonded to frontend electronics

Petal Cooling by MARTA



1. Petal loaded to ColdBox (CB)



2. Close CB (locked)

PTM

Temp, humidity, DP sensors

CO_2

MARTA

3. MARTA provides cooled liquid CO_2 to the CB

CO_2

CB

ATLAS ITk strip petal (500 V)

Temp, humidity, Dew Point sensors

LV module
TTi CPX400DP

HV module
CAEN R14xxET & DT14xxET

CB door lock

Genesys2 FPGA board

Data

Dry Air

To avoid liquid droplet formation

MARTA connected to CB & PTM, CO_2 flow changed in case of emergency

Interlock system/Emergency Stop Button for Petal CB Testing

Petal CB test

interlock system / emergency stop button

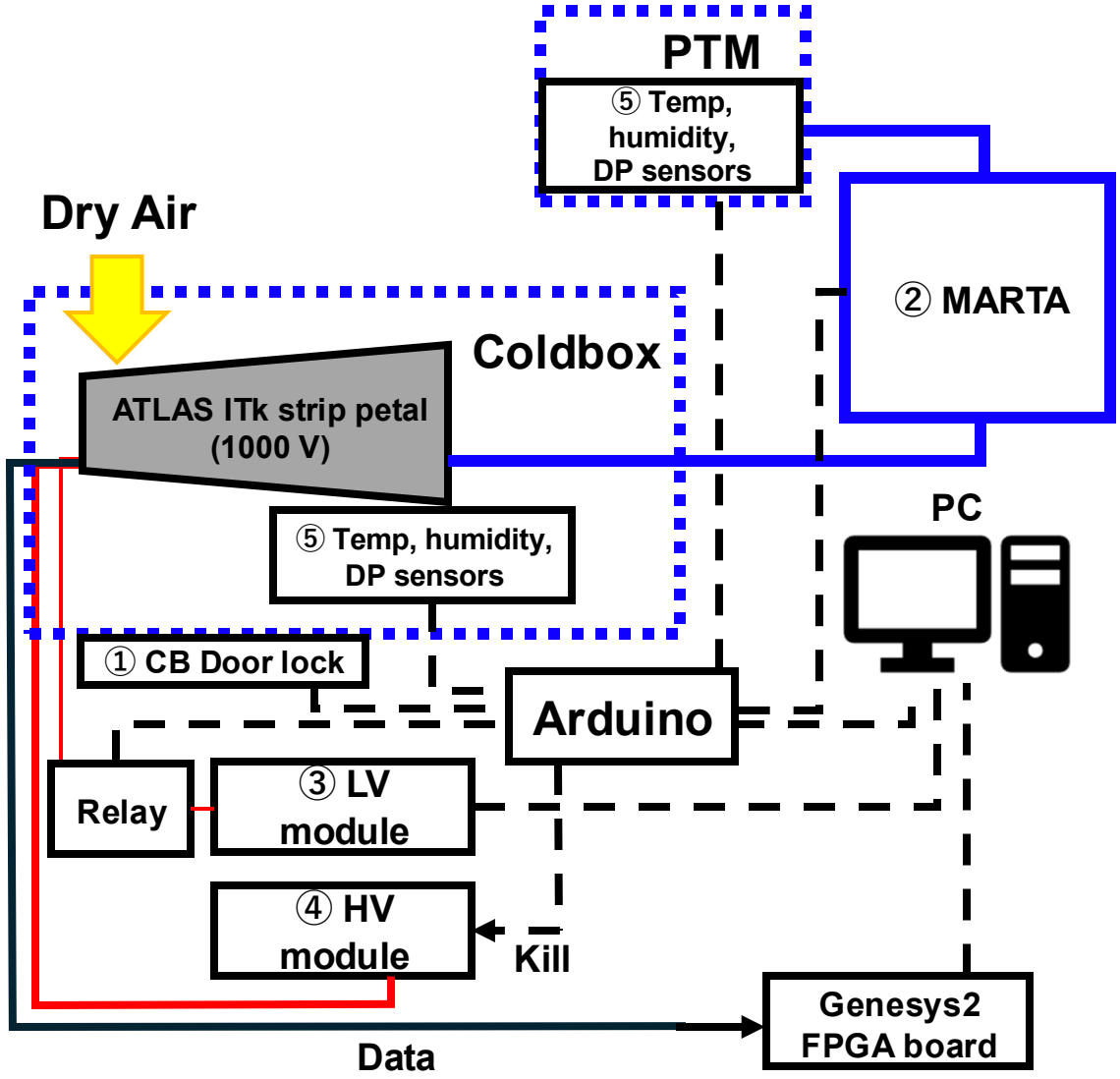
- Implemented through Arduino
- Arduino sends data to PC → GUI implementation
- Arduino can:

1. Allow/disallow CB door open/close
2. Allow/disallow MARTA
3. Allow/disallow LV supply
4. Allow/disallow HV supply

Define "states"

5. Monitor temperature, humidity, dew point in the CB/PTM, switch CO_2 flows to be CB or PTM, or CB door closed/opened

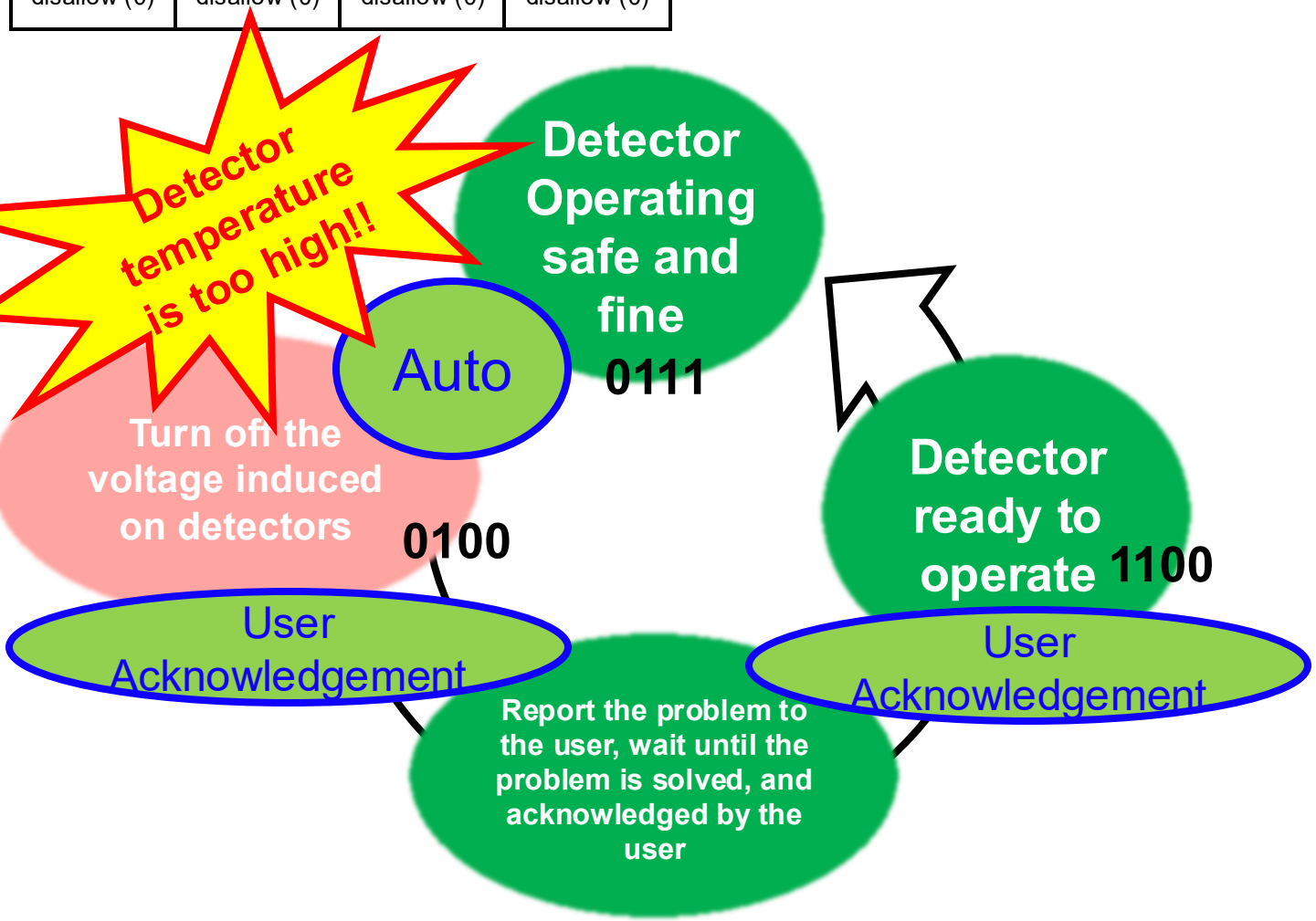
Conditions for state transition



Defining “States” for the Interlock System

Controlled by Arduino

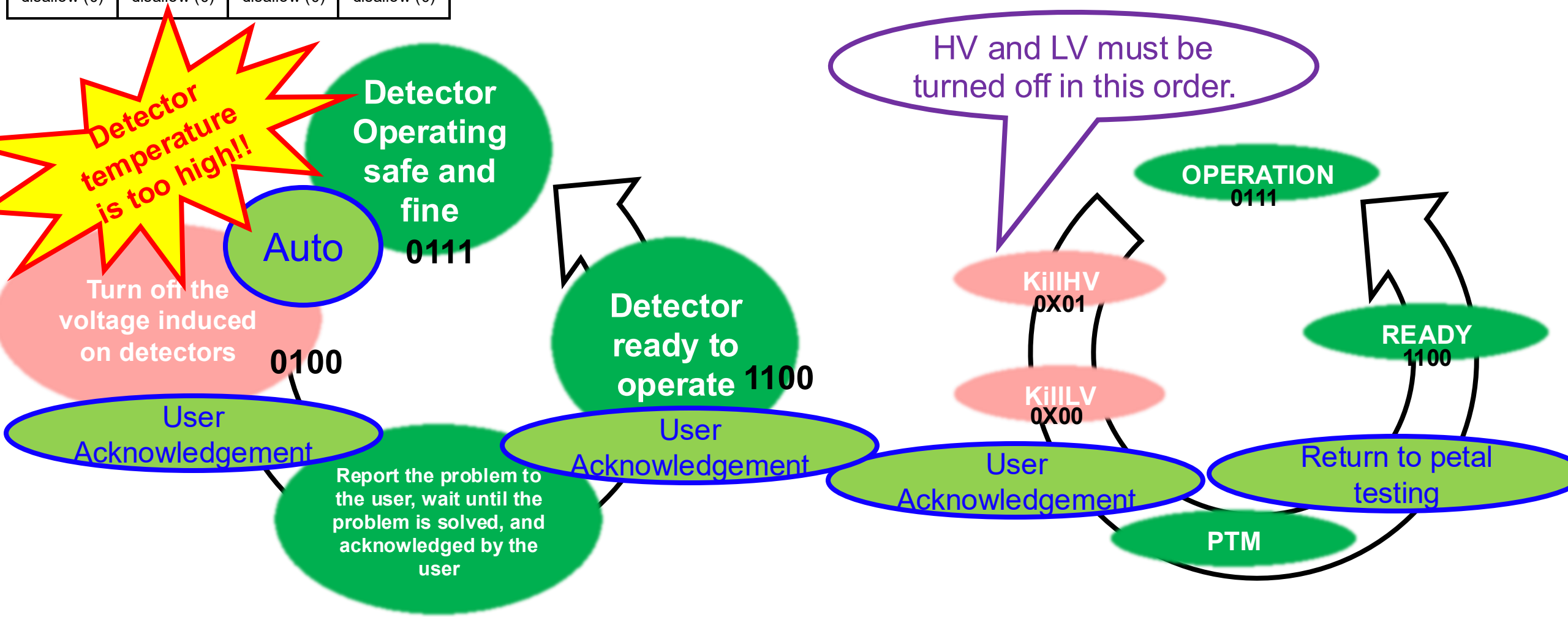
CB Door allow (1)/ disallow (0)	MARTA allow (1)/ disallow (0)	HV allow (1)/ disallow (0)	LV Allow (1)/ disallow (0)



Defining “States” for the Interlock System

Controlled by Arduino

CB Door allow (1)/ disallow (0)	MARTA allow (1)/ disallow (0)	HV allow (1)/ disallow (0)	LV Allow (1)/ disallow (0)

