RFQ Resonance Control Update: Control Framework and Initial Results

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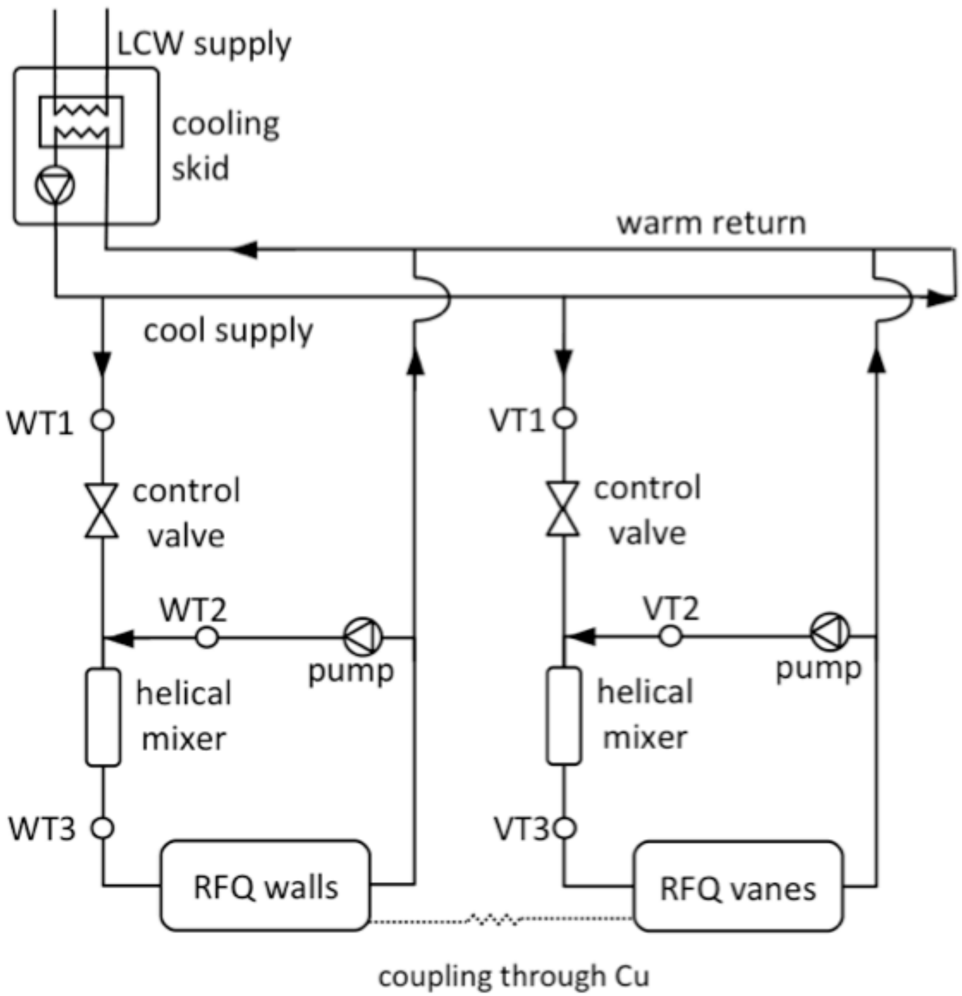
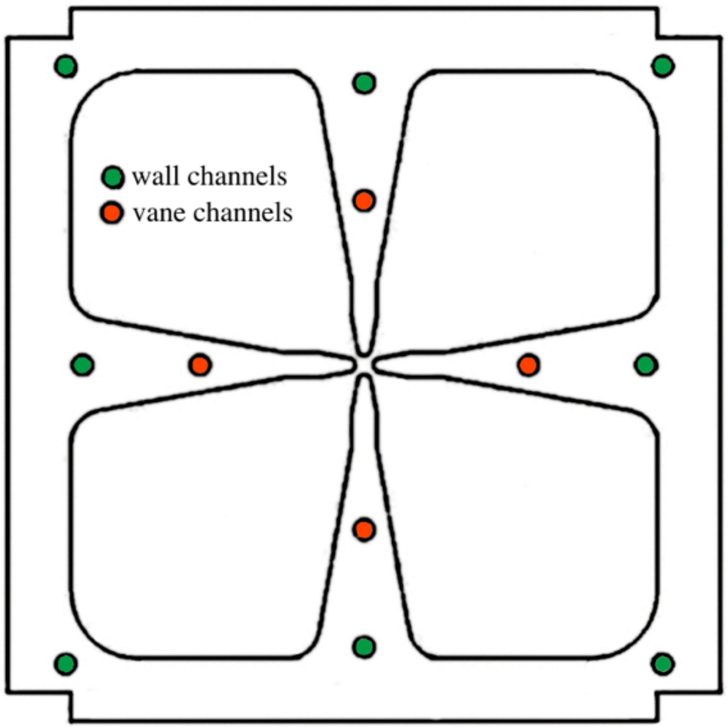
PIP-II Technical Meeting

