ICALEPCS2017
Barcelona · Spain, October 8-13 · Palau de Congressos de Catalunya
16th International Conference on Accelerator and Large Experimental Physics Control Systems

AUTOMATIC PID PERFORMANCE MONITORING APPLIED TO LHC CRYOGENICS

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WEAPL02

Summary

- Introduction
- Regulation performance indicator
- Application to LHC cryogenics
  - Computing infrastructure
  - Examples of poor regulation tunings
- Conclusion

Introduction

- CERN launched several data analytics techniques to help operation teams

- LHC Cryogenic systems
  - Use of ~ 5 000 PID regulation loops (Proportional-Integral-Derivative)
  - Impossible to detect easily poorly tuned regulation loops

- Important to detect poorly tuned loops
  - Too fast controllers accentuate the aging of actuators
  - Too slow controllers generate oscillations and can induce problems
  - Poorly tuned PID can provoke undesirable interlocks in case of unexpected disturbance

Regulation performance indicator

- A **Predictability Index** (PI) has been chosen
  - Applicable to any regulation loop
  - Easy to compute
  - Few parameters to be setup

- Estimate the predictability of the regulation loop
  - PI = 1 if fully predictable (best achievable controller)
  - PI = 0 if erratic behaviour (poorly tuned)

Prediction error: $\hat{e}(t+b) = a_0 + a_1 \cdot e(t) + a_2 \cdot e(t-1) + \ldots + a_m \cdot e(t-m-1)$

$$PI = \frac{\sigma_r^2}{mse} = \frac{\text{Error residue variance}}{\text{Mean square error}}$$

Predictability index parameters

- Parametrization of the algorithm per loop:
  - **Ts**: Sampling time
  - **T_W**: Time window to compute each predictability index
  - **T**: Time constant of the regulation loop
    - ✓ Equal to the prediction horizon (b=T)
    - ✓ Half of the regression model order (m = 2.T)
  - **PI_L**: minimum predictability index to consider the loop as correctly tuned

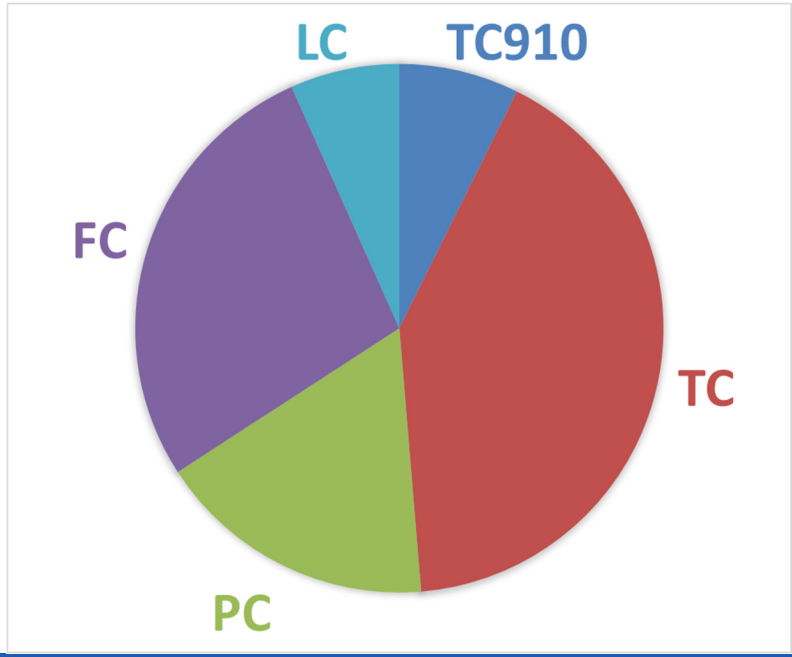
- **Additional parameters to avoid "false positive"**
  - **σ_y**: Minimum controller output standard deviation to consider the loop
    - ✓ Avoid all regulation loops disabled or saturating
  - **N**: Number of abnormal time windows over 24 hr to classify the loop as "poorly tuned"

Application to LHC cryogenics

- 3 000 PID loops selected over the 5 000
  - Discard all loops not used during normal operation of LHC
  - Alleviate calculations

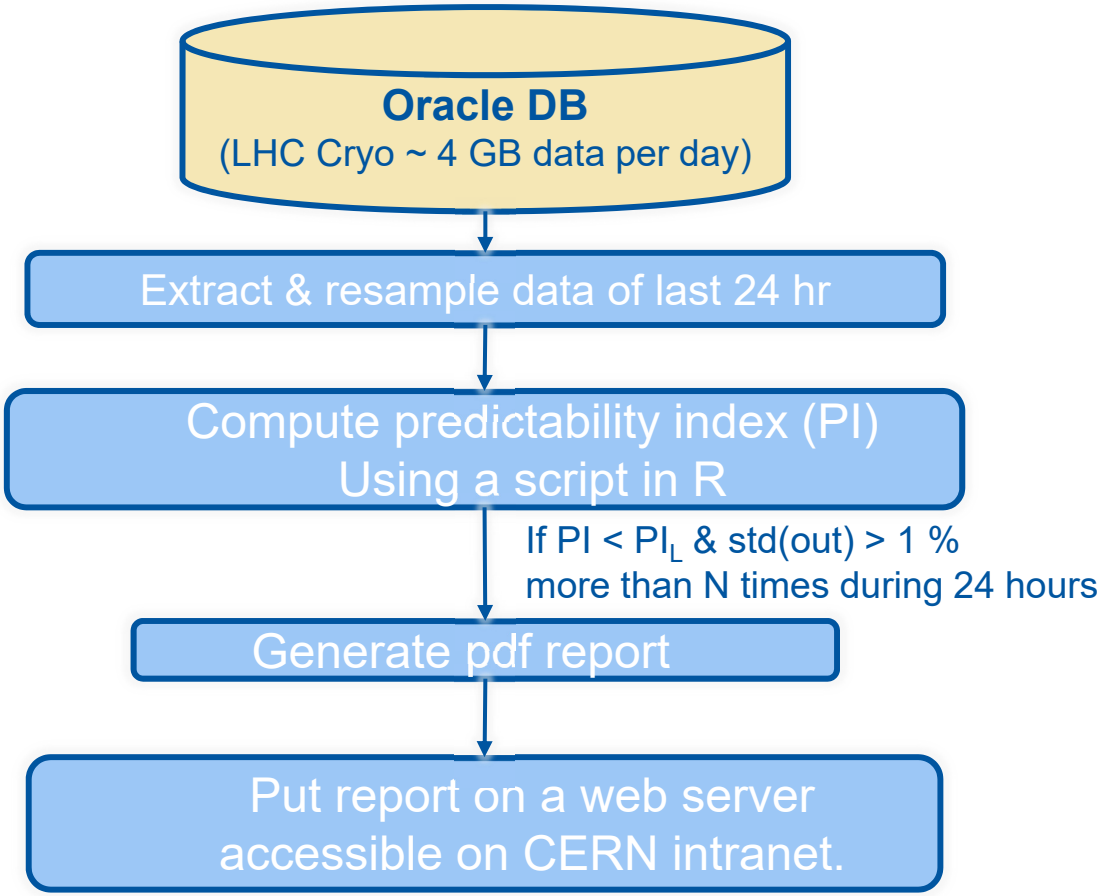
- 5 main “controller groups” has been setup for parametrization
  - **TC_{910}**: 1.9 K regulation loops for superconducting magnets (#220)
  - **TC**: all other temperature controllers (#1250)
  - **PC**: Pressure controllers (#520)
  - **FC**: Flow controllers (#830)
  - **LC**: Level controllers (#200)