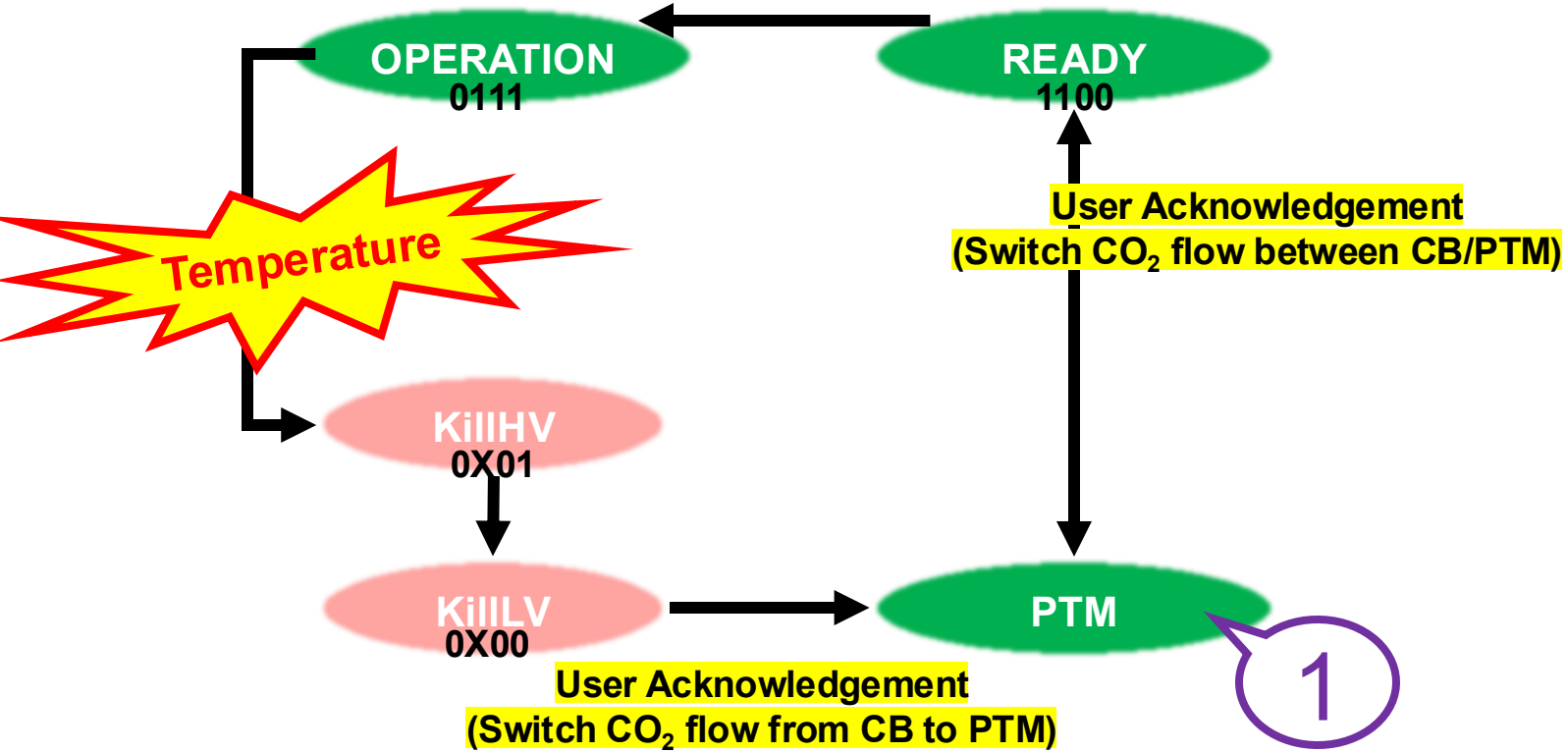


ex.) MARTA shuts down while OPERATION, causing temperature rise in the CB

Controlled by Arduino

CB Door	MARTA	HV	LV
allow (1)/ disallow (0)	allow (1)/ disallow (0)	allow (1)/ disallow (0)	Allow (1)/ disallow (0)

Unforeseen situations such as chiller and valve composing the MARTA break



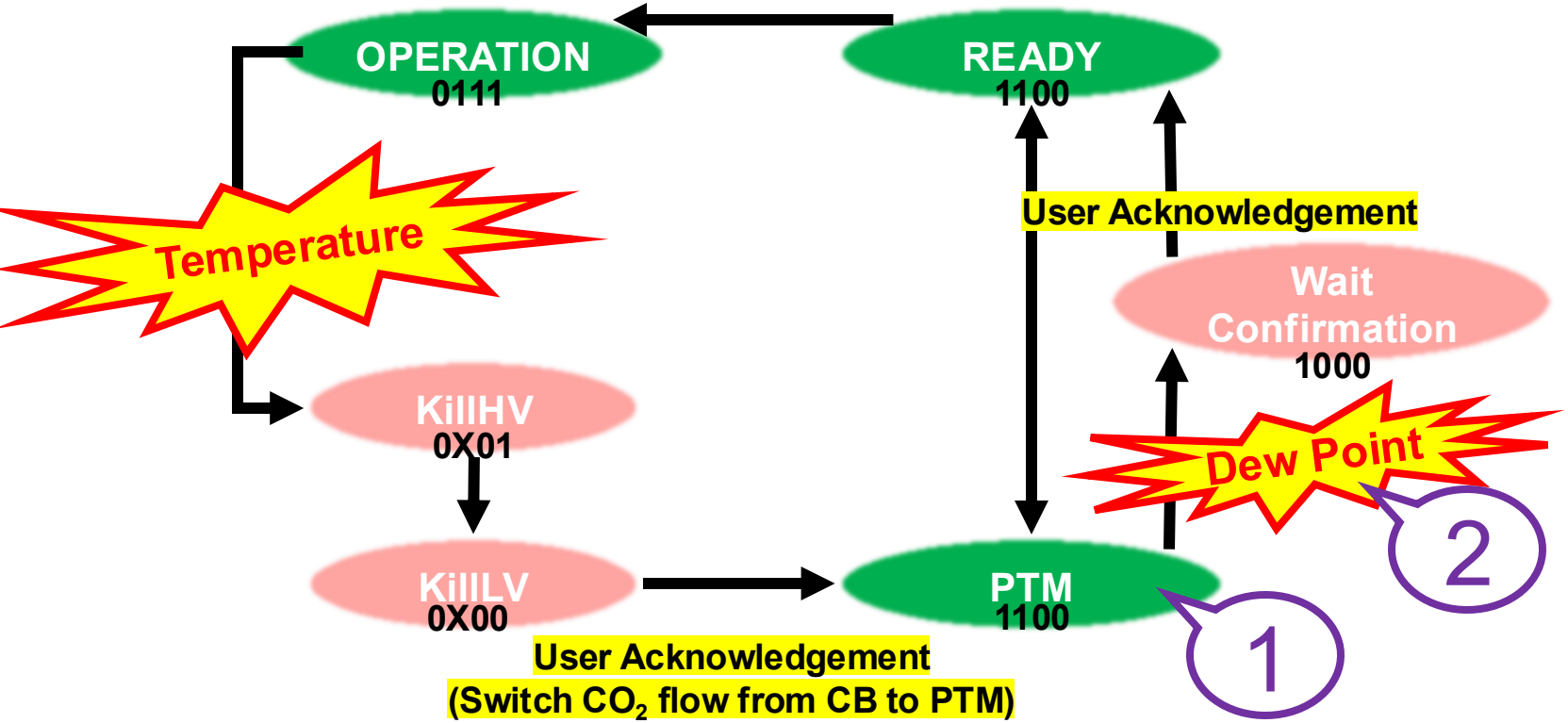
1. PTM: To wait for user acknowledgement.

ex.) MARTA shuts down while OPERATION, causing temperature rise in the CB

Unforeseen situations such as chiller and valve composing the MARTA break

Controlled by Arduino

CB Door	MARTA	HV	LV
allow (1)/ disallow (0)	allow (1)/ disallow (0)	allow (1)/ disallow (0)	Allow (1)/ disallow (0)



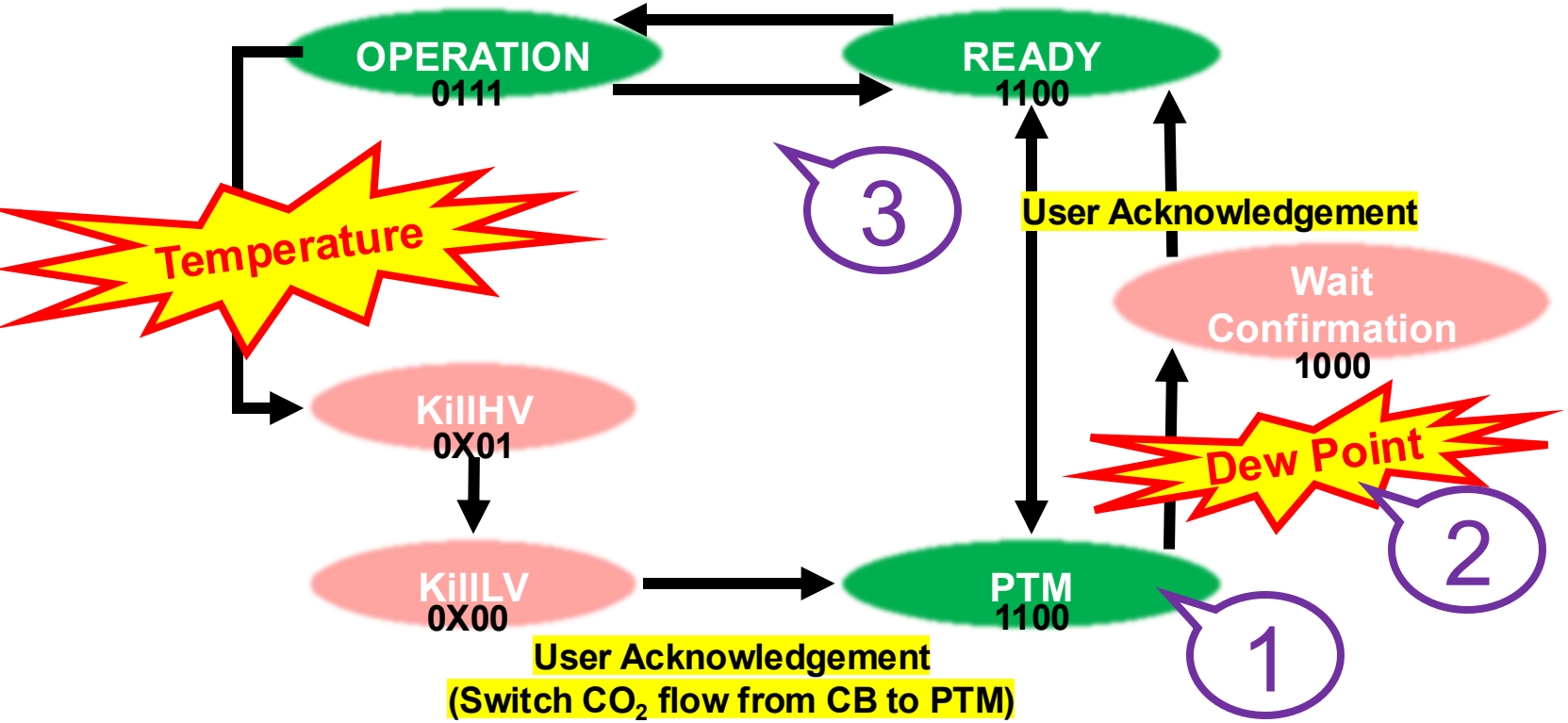
1. PTM: To wait for user acknowledgement.
2. Make sure that the inside of the PTM does not get wet.