2016-08-30

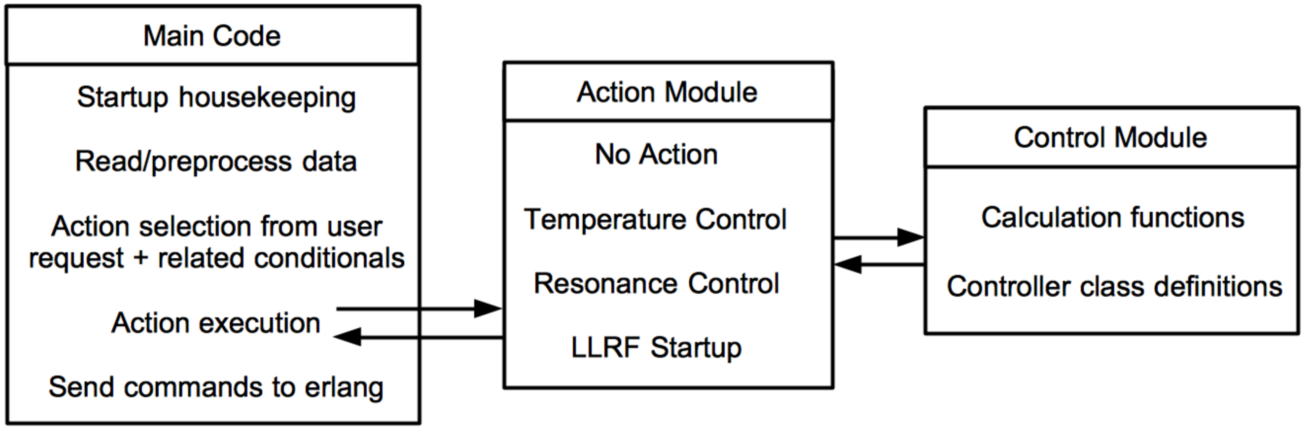
RFQ Cooling System



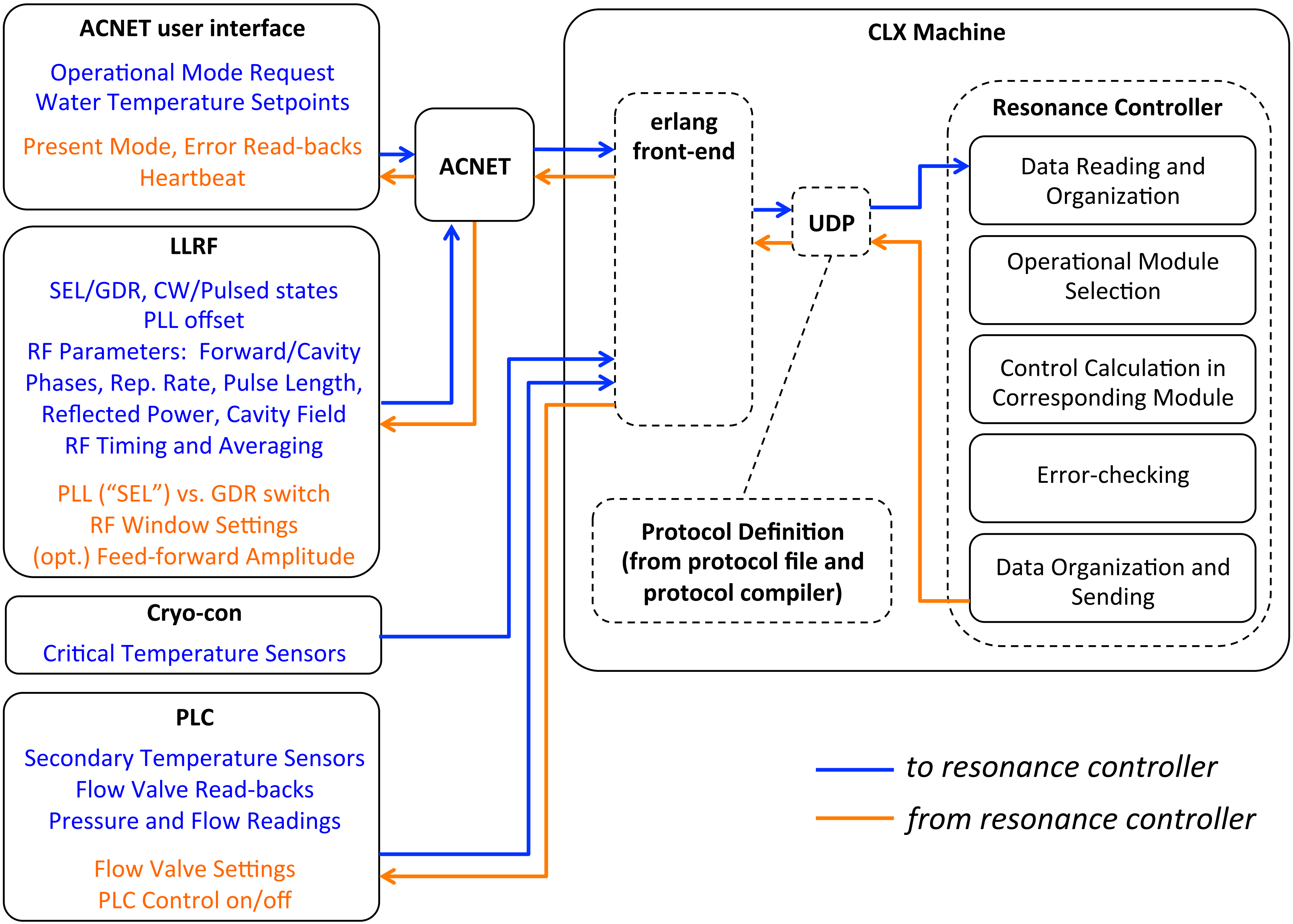


Main Framework

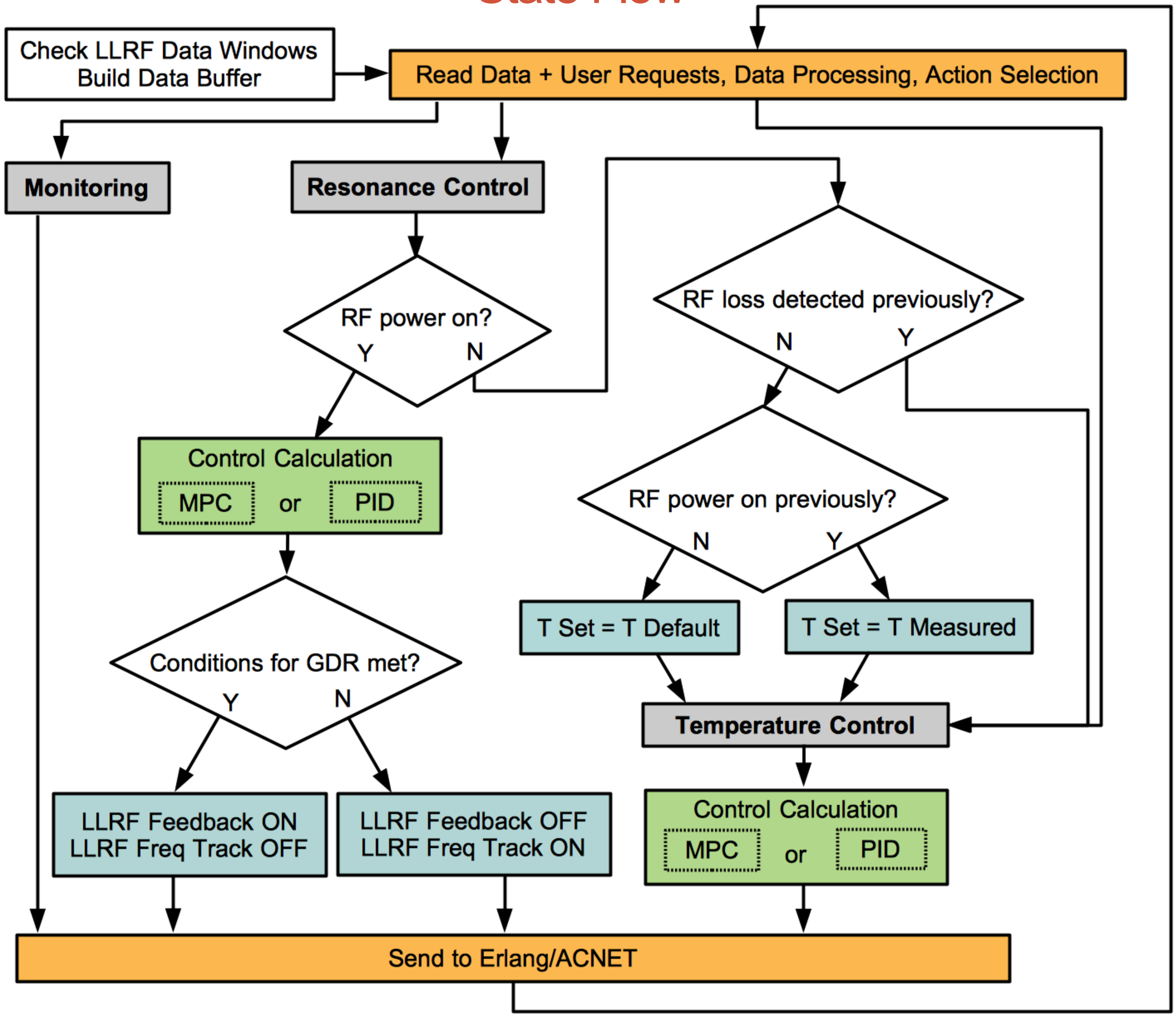
- SEL/GDR switching
  - GDR: reflected power (< 1 kW), detuning (< 1000 Hz), and cavity field set vs. read (< 0.5 kV)
- Resonant frequency calculated in both SEL and GDR
- Detects trips and holds water temperature until RF returns
- User-requested operational states:
  - Monitoring/No action
  - PI or MPC temperature control with default or user set point
  - PI or MPC resonance control
  - LLRF startup and controlled RF recovery after a trip
  - PLC control
- Modular for easy adjustments/additions:



Major System Components and Interfaces



State Flow

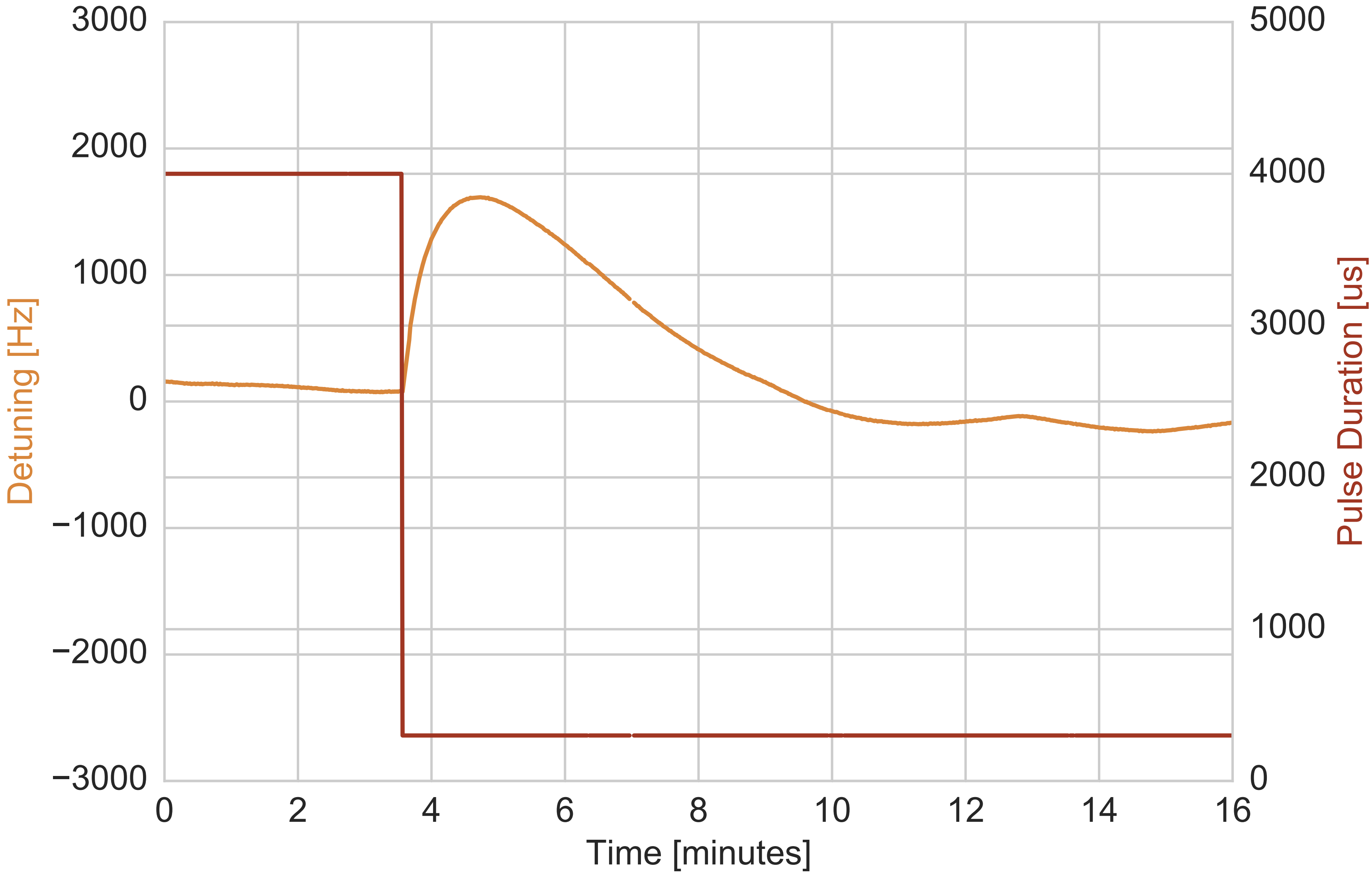


Check LLRF Data Windows
Build Data Buffer
Read Data + User Requests, Data Processing, Action Selection
Monitoring
Resonance Control
RF power on?
Y
N
RF loss detected previously?
N
Y
Control Calculation
MPC
or
PID
RF power on previously?
N
Y
T Set = T Default
T Set = T Measured
Conditions for GDR met?
Y
N
Temperature Control
LLRF Feedback ON
LLRF Freq Track OFF
LLRF Feedback OFF
LLRF Freq Track ON
Control Calculation
MPC
or
PID
Send to Erlang/ACNET