Group	t_s	t_W	T	N	PI_L	$\bar{\sigma}_y$
TC_{910}	60 *s*	12 *hr*	120 *min*	1	0.2	1 %
TC	60 *s*	5 *hr*	30 *min*	3	0.4	1 %
PC	10 *s*	1 *hr*	3 *min*	3	0.4	1 %
FC	10 *s*	1 *hr*	2 *min*	3	0.4	1 %
LC	10 *s*	1 *hr*	2 *min*	3	0.4	1 %



Computing infrastructure

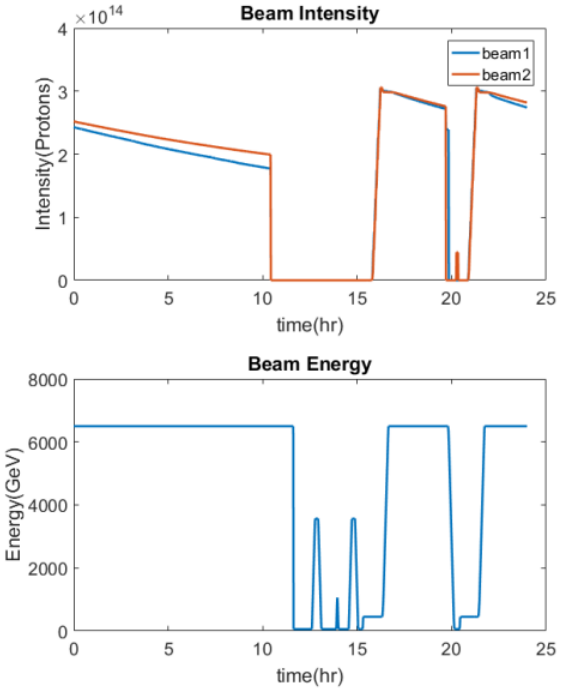
- Calculations performed in the CERN computing centre
  - Currently done in a single Linux Virtual Machine



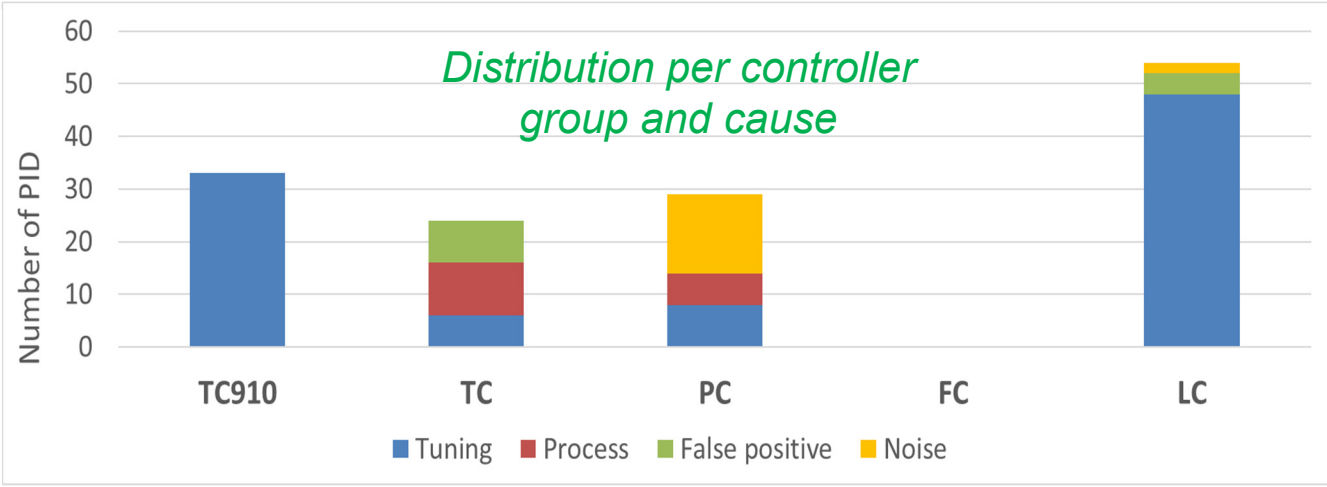
- ➔ Script executed every day at midnight
- ➔ Takes about 6 hours of computation for the 3000 PID loops.
- ➔ Can be scaled-up using the CERN Hadoop cluster with parallelisation in a spark job.