ex.) MARTA shuts down while OPERATION, causing temperature rise in the CB

Unforeseen situations such as chiller and valve composing the MARTA break

Controlled by Arduino

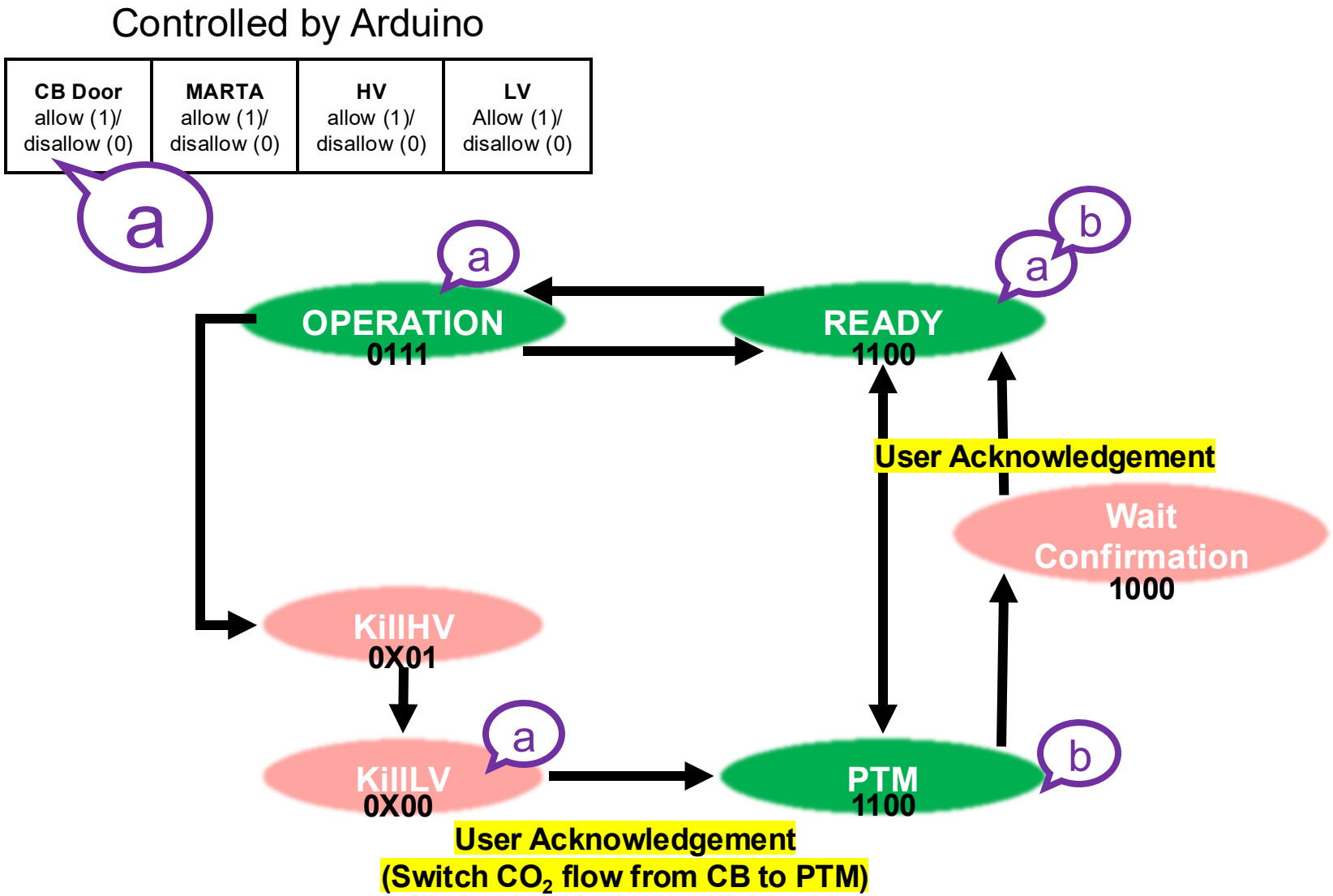
CB Door	MARTA	HV	LV
allow (1)/ disallow (0)	allow (1)/ disallow (0)	allow (1)/ disallow (0)	Allow (1)/ disallow (0)



1. PTM: To wait for user acknowledgement.
2. Make sure that the inside of the PTM does not get wet.
3. Stop the CB testing (without any emergencies)

Controlled by Arduino

CB Door	MARTA	HV	LV
allow (1)/ disallow (0)	allow (1)/ disallow (0)	allow (1)/ disallow (0)	Allow (1)/ disallow (0)



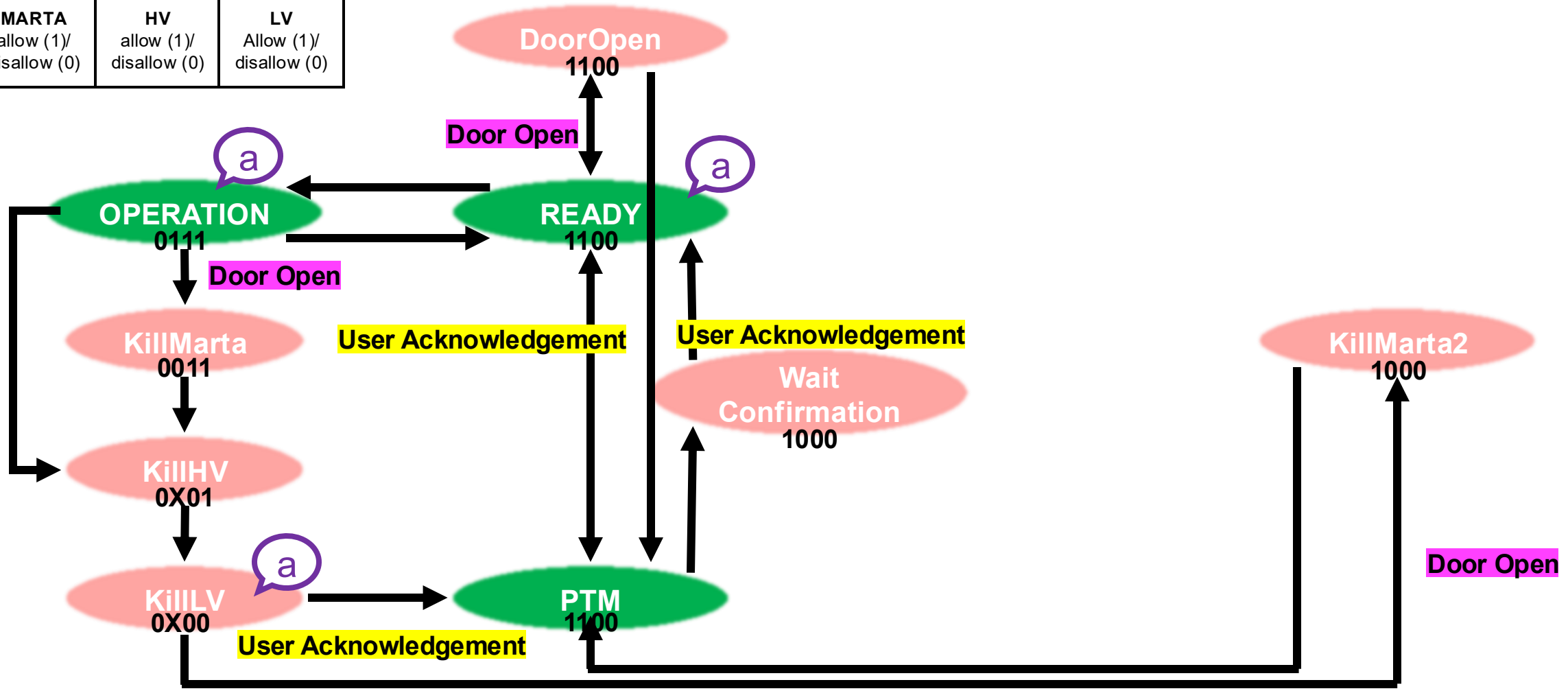
a. CB door opened during OPERATION/READY/KillLV
b. When the petal is too cold and CB door is opened, liquid could form on sensors/electronics

State Machine Design

ex.) CB Door Opened while OPERATION/READY/KillLV

Controlled by Arduino

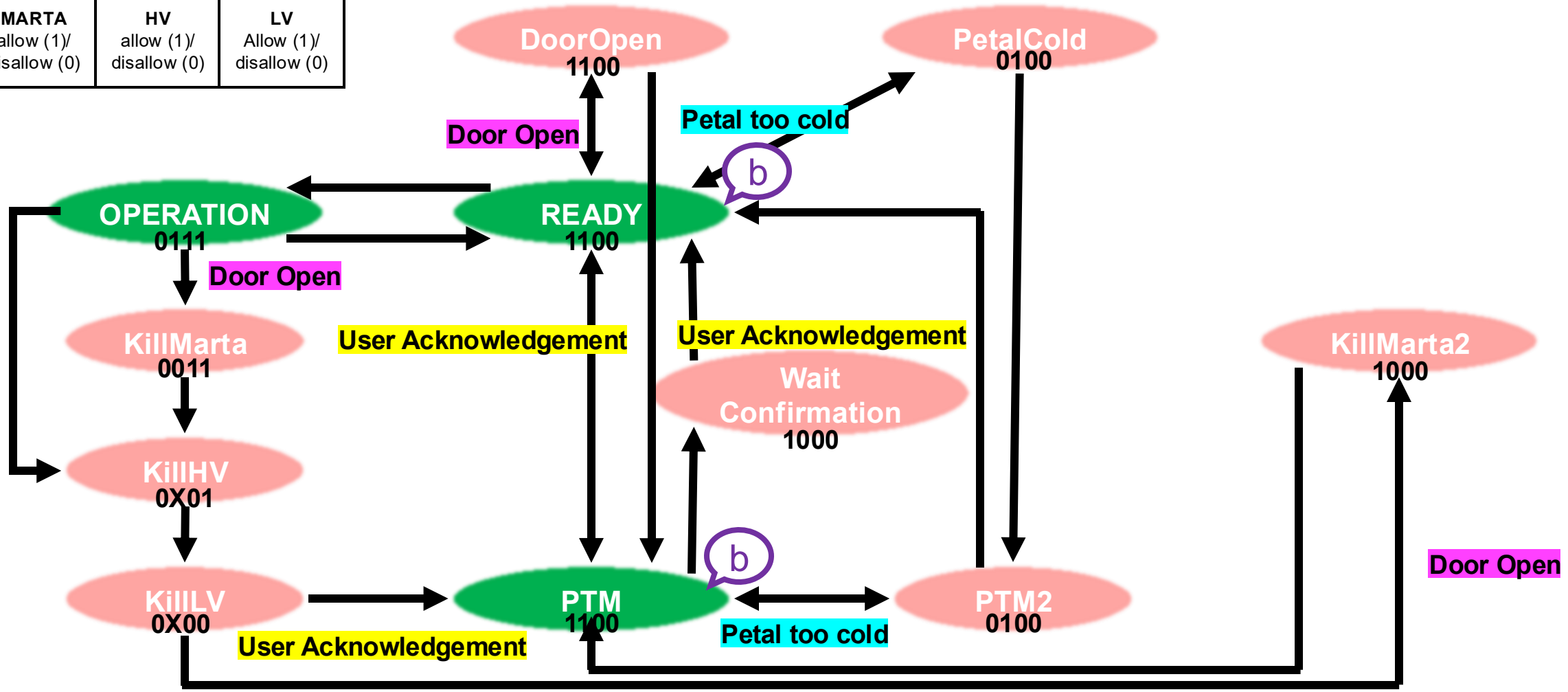
CB Door	MARTA	HV	LV
allow (1)/ disallow (0)	allow (1)/ disallow (0)	allow (1)/ disallow (0)	Allow (1)/ disallow (0)



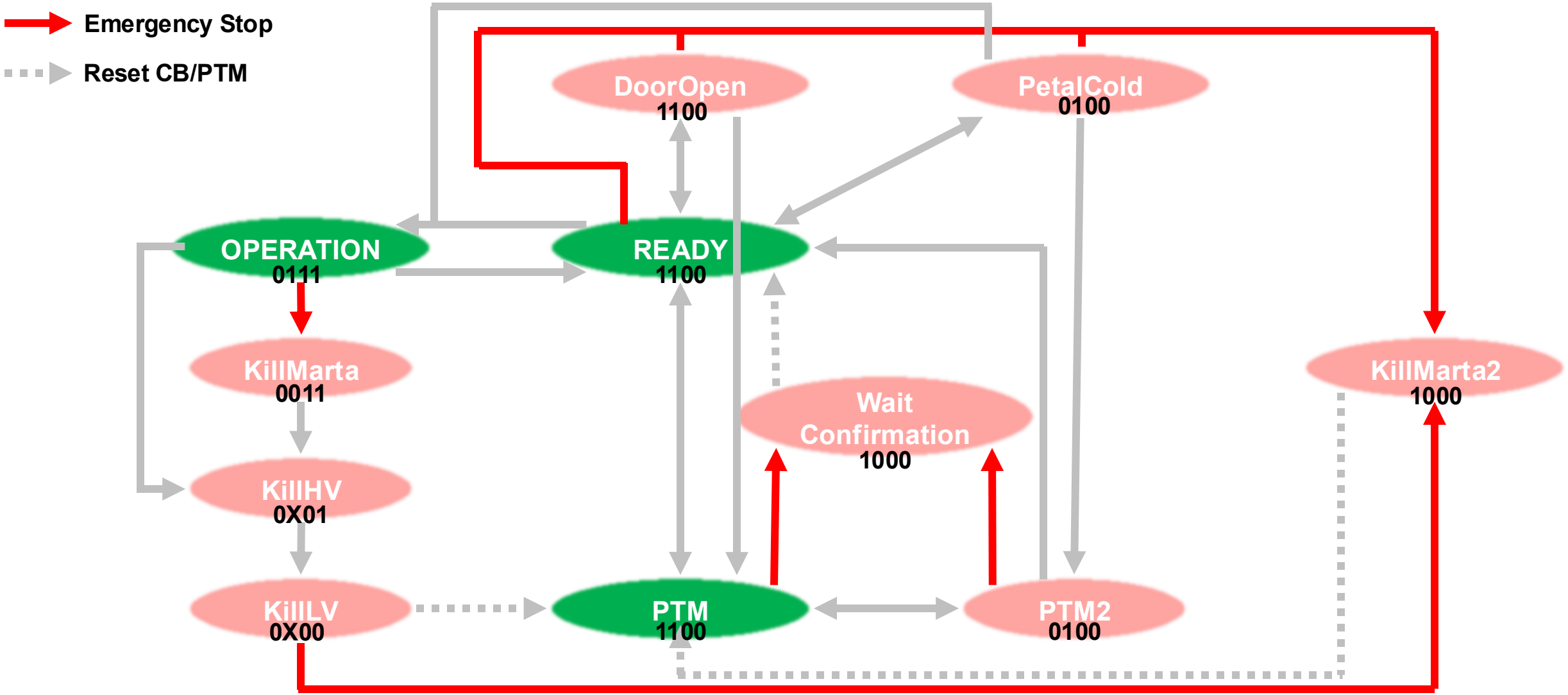
State Machine Design
ex.) Petal too cold to open CB Door