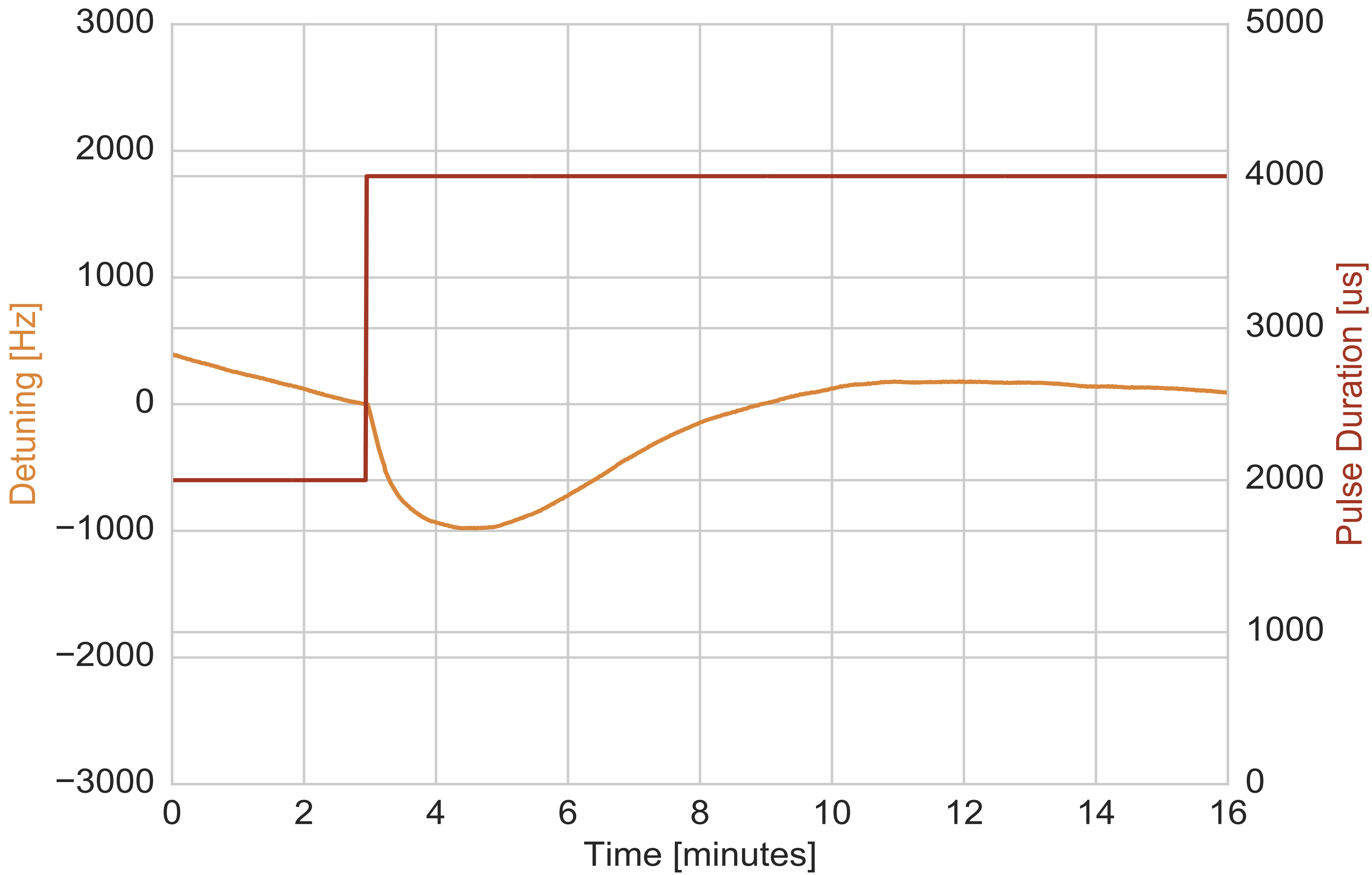
Tested Capabilities (8/22, 8/24, 8/25)

- Switching between requested states
  - 1 – no action, just monitoring (useful for MPC)
  - 3 – PI temperature control using default set point (hard-coded, right now 25 °C)
  - 4 – PI temperature control using user set point (given via ACNET)
  - 7 – Resonance control with PI on the vane valve
- Switching between SEL/GDR and turning RF feedback off/on
  - Sent actions are correct, but still need to fix UDP communication issue
- Basic trip handling
- Resonance control operation in pulsed mode with changing pulse width and forward power
- Resonance control operation in low power CW mode
- Also tried PI resonance control on the vanes with minor PI temperature control on the walls → needs additional tuning; right now better to move to MPC
- Caveat on data shown in the next slides: few apples-to-apples comparisons just yet