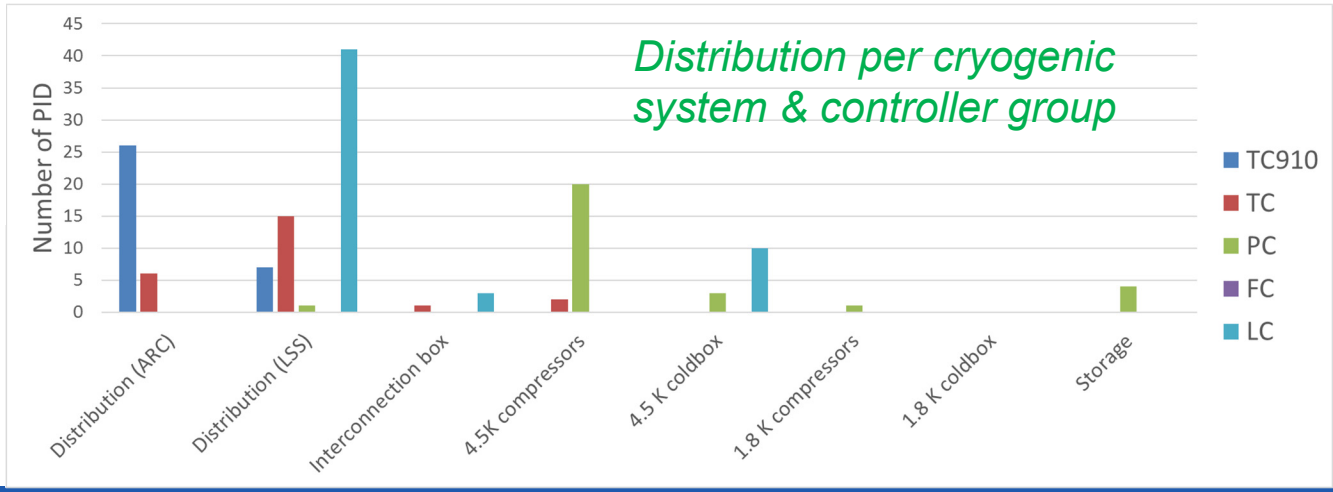
Results on 1 day (31st July 2017)

Typical day for LHC



140 poorly tuned PID detected





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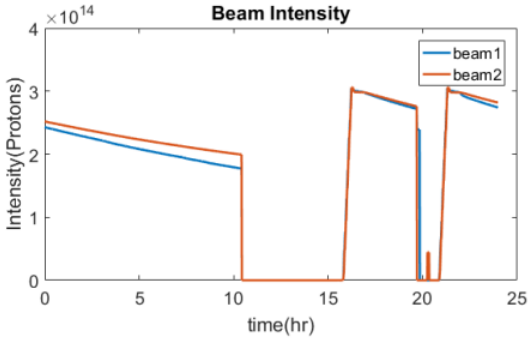

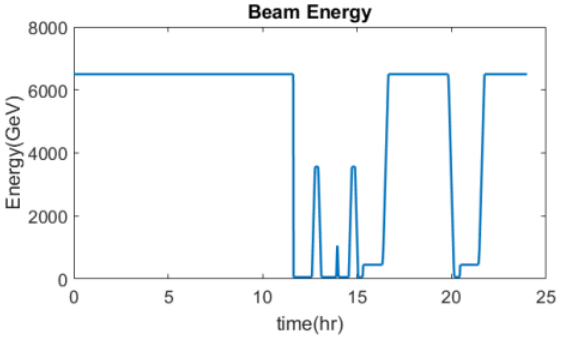

★ Example LC poor tuning

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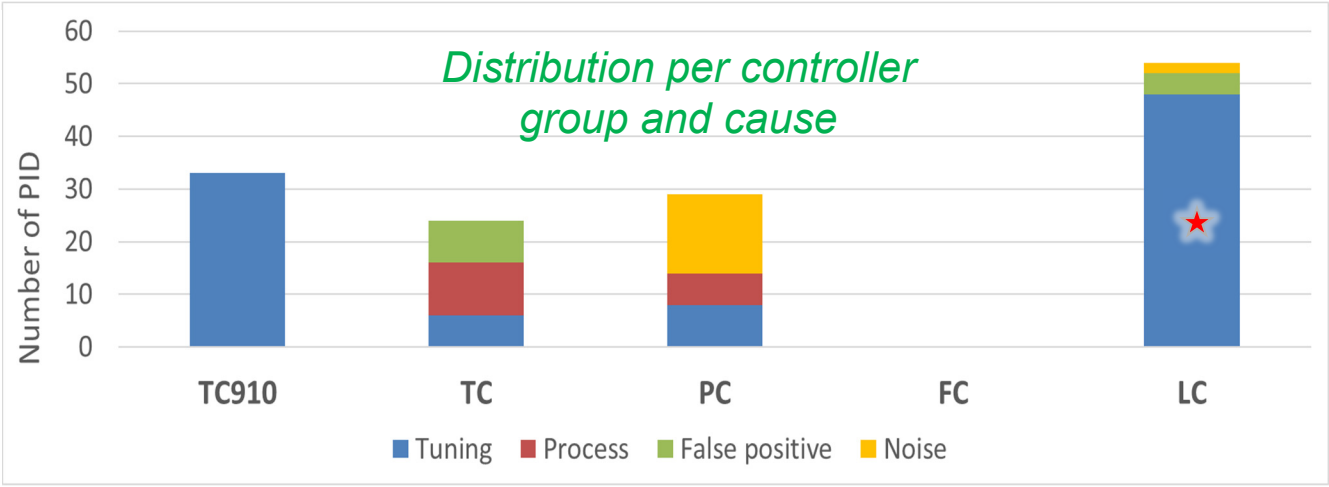