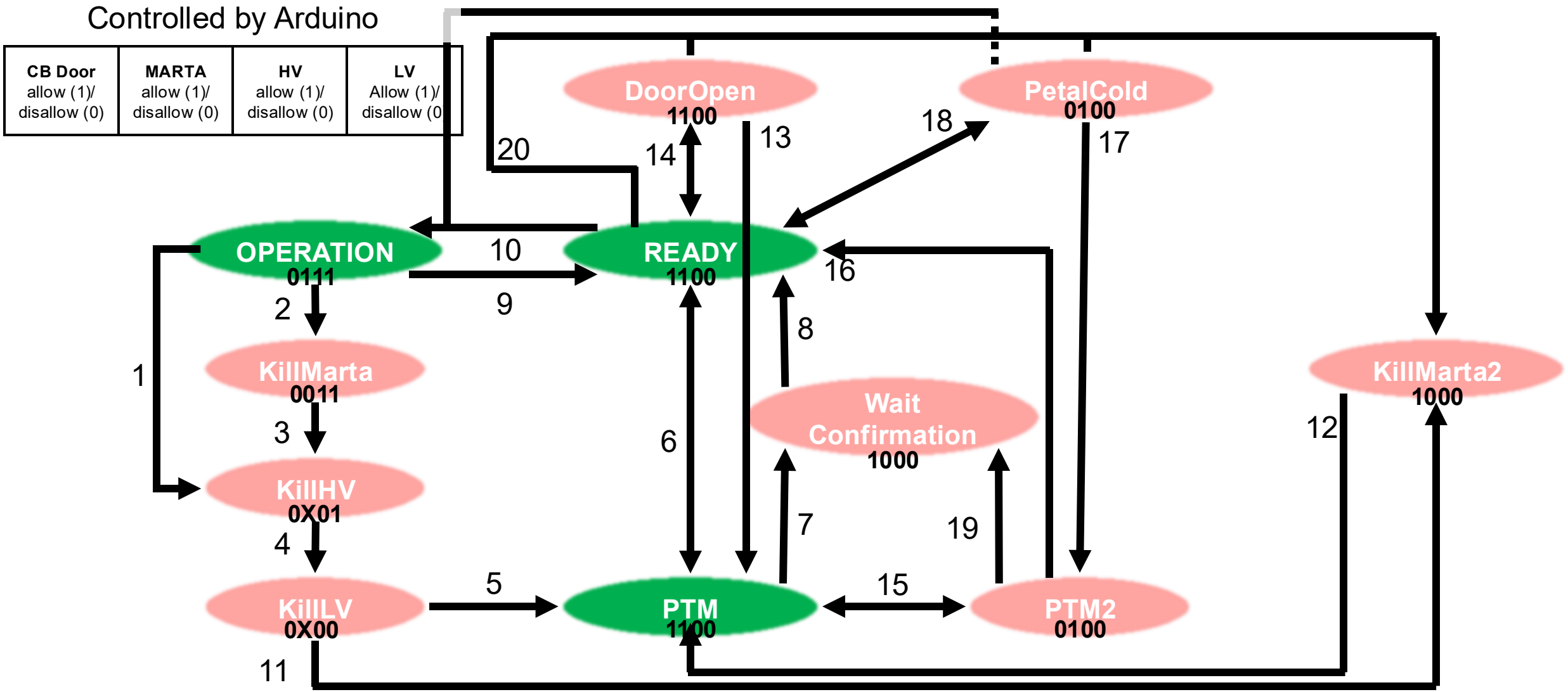
Controlled by Arduino

CB Door	MARTA	HV	LV
allow (1)/ disallow (0)	allow (1)/ disallow (0)	allow (1)/ disallow (0)	Allow (1)/ disallow (0)



Emergency Stop Button




Controlled by Arduino
CB Door
allow (1)/
disallow (0)
MARTA
allow (1)/
disallow (0)
HV
allow (1)/
disallow (0)
LV
Allow (1)/
disallow (0)
DoorOpen
1100
PetalCold
0100
OPERATION
0111
READY
1100
KillMarta
0011
KillMarta2
1000
Wait
Confirmation
1000
KillHV
0X01
KillLV
0X00
PTM
1100
PTM2
0100
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Conditions for State Transition

	CB Dew Point	CB temperature	Sensor Temperature	MARTA_on	HV_on	door_closed	CBnotPTM	Reset CMD	Kill ILCK CMD
1	X	X	• threshold • ! NaN	MARTA OFF & HV ON		X	PTM	X	X
2	• > threshold – minTemp • ! NaN	X	X	X	X	Door OPEN	X	X	Kill
3	X	X	X	X	X	X	X	X	X
4★	X	X	X	X	HV OFF	X	X	X	X
5	X	X	X	X	X	X	PTM	Reset	X
6	X	X	X	X	X	X	CB/PTM	X	X
7	> threshold	X	X	X	X	X	X	X	Kill
8	X	X	X	X	X	X	CB	Reset	X
9	X	X	X	MARTA OFF & HV OFF		X	X	X	X
10	X	X	! NaN & MARTA ON		X	X	X	X	X

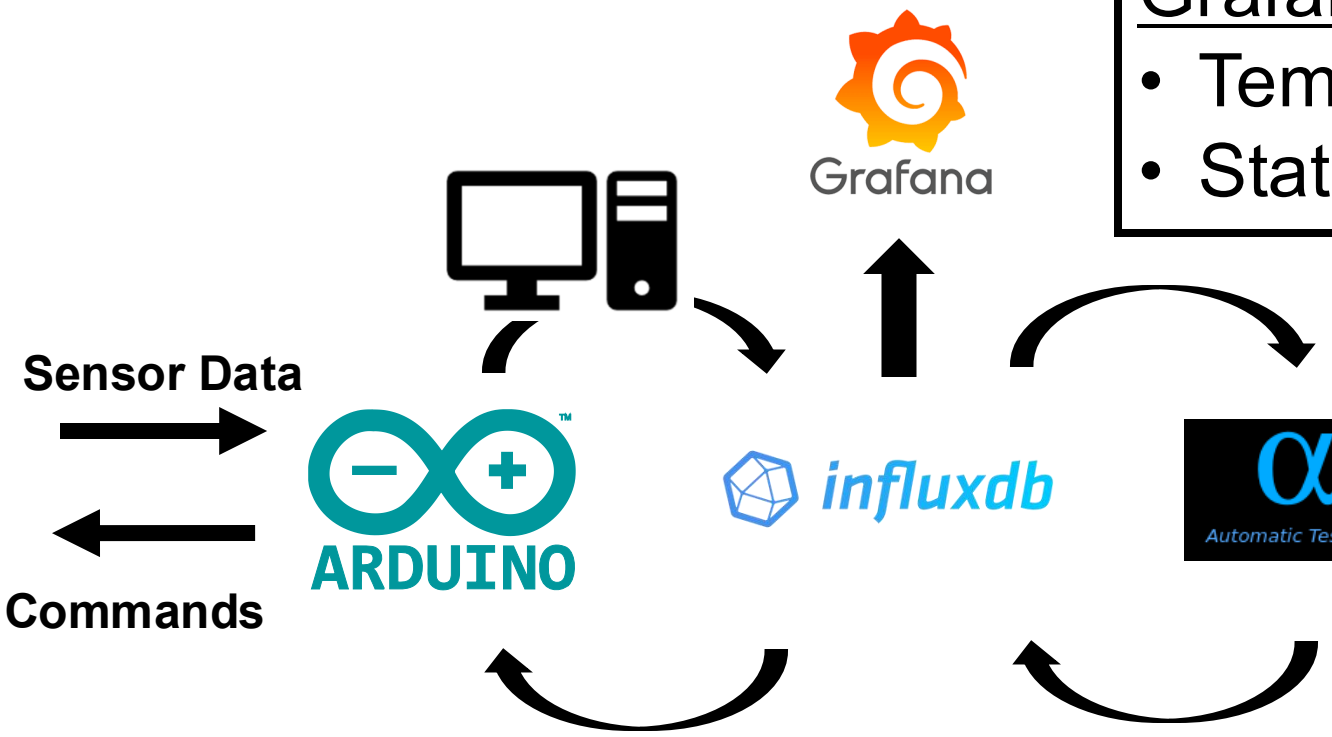
★ Additional condition forcing the transition to killLV when HV is not confirmed to be OFF within the HV ramp down time of 10V/s.

Conditions for State Transition

	CB Dew Point	CB temperature	Sensor Temperature	MARTA_on	HV_on	door_closed	CBnotPTM	Reset CMD	Kill ILCK CMD
11	X	X	X	Door Open & MARTA ON	X	Door Open & MARTA ON	X	X	Kill
12	X	X	X	X	X	X	PTM	Reset	X
13	X	X	X	X	X	X	PTM	X	X
14	X	X	X	X	X	Door OPEN/CLOSE	X	X	X
15	X	X	10 degrees	X	X	X	X	X	X
16	X	X	X	X	X	X	CB	X	X
17	X	X	X	X	X	X	PTM	X	X
18	X	X	10 degrees	X	X	X	X	X	X
19	X	X	X	X	X	X	X	X	Kill
20	X	X	X	X	X	X	X	X	Kill

2. Real-Time Monitoring GUI Implementation for Petal CB Testing & Thermal Closure Dry-Out Test

Real-Time Monitoring GUI (Graphical User Interphase)