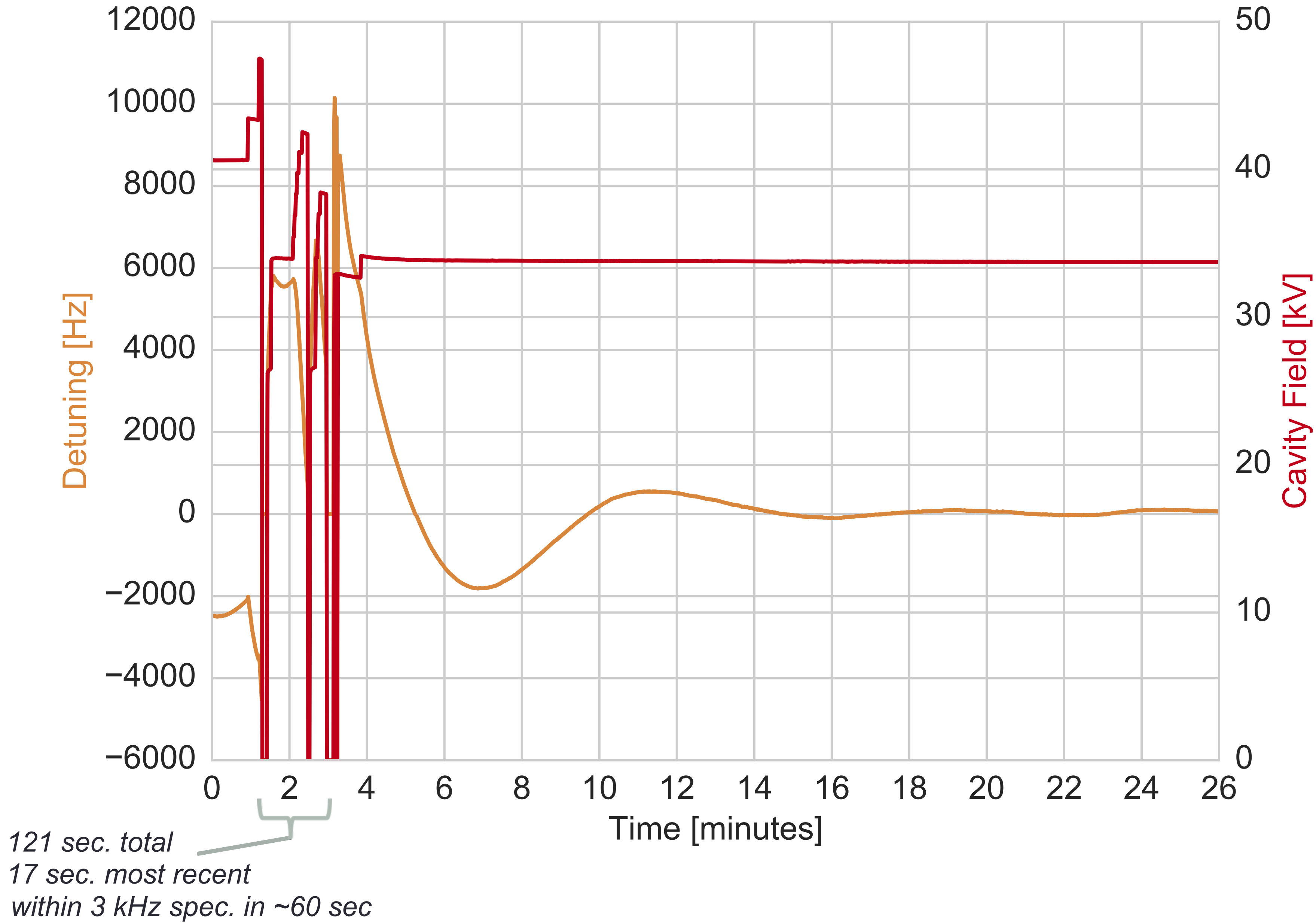
Pulsed Operation, Cavity Field at 60 kV



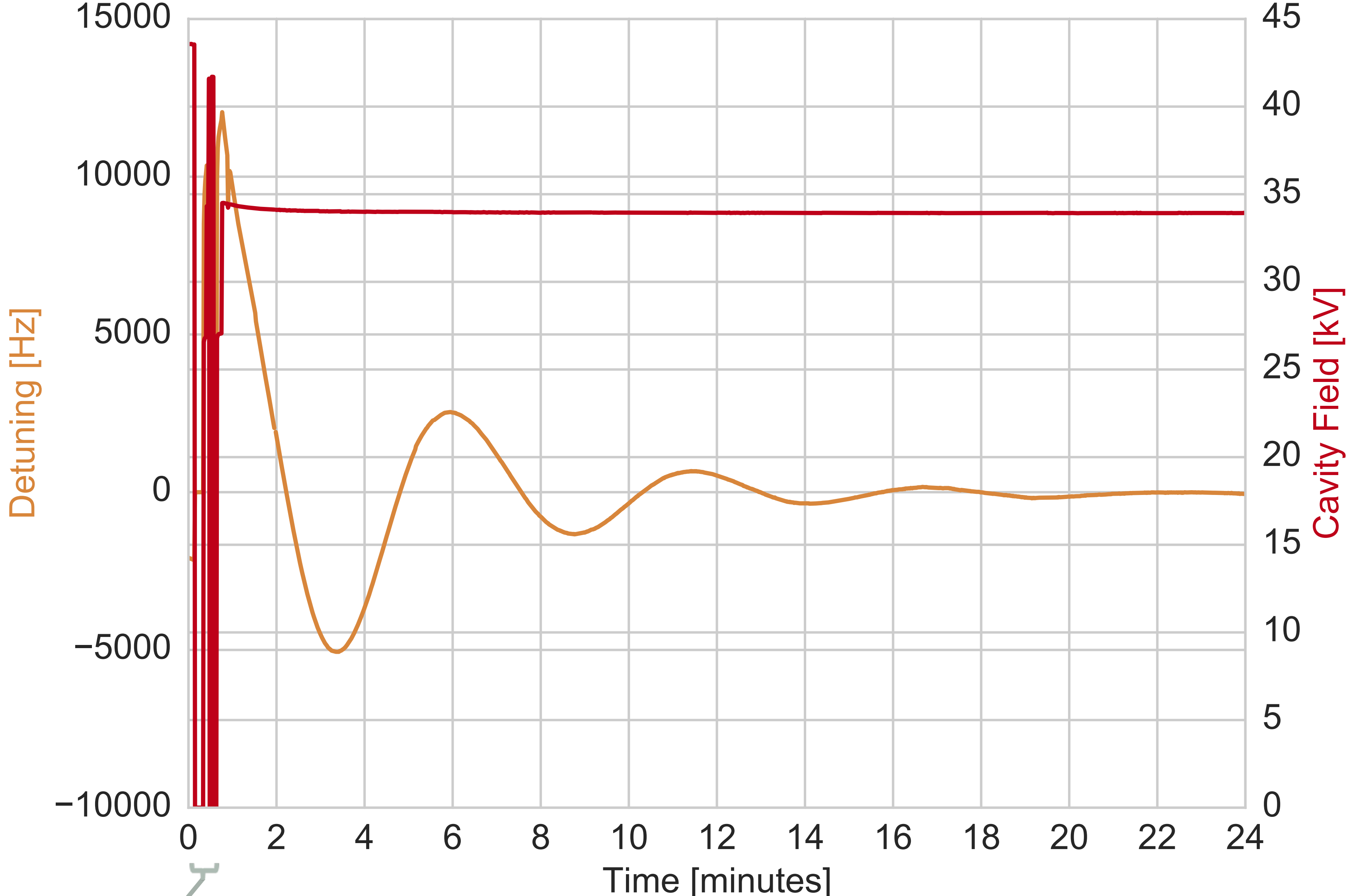
Pulsed Operation, Cavity Field at 60 kV



CW Operation After a Trip



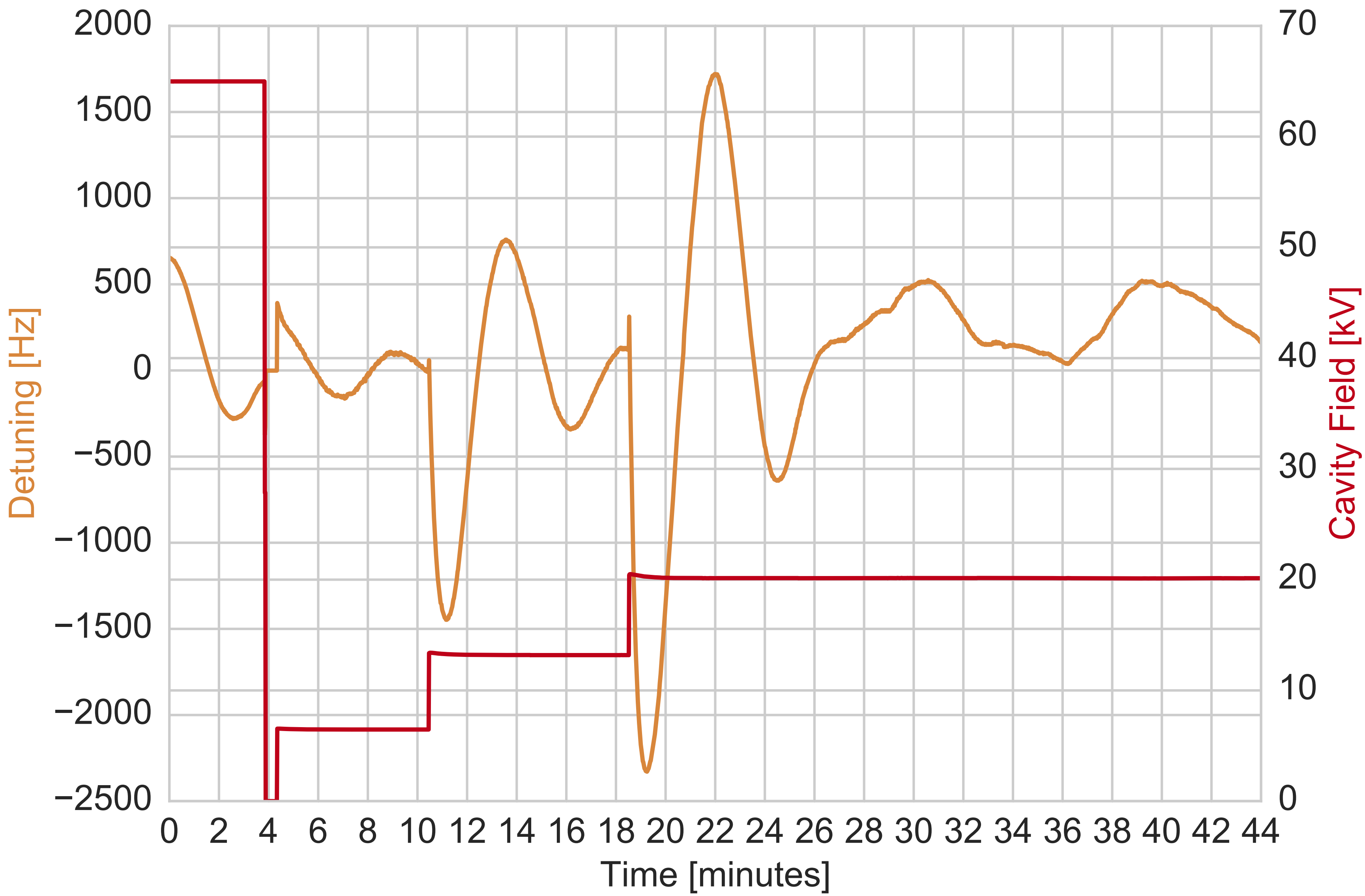
CW Operation After a Trip



31 sec. total
3 sec. most recent

Note: this was before adjusting control blocking (should be better now)

CW Operation



Note: this was before adjusting control blocking (should be better now)

Present Limitations (i.e. why we're also doing MPC)

- Fluctuations in the supply temperature

- Flow curves
  - Nonlinear + coupled