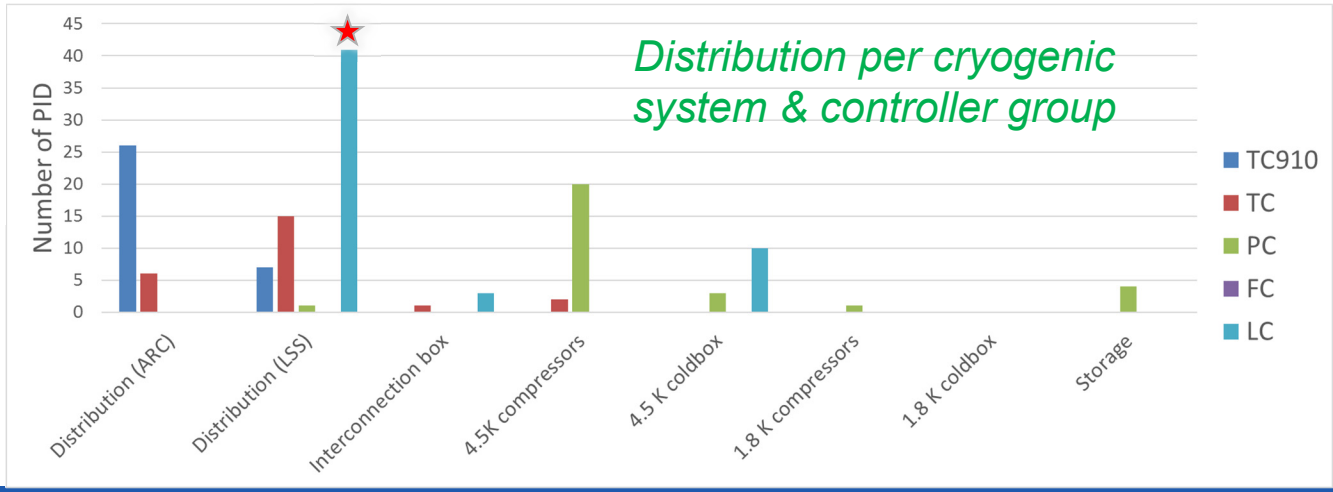

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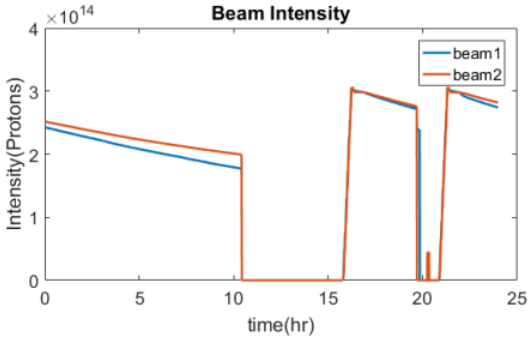

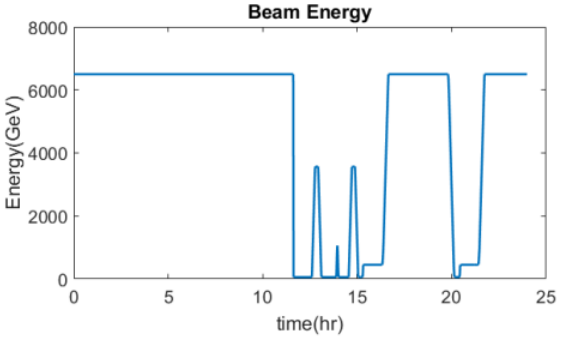

★ Example LC poor tuning

★ Example TC poor tuning

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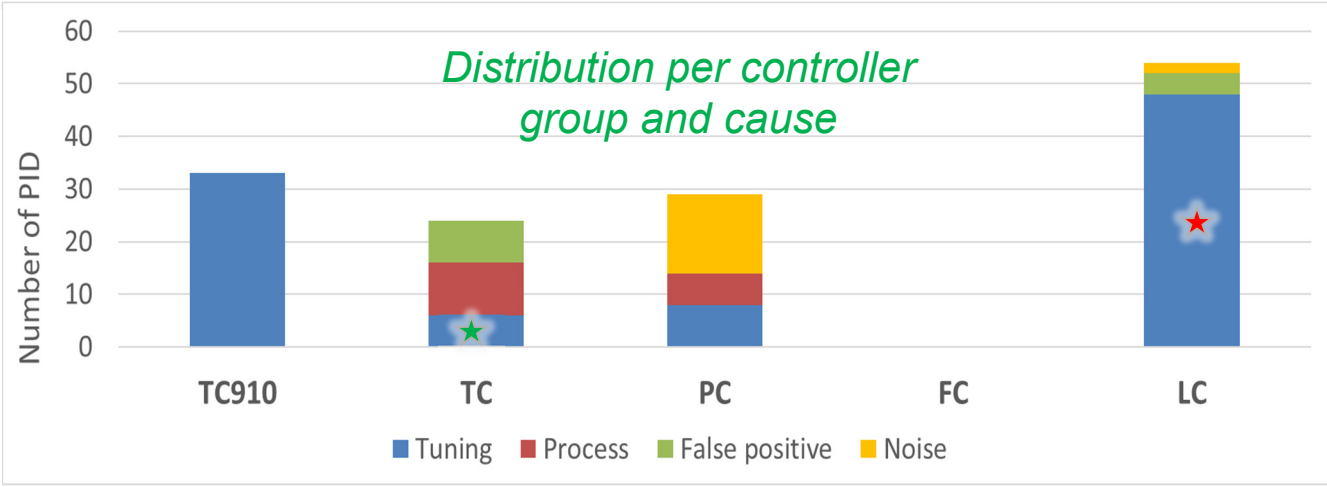