Grafana: GUI
- Temperature, humidity, dew point plots
- State monitoring

ATOM: QT-based GUI
- User Acknowledgement Button
- Emergency Stop Button

InfluxDB:
SQL-based Time series database

Grafana:
Real-Time State, Temperature, Humidity, Dew Point Monitoring

Grafana

Current State

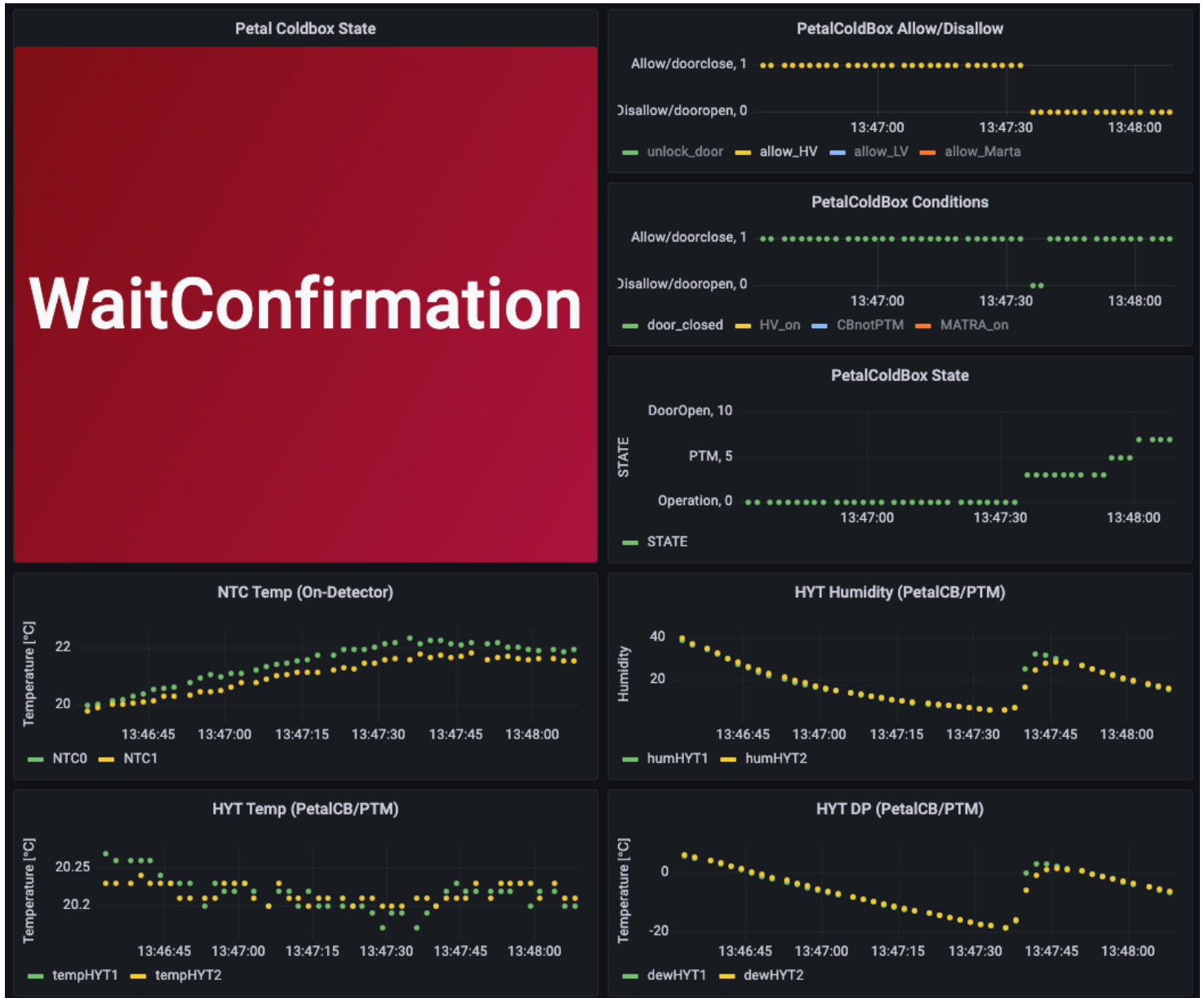
Detector Temperature

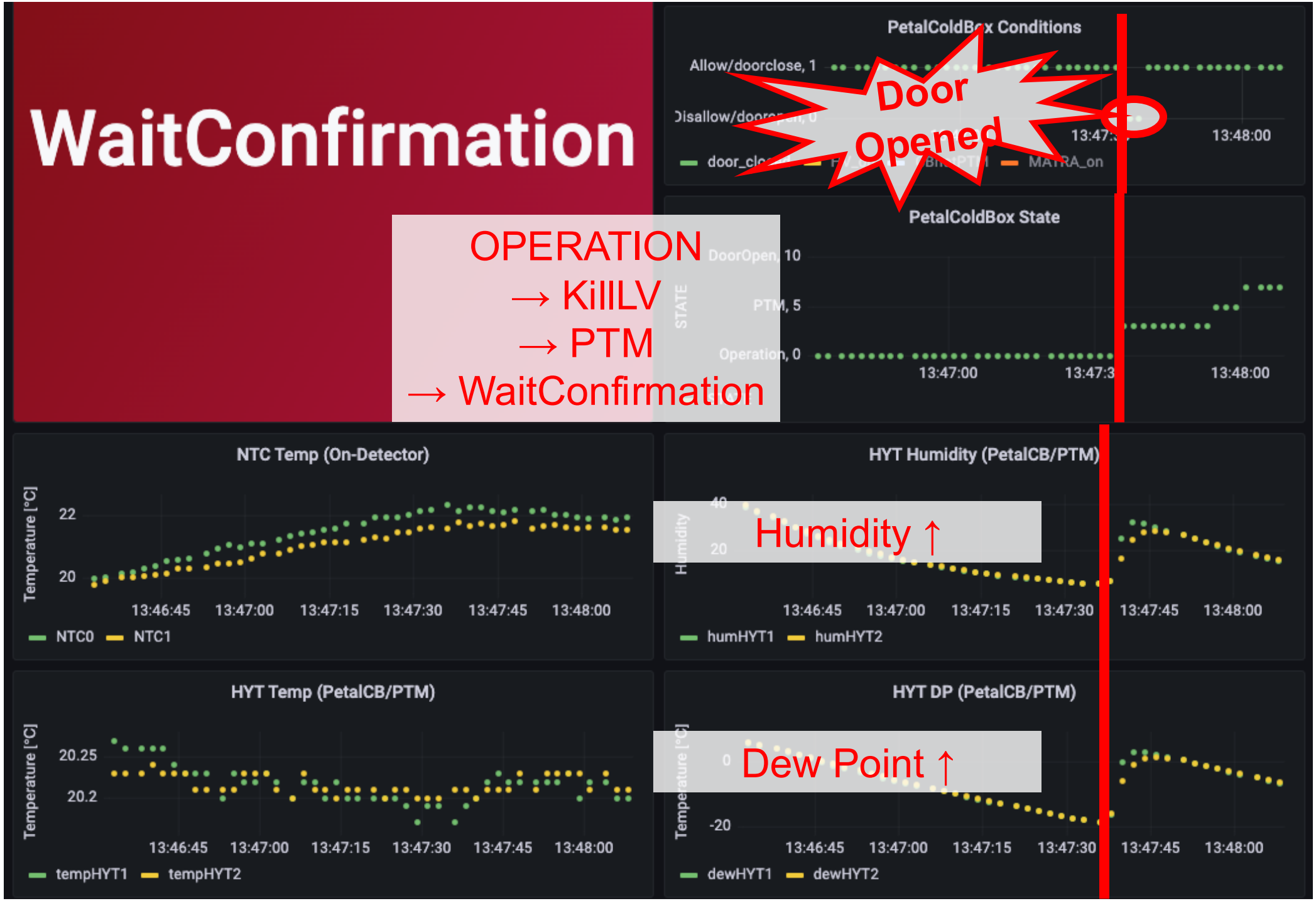
CB/PTM Temperature

State Transition

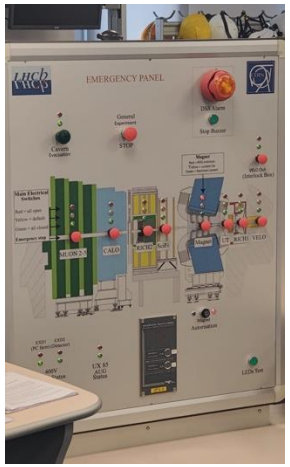
Humidity

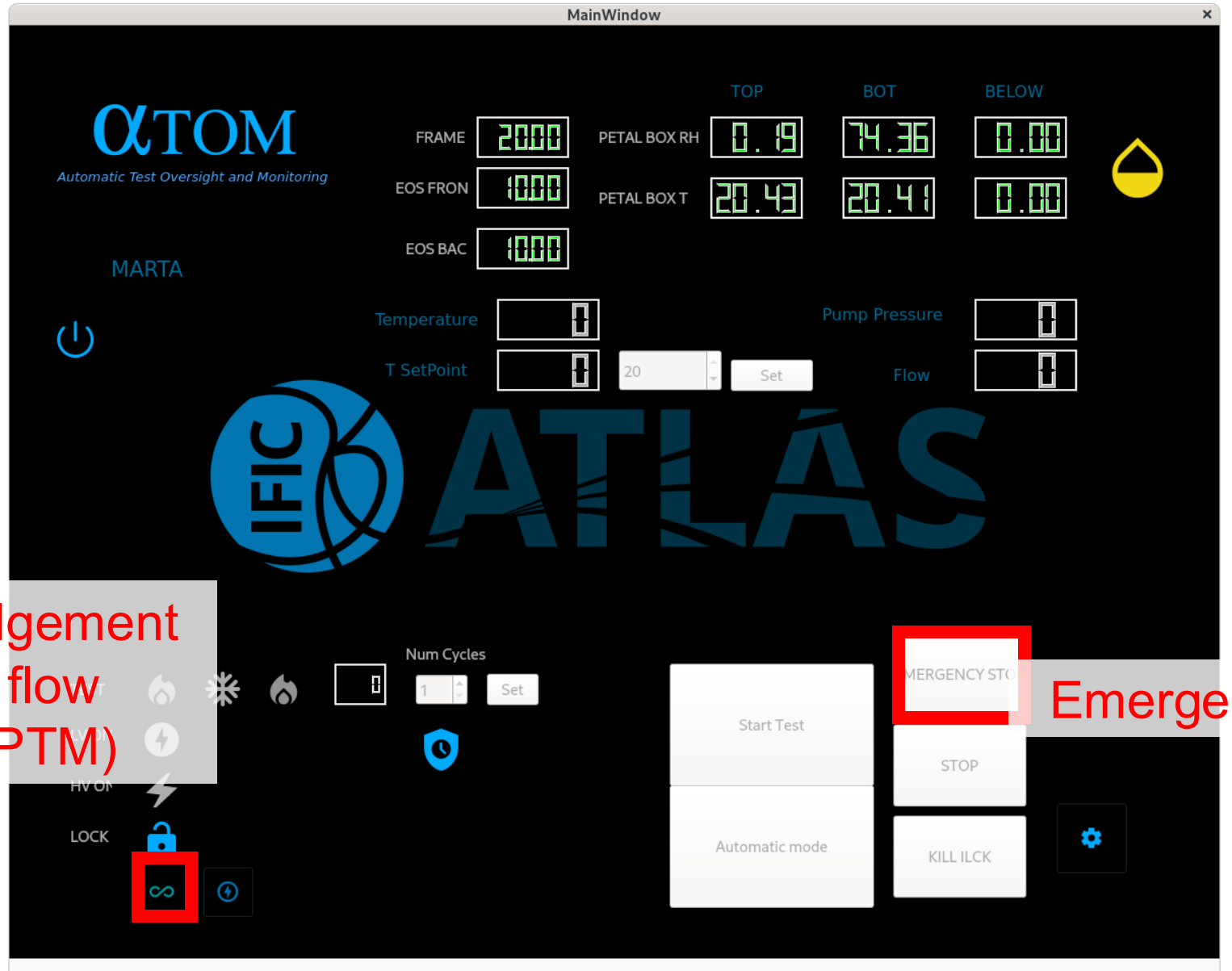
Dew Point




WaitConfirmation
PetalColdBox Conditions
Allow/doorclose, 1
Disallow/doorclose, 0
13:47:3
13:48:00
door_clo
MATRA_on
Door Opened
PetalColdBox State
DoorOpen, 10
PTM, 5
Operation, 0
STATE
13:47:00
13:47:3
13:48:00
OPERATION
→ KillLV
→ PTM
→ WaitConfirmation
NTC Temp (On-Detector)
Temperature [°C]
22
20
13:46:45
13:47:00
13:47:15
13:47:30
13:47:45
13:48:00
NTC0
NTC1
HYT Humidity (PetalCB/PTM)
Humidity
40
20
Humidity ↑
13:46:45
13:47:00
13:47:15
13:47:30
13:47:45
13:48:00
humHYT1
humHYT2
HYT Temp (PetalCB/PTM)
Temperature [°C]
20.25
20.2
13:46:45
13:47:00
13:47:15
13:47:30
13:47:45
13:48:00
tempHYT1
tempHYT2
HYT DP (PetalCB/PTM)
Temperature [°C]
0
-20
Dew Point ↑
13:46:45
13:47:00
13:47:15
13:47:30
13:47:45
13:48:00
dewHYT1
dewHYT2

ATOM:
User Acknowledgement Button, Emergency Stop Button



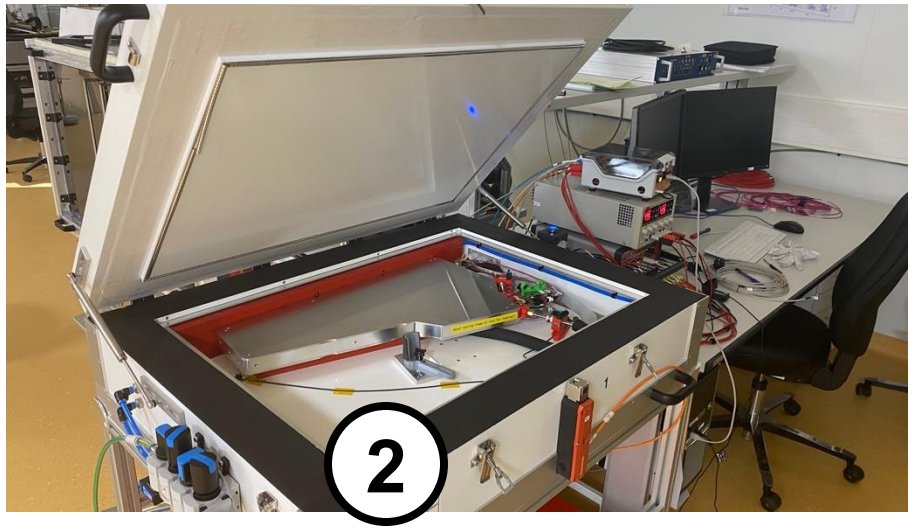


User Acknowledgement (Switch CO_2 flow between CB/PTM)

Emergency Stop Button

My Projects

Petal ColdBox (CB) Testing



1

Interlock System & Emergency Stop Button
Design/Test for Safe Operation of CB Testing

2

Real-Time Monitoring GUI
Implementation
(Temperature, humidity, Dew Point**, STATES)**

Thermal Enclosure Dry-Out Test

3

Real-Time Monitoring GUI
Implementation
(Temperature, humidity, Dew Point)