  - Intermediate skid pressure fluctuates

  → For PI, have a fitted correction for this

- Transport delays and thermal responses

  → Placed some blocking in the PI loops

- Water temperature control with PI is deliberately low gain—otherwise the loops will fight each other

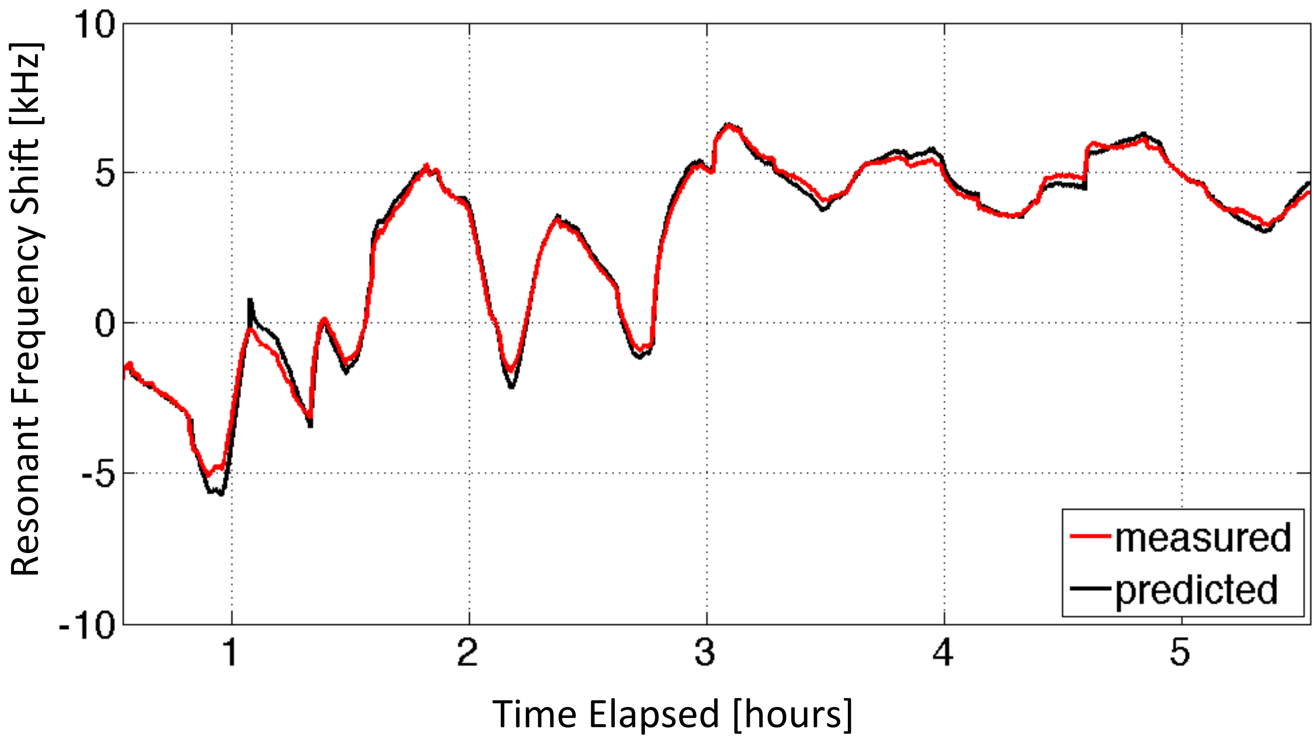
- PI resonance control is only on the vanes

- Need to watch wall temperature in CW

MPC: Neural Network Model for Pulsed Operation

Inputs:
- Vane valve setting
- Wall valve setting
- Average RF power
- Water temperatures
- Ambient temperature and humidity