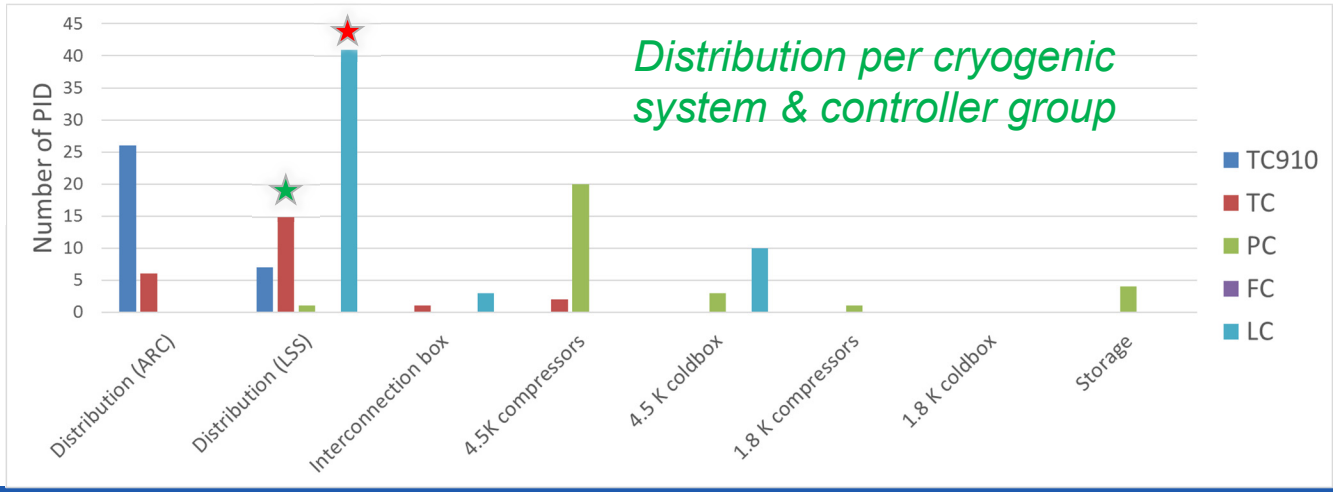

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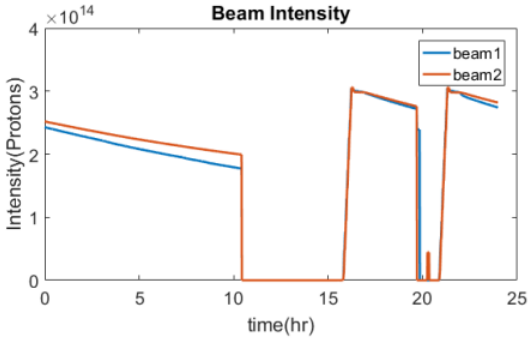

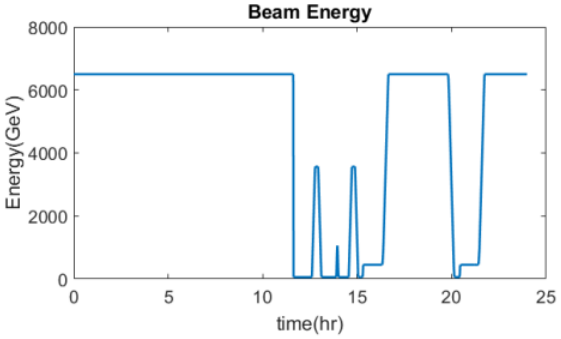

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★ Example TC poor tuning

★ Example LC false positive

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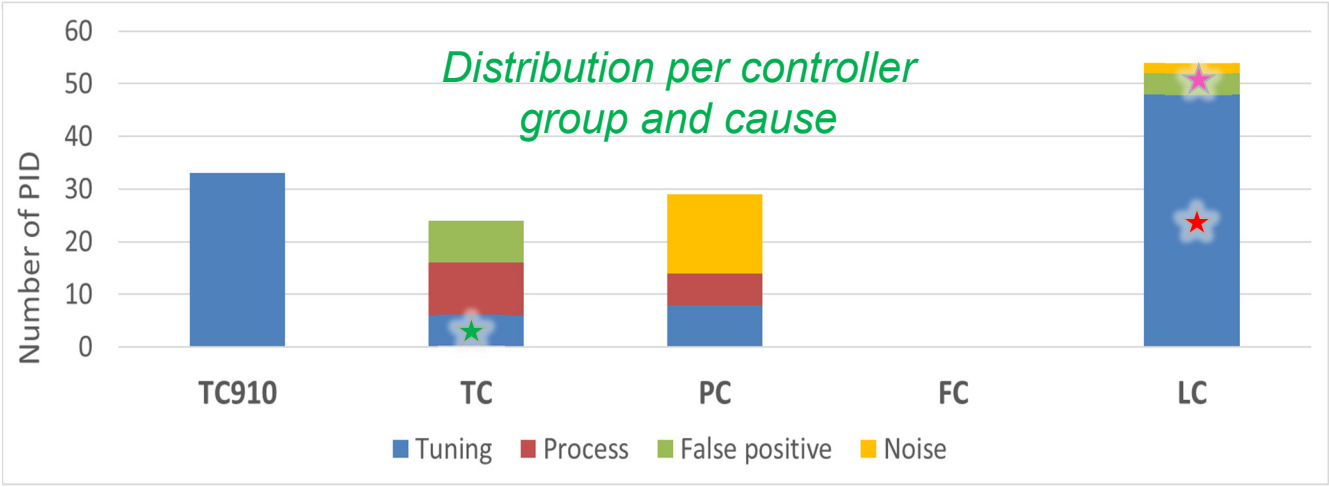
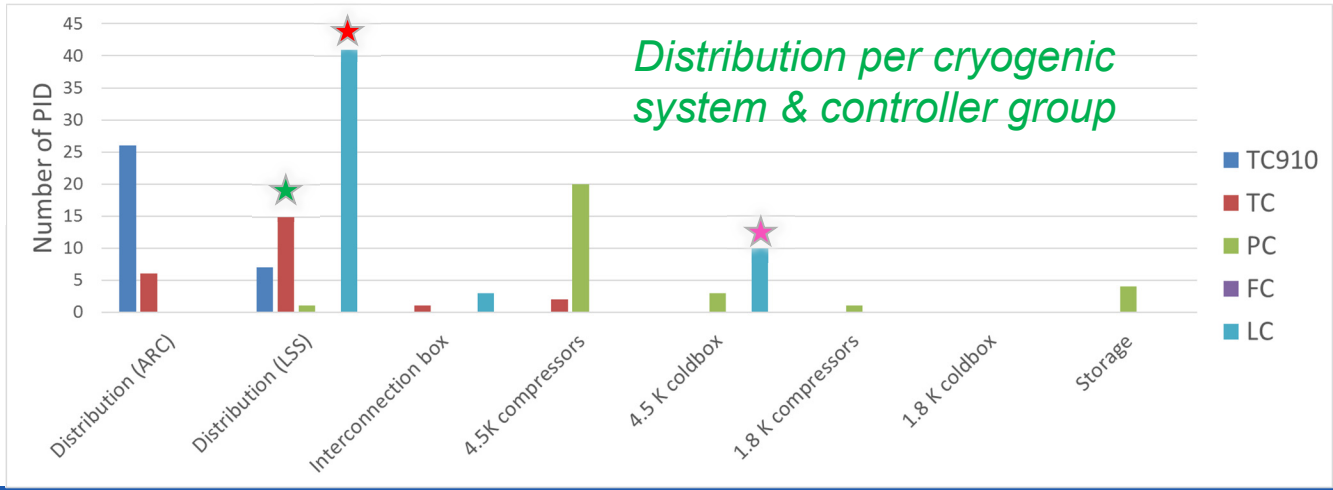
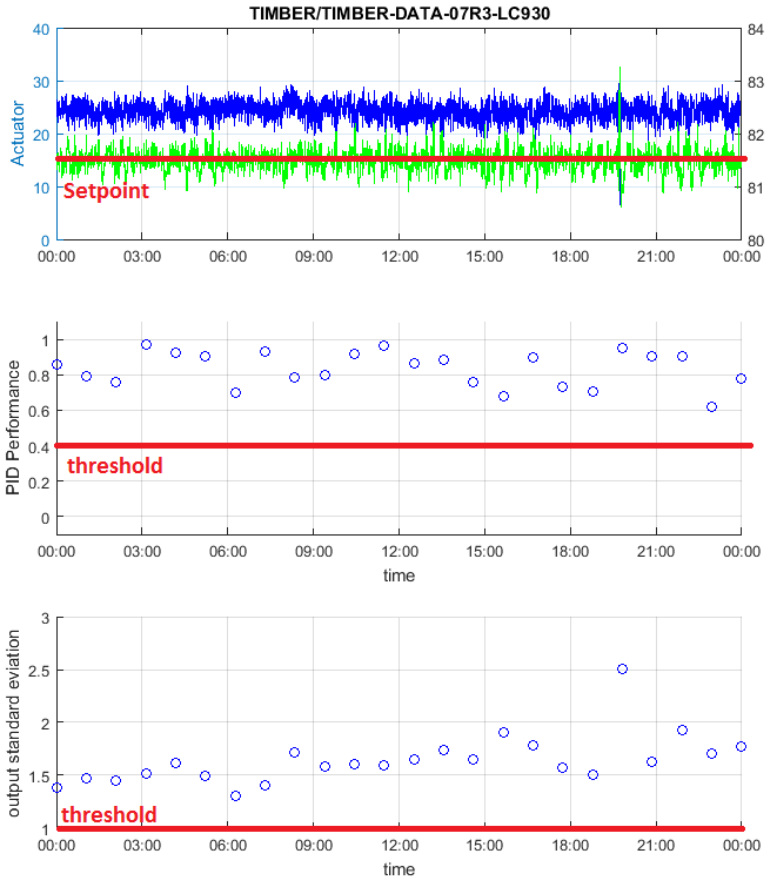