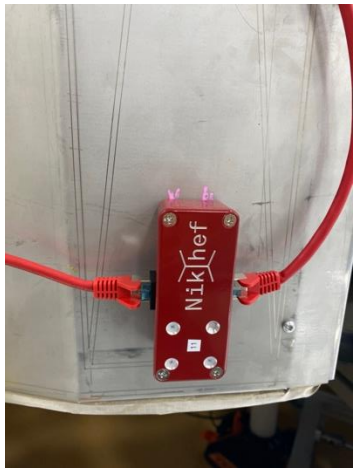
LARGER SCALE

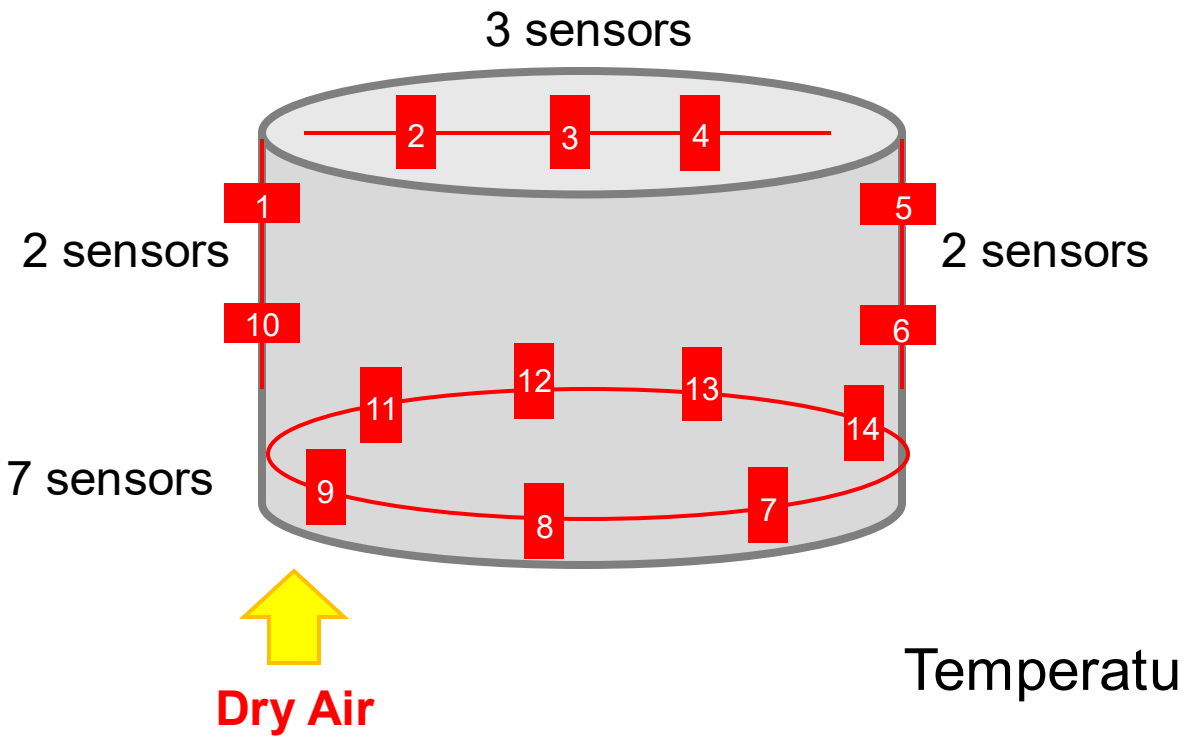
Thermal Enclosure Dry-Out Test

Thermal Enclosure Arrival July 30th, 2025

Thermal Enclosure mounted on endcap structure (to be inserted in ATLAS)

Thermal Enclosure Dry-Out Test





Attaching 14 Nikhef
Temperature/Humidity/Dew Point sensors

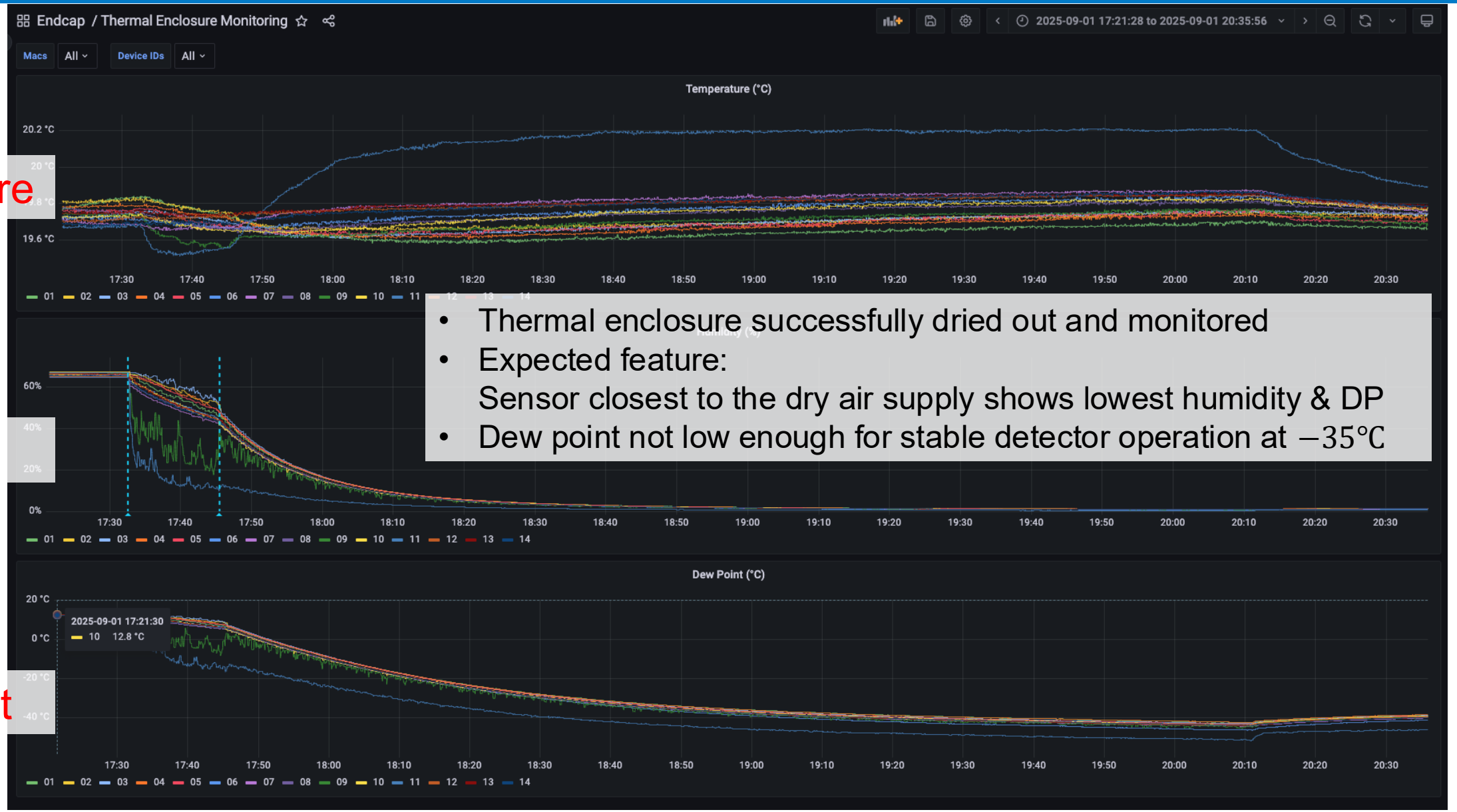
Thermal Enclosure Dry-Out Test

Grafana

Temperature

Humidity

Dew Point

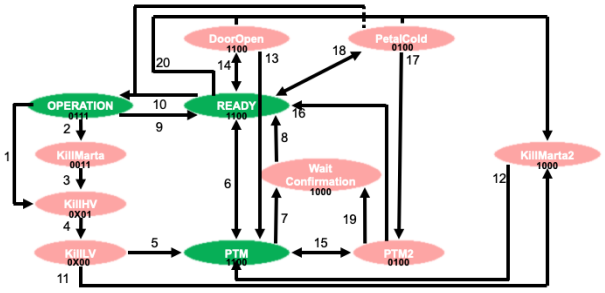


- Thermal enclosure successfully dried out and monitored
- Expected feature:
  Sensor closest to the dry air supply shows lowest humidity & DP
- Dew point not low enough for stable detector operation at −35℃

Conclusion and Future Prospects

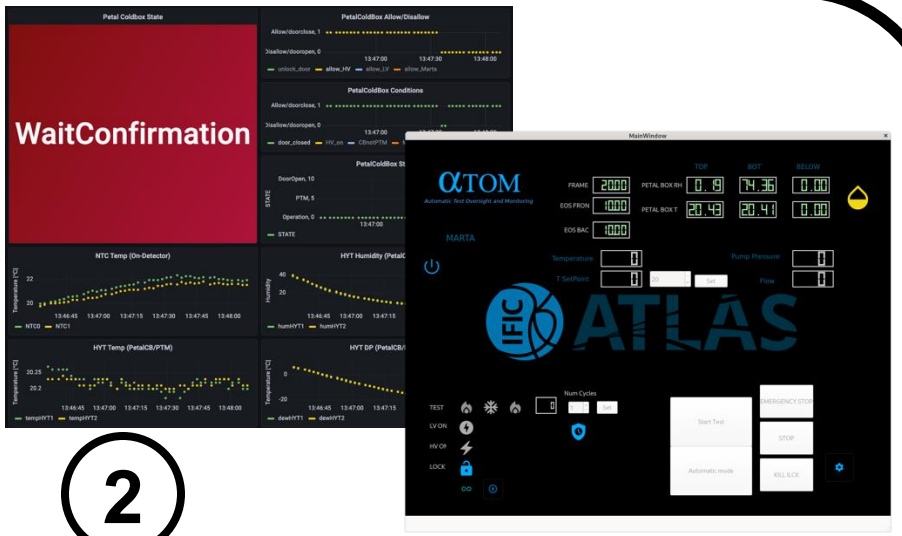
Conclusion

Petal CB Test



1

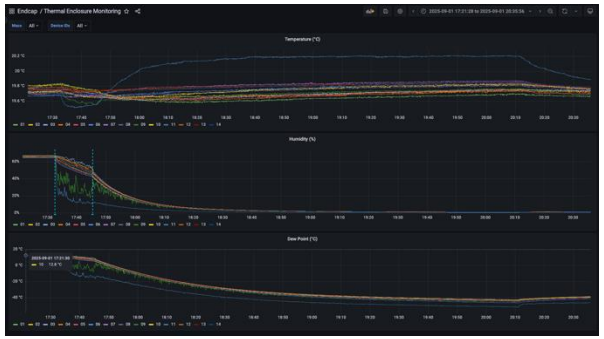
Interlock system & emergency stop button for the ATLAS ITk endcap petal CB testing was designed



2

Real-time monitoring GUI was implemented for the CB testing and the thermal enclosure dry-out test using Grafana and ATOM (Temperature, humidity, Dew Point, STATES)

Thermal Enclosure Dry-Out Test



2’

Prospects

- Improve the tightness of the thermal enclosure
- Cold test with 16 petals installed on the endcap structure by the end of this year

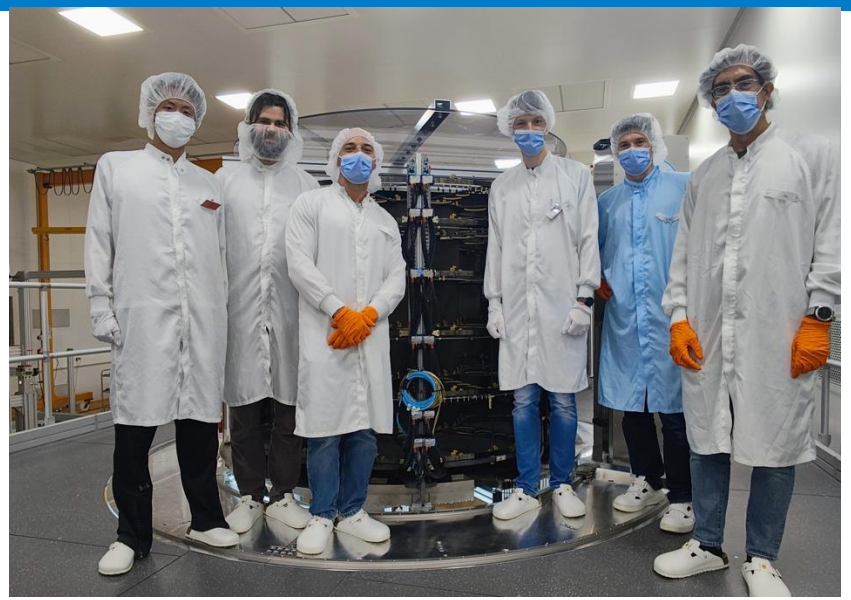
Special Thanks…

Konstantin, Jan-Hendrik, Elizaveta, Sergio, and all the others I have met in DESY DAF

Nick & Olaf, for organizing this summer school

… And for everyone who was involved in taking me here

Dear Summie Friends, for making experience here awesome!!