Mean absolute prediction error:
- 346 Hz on the test set
- 98 Hz on the validation set
- 115 Hz across all sets



See A.L. Edelen, IPAC16, THPOY20

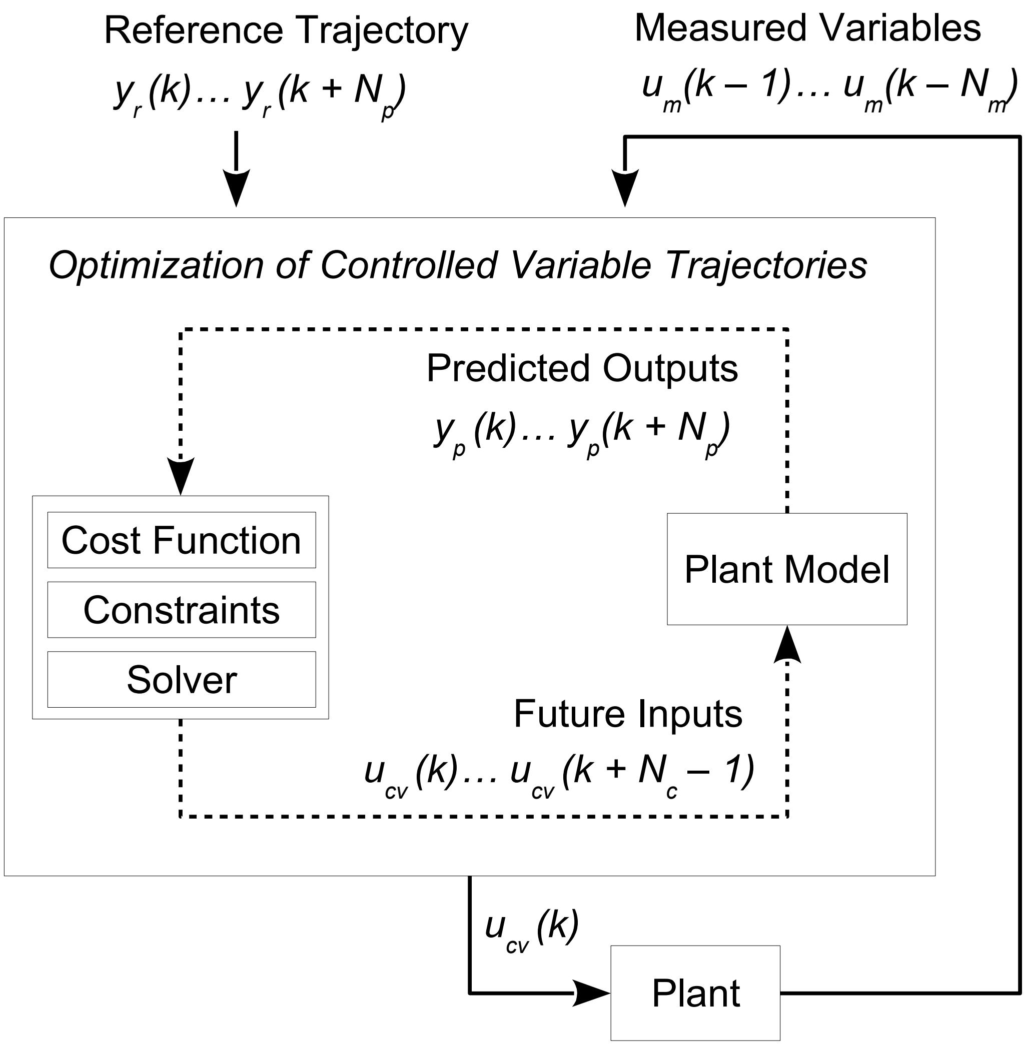
Conclusions

- Pulsed operation with PI resonance control is operational:
  - Can set/change cavity field + pulse length arbitrarily
- CW operation with PI resonance control is operational:
  - Need to watch the supply temperature and wall temperature
- Either case:
  - Susceptible to supply temperature fluctuations
  - Could benefit from some additional tuning
- MPC will improve upon this:
  - Supply disturbance rejections
  - Simultaneous vane/wall control
  - Shouldn't have oscillatory behavior á la PI
- To do:
  - Fix SEL/GDR switching communication
  - Finish MPC + MPC testing in framework
  - For PI: some tuning of gains and valve correction weighting (esp. in T control)

Practical Recommendations

- P127 >> rescntl 1 is the parameter page
- To set requested state, set P:QRCMOD
  - 1 is no action
  - 3 is temperature control with default set points
  - 4 is temperature control with user set points
  - 7 is resonance control with PI (should primarily be using this one)
- To set water temperature set points:
  - P:QRCTSV for the vane
  - P:QRCTSW for the wall
- For PI, the wall valve set (P:WRWSV) at 15% for pulsed, 30-40% for CW
- If having problems, check P:WISS1P (skid pressure) to make sure it isn't consistently low (e.g. < 50 psi)
- In CW:
  - Watch WRWT03 to make sure it isn't getting too high (e.g. > 35 deg C; increase wall valve by 10 % or so)
  - Watch P:WISLT and P:WISLST (intermediate skid and LCW temperature)—if these get too high there's a problem with the water system (e.g. chillers)

Model Predictive Control



N_m previous measurements

N_p future time steps predicted

N_c future time steps controlled

$$\sum_{i=1}^{N_p} \{w_y \left[y_r(k+i) - y_p(k+i)\right]\}^2$$

(output variable targets)