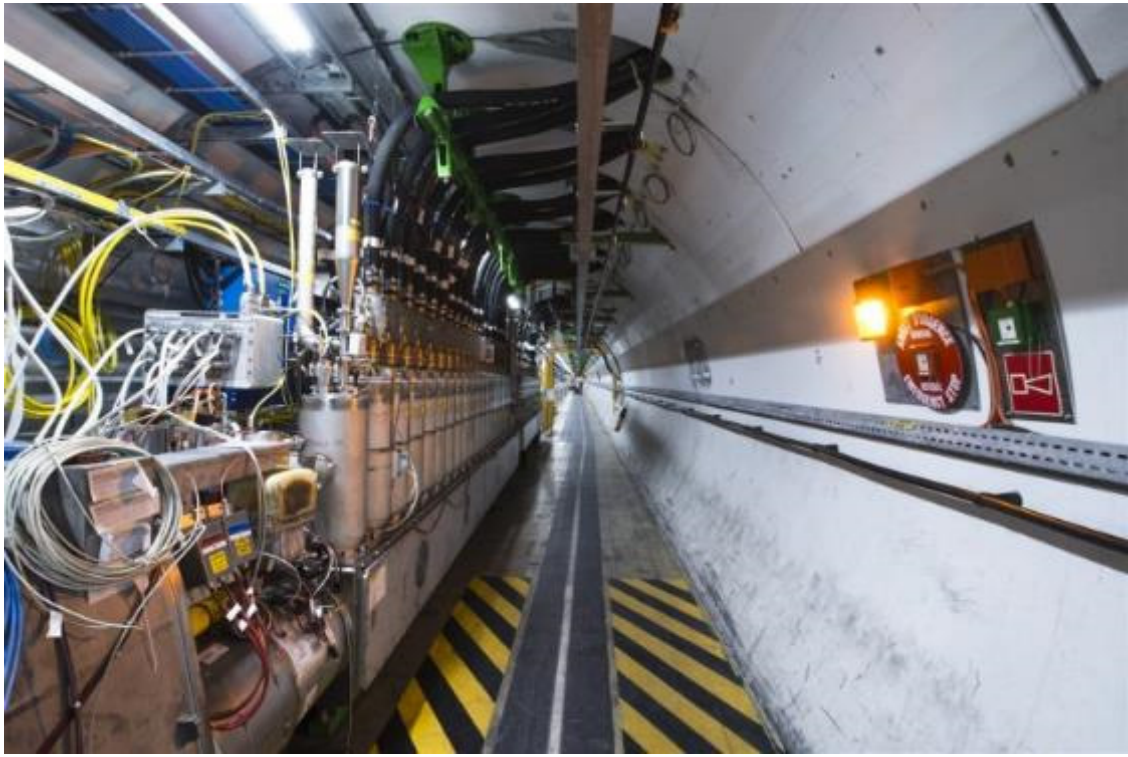


Poor tuning example: Level controller

- DFB liquid helium **level controller** (Distribution Feed Box)
  - ✓ Allow the powering of superconducting magnets: very narrow regulation range