First attachment of service module to the thermal enclosure

Ramen place in Hamburg (was bad)

Weekend trip to Berlin

Supplementary

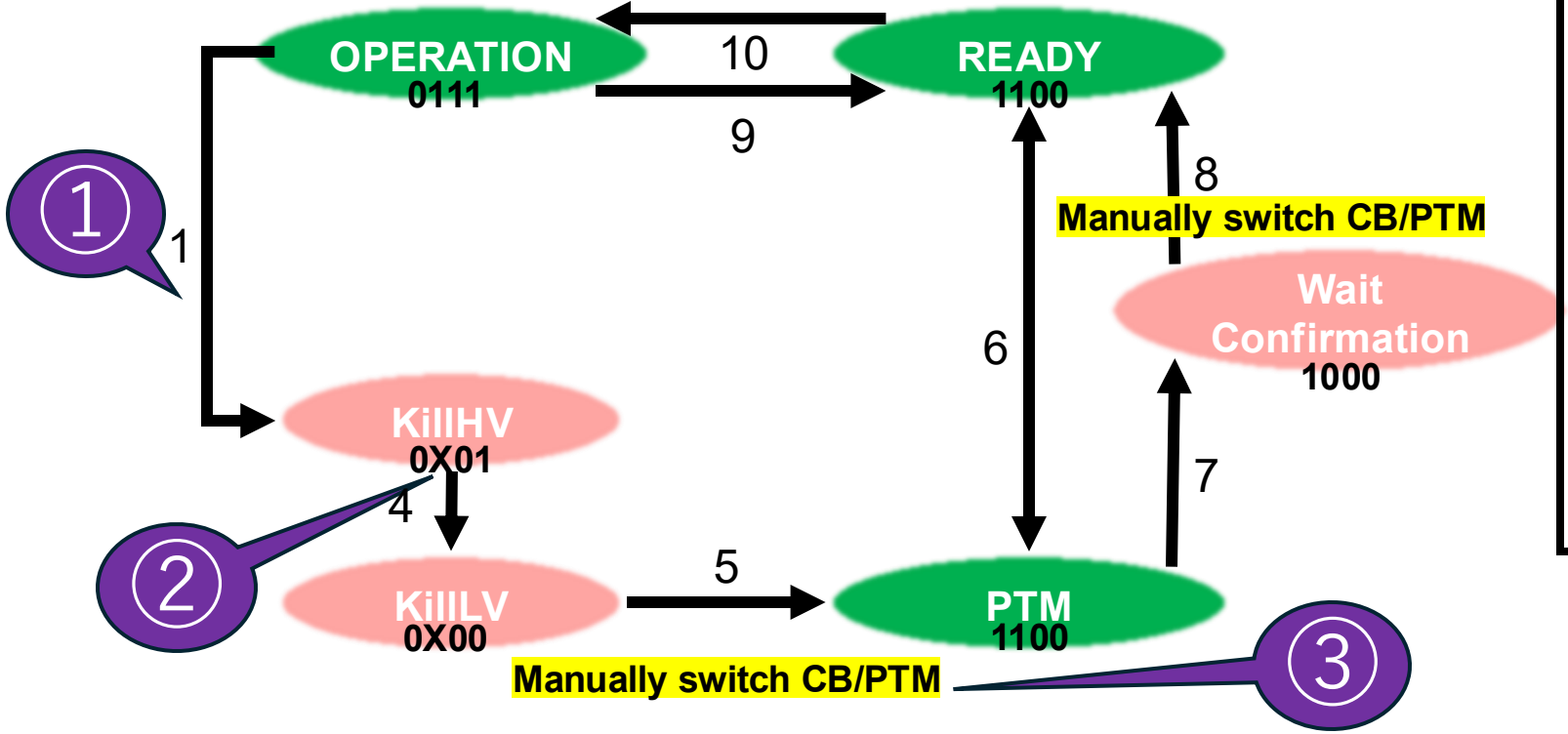
ii. State Machine Implementation

ex.) MARTA shuts down while OPERATION, causing temperature rise in the CB

① Develop interlock system for the safe operation of CB test

CB Door allow/ disallow	MARTA allow/ disallow	HV allow/ disallow	LV allow/ disallow

Unforeseen situations such as chiller and valve composing the MARTA break



① HV and LV must be killed in this order. This is because HV induced on strips are distributed by power board on the hybrids, and the power board is controlled by LV, HV must be slowly turned off before turning off LV.
② Marta allow/disallow don't care for HV/LV, because of the reason provided in the next slide.
③ Cannot go immediately to READY state, a user input is required, acknowledging the error.

Next slides onwards will take other situations into account.

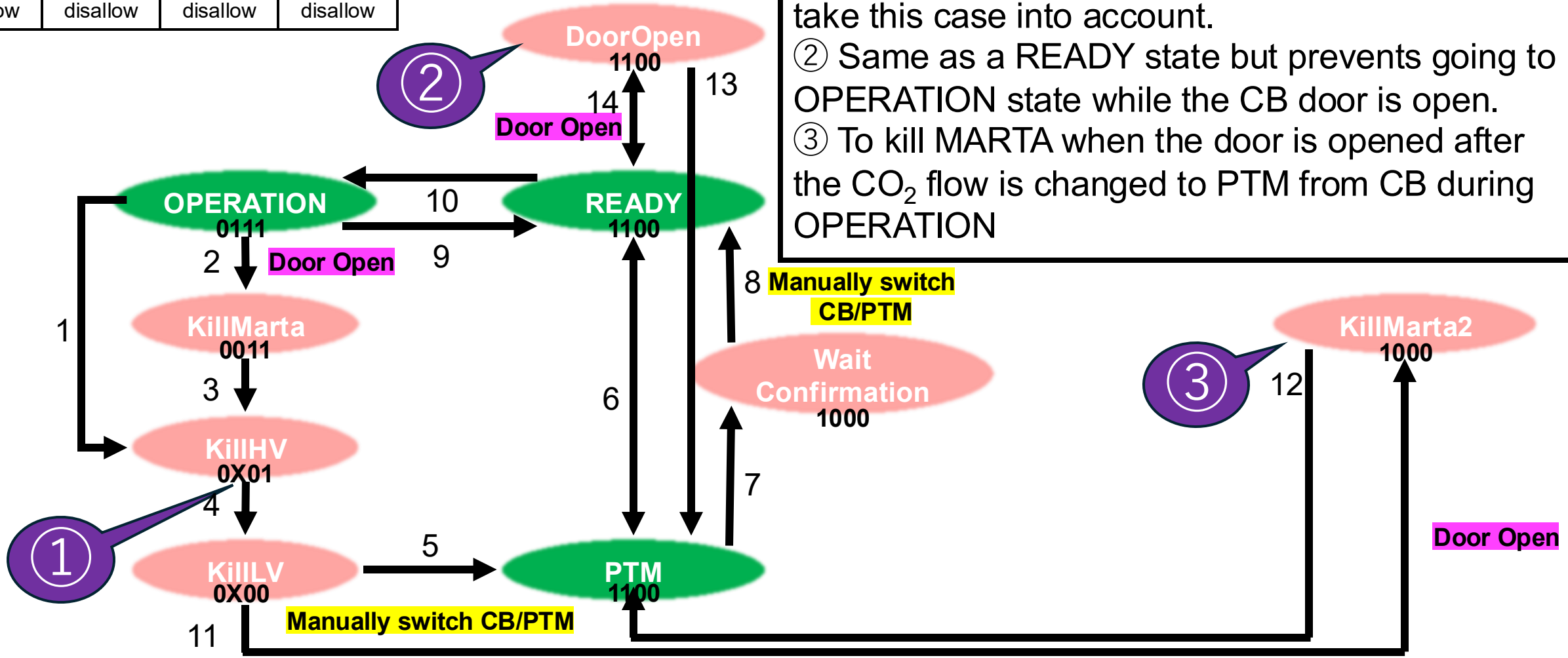
ii. State Machine Implementation

ex.) CB Door Opened while Operation/Ready

① Develop interlock system for the safe operation of CB test

CB Door allow/ disallow	MARTA allow/ disallow	HV allow/ disallow	LV allow/ disallow

① Marta allow/disallow for HV/LV is don't care to take this case into account.
② Same as a READY state but prevents going to OPERATION state while the CB door is open.
③ To kill MARTA when the door is opened after the CO_2 flow is changed to PTM from CB during OPERATION

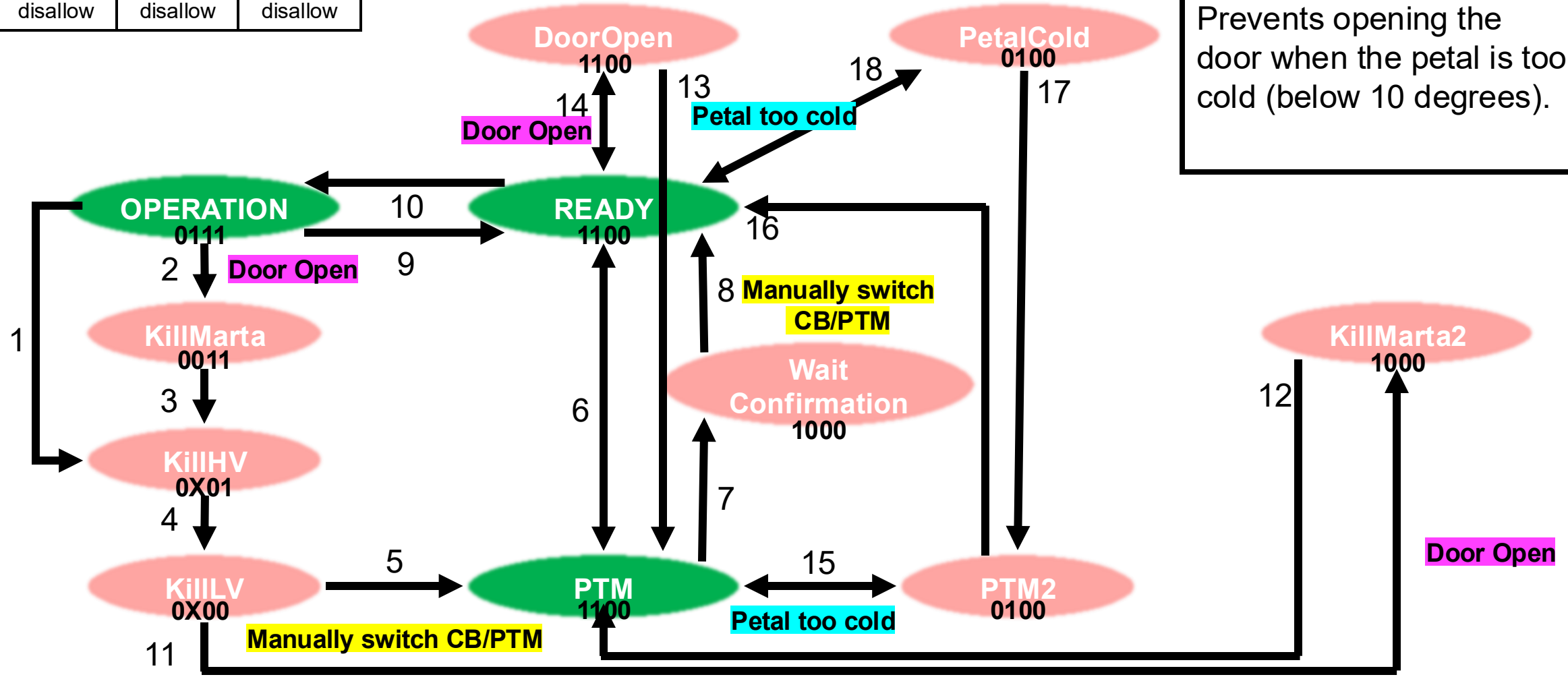


ii. State Machine Implementation
ex.) Petal too cold to open CB Door

① Develop interlock system for the safe operation of CB test

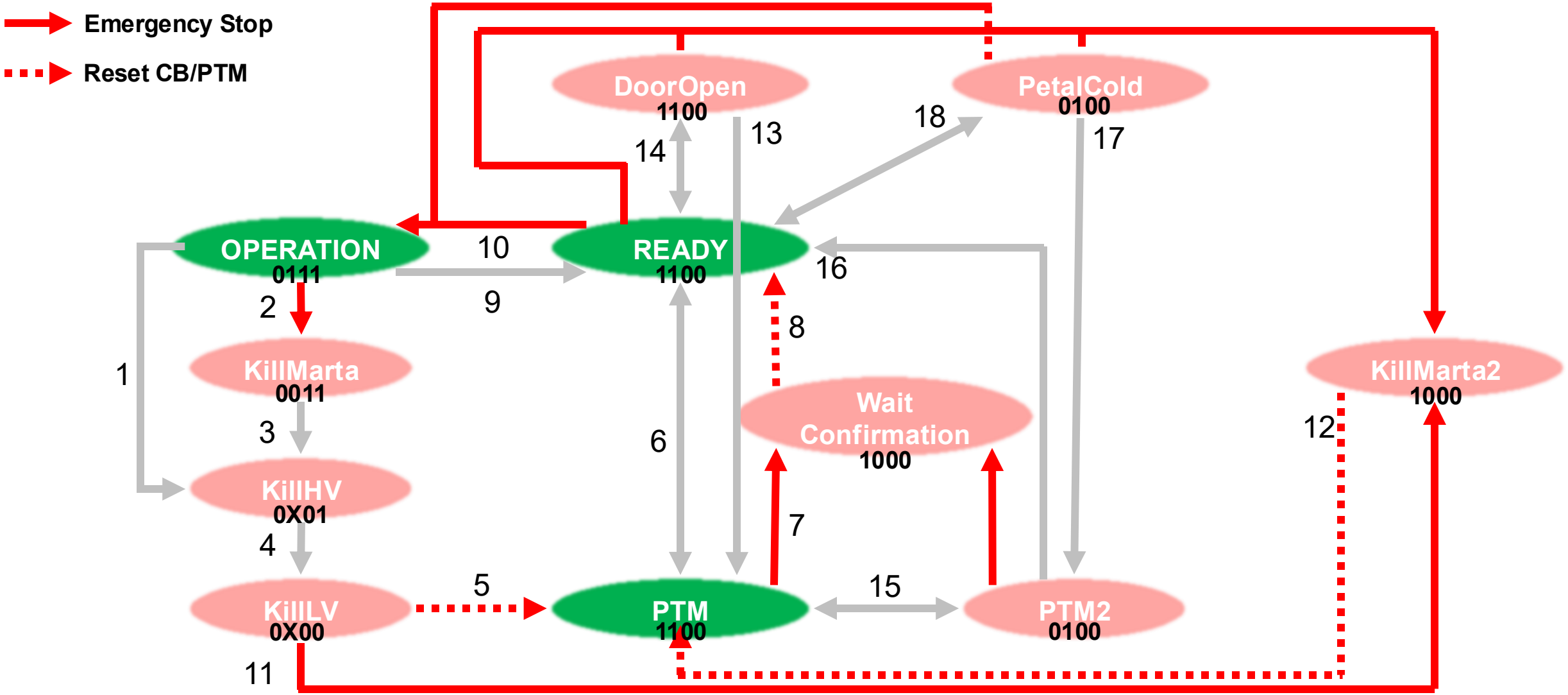
CB Door	MARTA	HV	LV
allow/ disallow	allow/ disallow	allow/ disallow	allow/ disallow

Prevents opening the door when the petal is too cold (below 10 degrees).