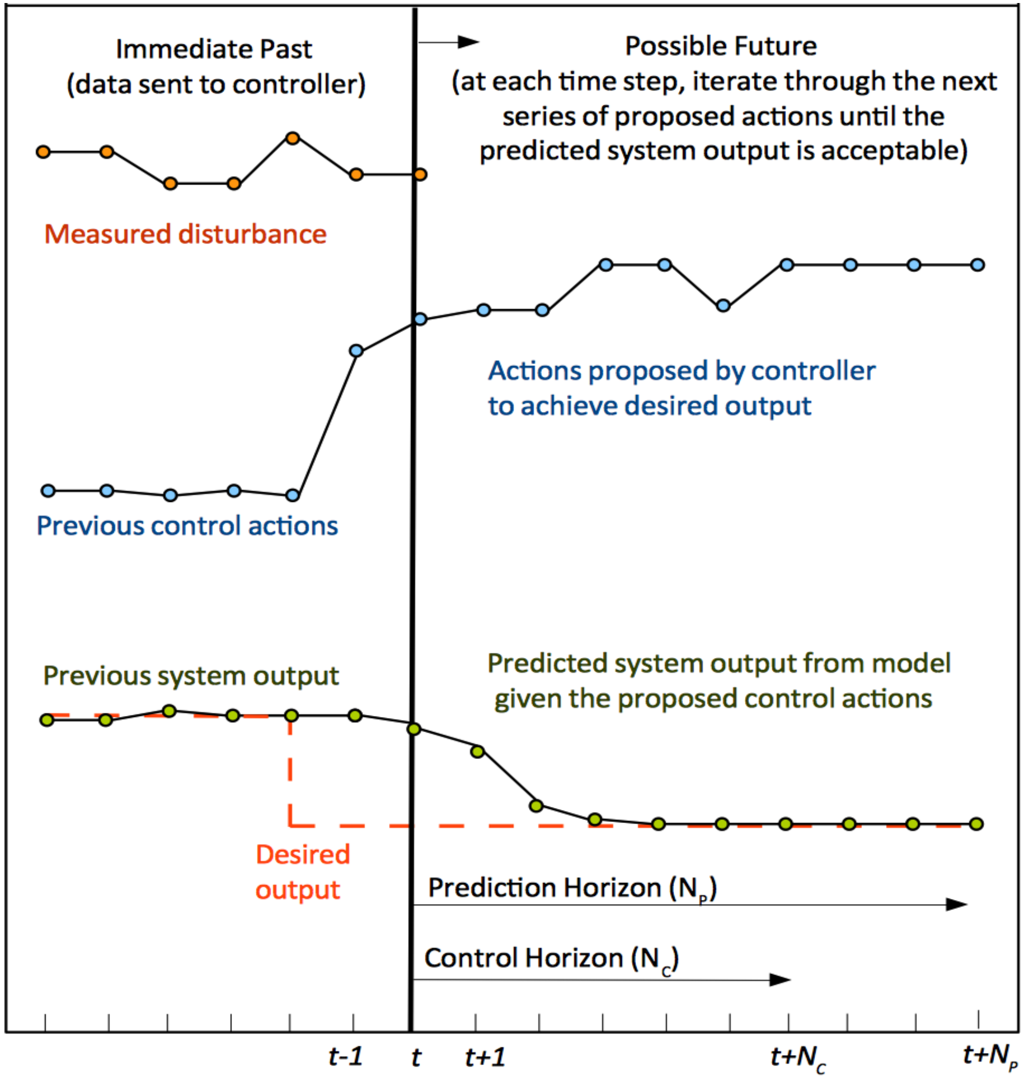
$$\sum_{j=1}^{n_{cv}} \sum_{i=0}^{N_p-1} \{w_{u,j} \left[u_j(k+i) - u_{j,ref}(k+i)\right]\}^2$$

(controllable variable targets)

$$\sum_{j=1}^{n_{cv}} \sum_{i=0}^{N_p-1} \{w_{\Delta u,j} \left[u_j(k+i) - u_j(k+i-1)\right]\}^2$$

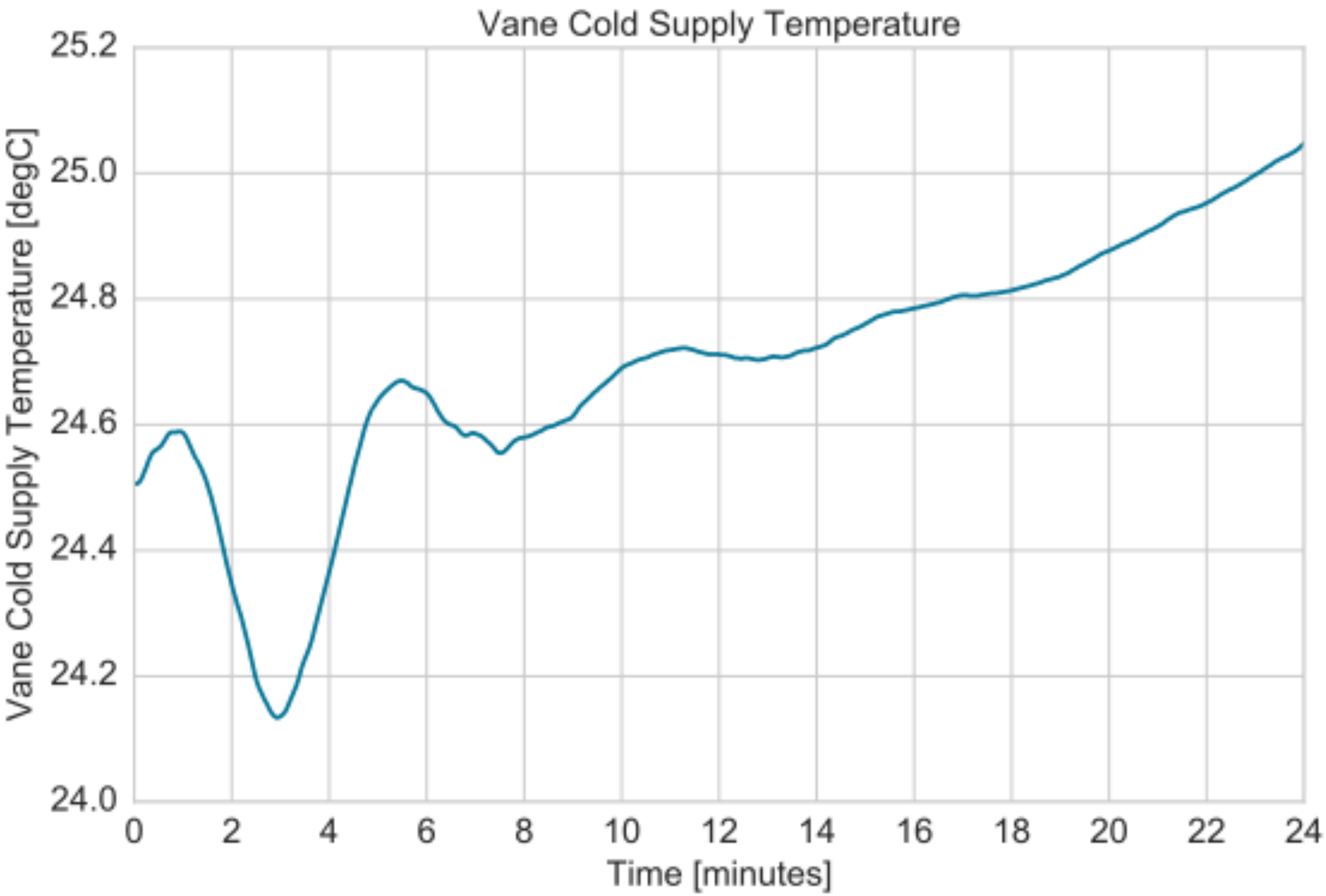
(movement size)

Model Predictive Control



Basic concept: use a predictive model to assess the outcome of possible future actions

Example temperature increase during CW



Example supply temperature change