Good tuning





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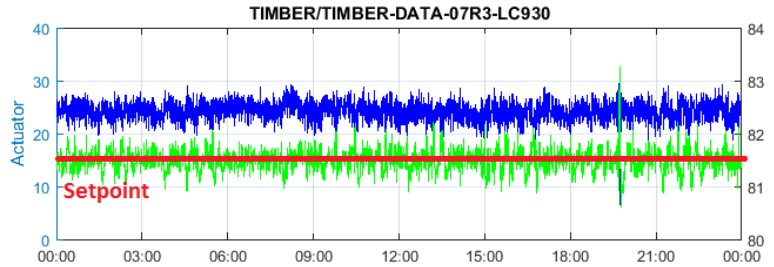

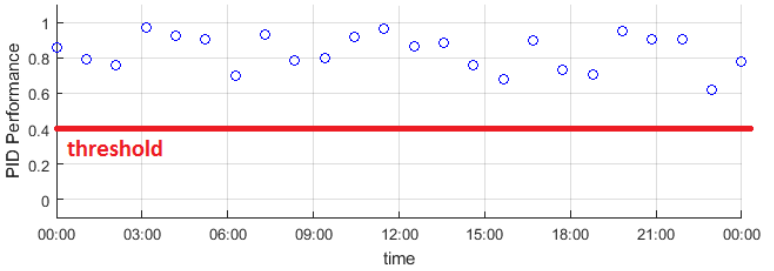

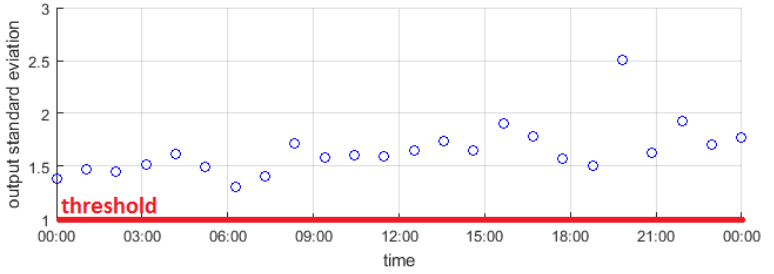

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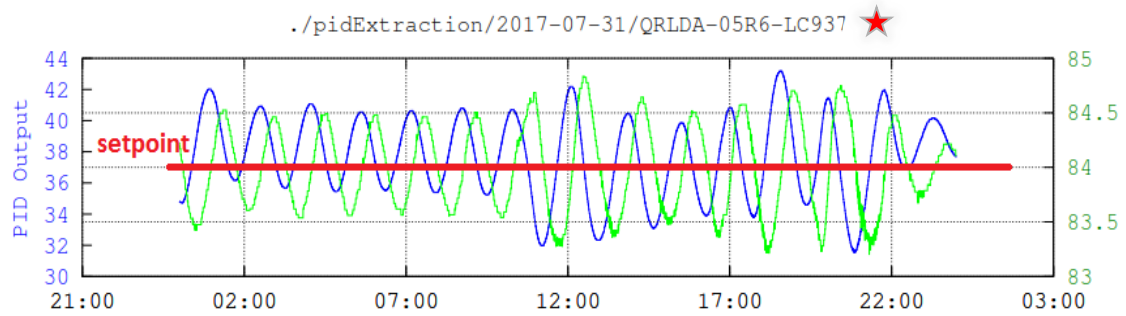
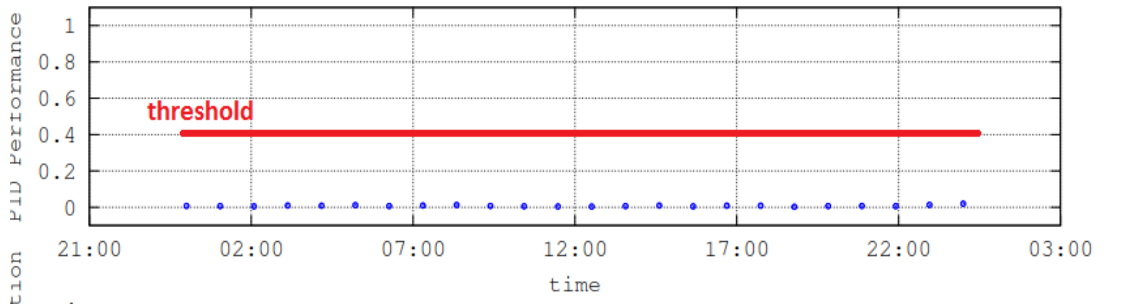
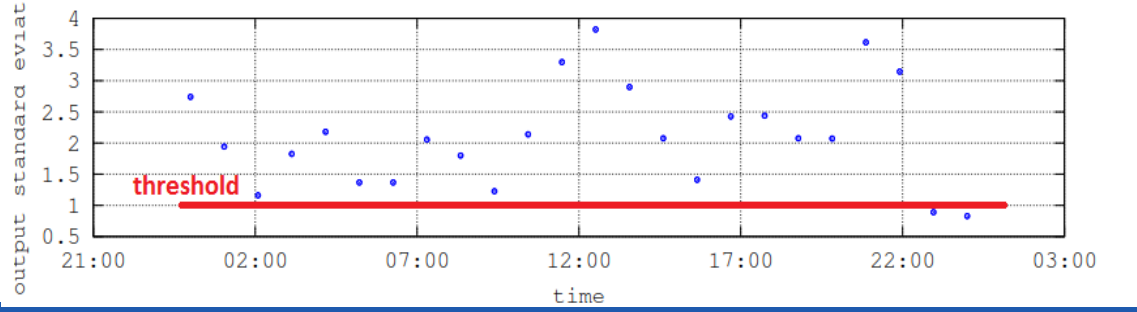
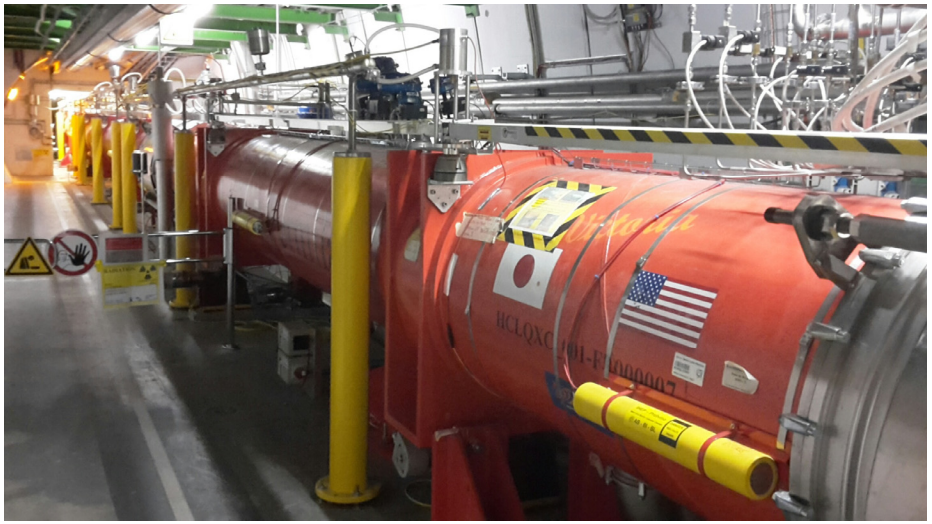