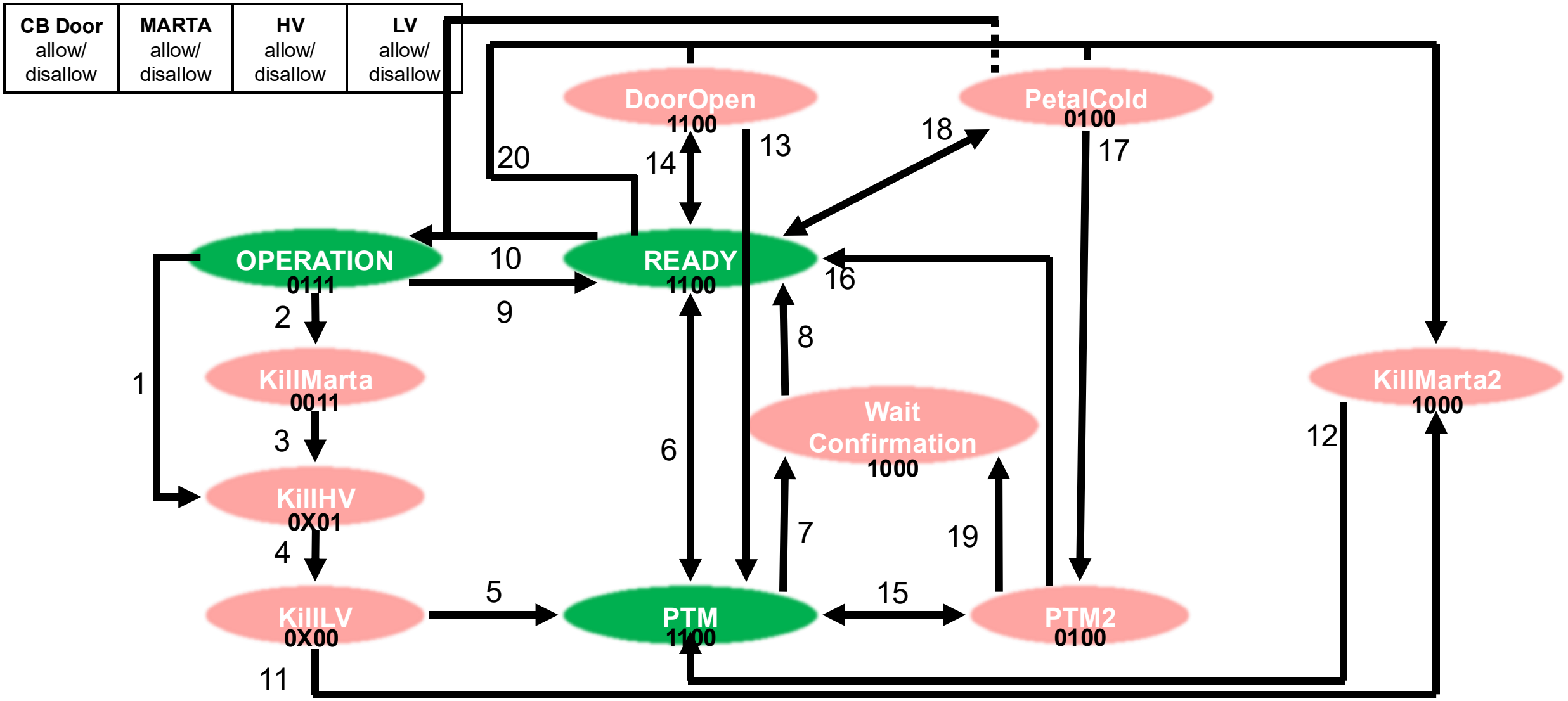
Emergency Stop

① Develop interlock system for the safe operation of CB test



ii. State Machine Implementation
Complete Version including Kill Interlock

② Implement GUI to monitor and control CB test status via Grafana and Atom



Conditions for State Transition

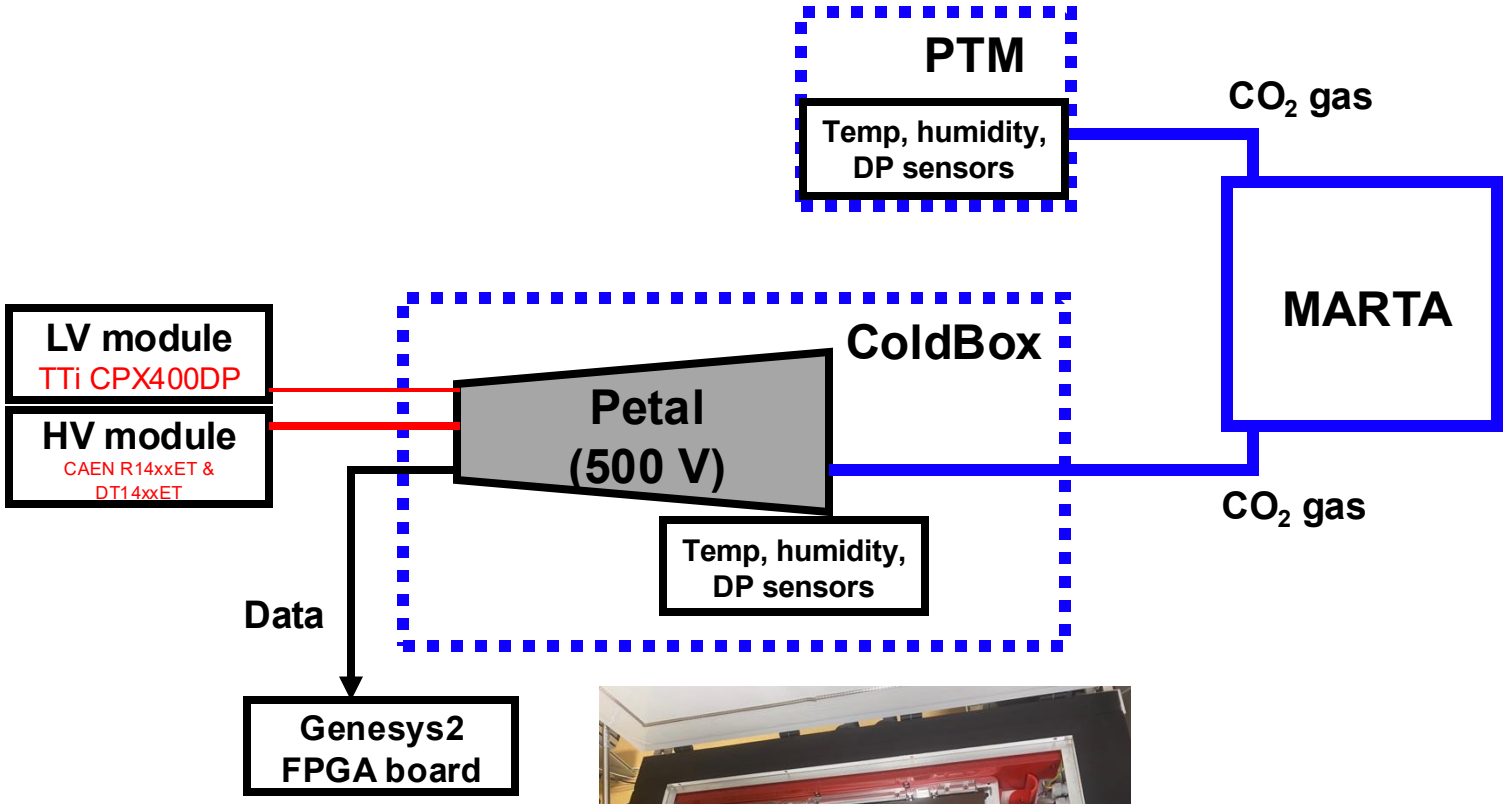
	CB Dew Point	CB temperature	Sensor Temperature	MARTA_on	HV_on	door_closed	CBnotPTM	Reset CMD	Kill ILCK CMD
1	X	X	• threshold • ! NaN	MARTA OFF & HV ON		X	PTM	X	X
2	• > threshold – minTemp • ! NaN	X	X	X	X	Door OPEN	X	X	Kill
3	X	X	X	X	X	X	X	X	X
4★	X	X	X	X	HV OFF	X	X	X	X
5	X	X	X	X	X	X	PTM	Reset	X
6	X	X	X	X	X	X	CB/PTM	X	X
7	> threshold	X	X	X	X	X	X	X	Kill
8	X	X	X	X	X	X	CB	Reset	X
9	X	X	X	MARTA OFF & HV OFF		X	X	X	X
10	X	X	! NaN & MARTA ON		X	X	X	X	X

★ Additional condition forcing the transition to killLV when HV is not confirmed to be OFF within the HV ramp down time of 10V/s.

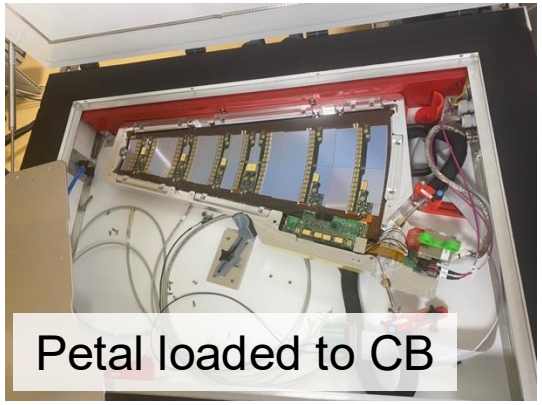
Conditions for State Transition

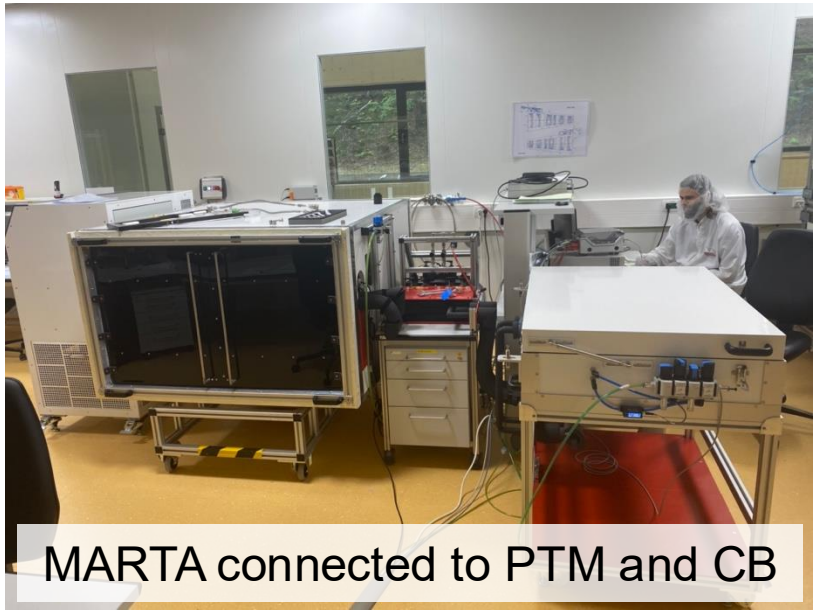
	CB Dew Point	CB temperature	Sensor Temperature	MARTA_on	HV_on	door_closed	CBnotPTM	Reset CMD	Kill ILCK CMD
11	X	X	X	Door Open & MARTA ON	X	Door Open & MARTA ON	X	X	Kill
12	X	X	X	X	X	X	PTM	Reset	X
13	X	X	X	X	X	X	PTM	X	X
14	X	X	X	X	X	Door OPEN/CLOSE	X	X	X
15	X	X	10 degrees	X	X	X	X	X	X
16	X	X	X	X	X	X	CB	X	X
17	X	X	X	X	X	X	PTM	X	X
18	X	X	10 degrees	X	X	X	X	X	X
19	X	X	X	X	X	X	X	X	Kill
20	X	X	X	X	X	X	X	X	Kill

Petal Cooling by MARTA




Opened/Closed CB


Petal loaded to CB


MARTA connected to PTM and CB

Petal Cooling