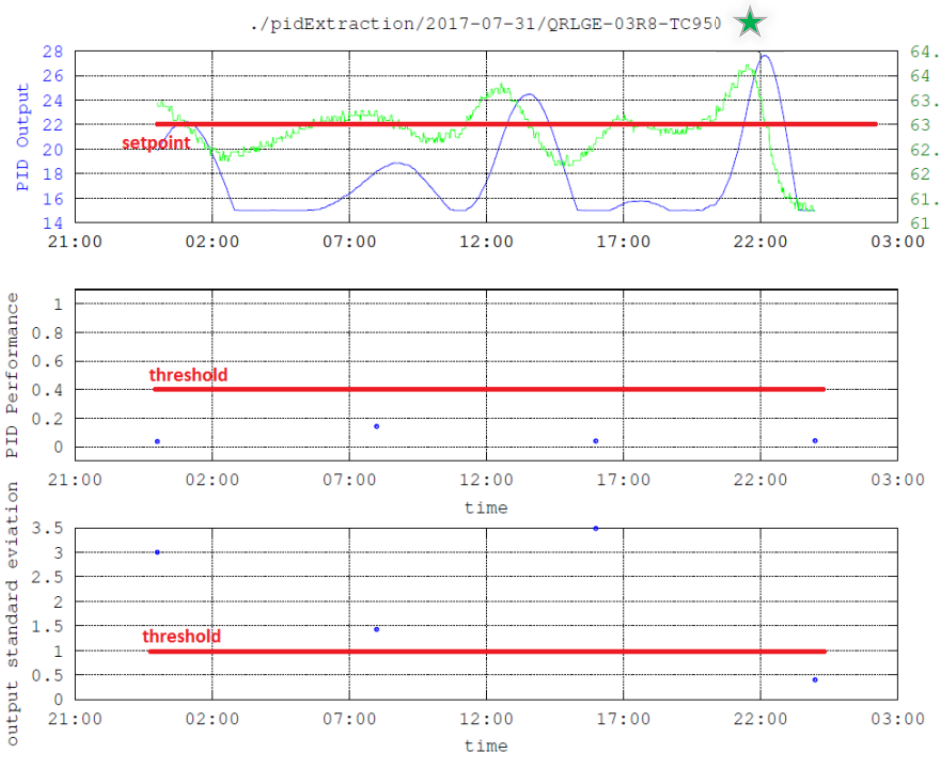




Example of poor tuning: temperature controller

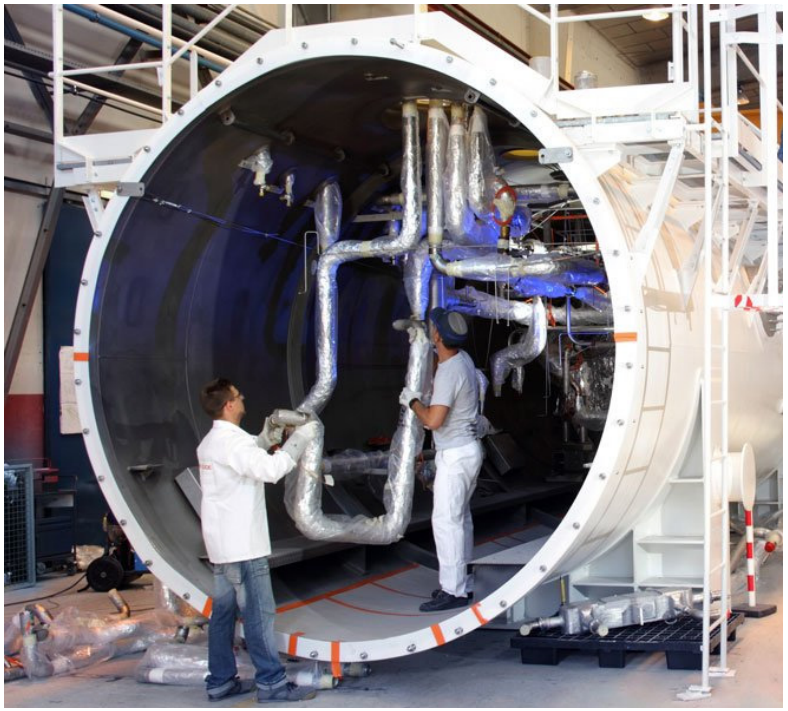
- Thermal shield **temperature controller** for an Inner Triplet superconducting magnet
  - ✓ Reduce the heat load on the cold mass (1.9 K)
  - ✓ Temperature variations induce movement of magnets: misalignment for LHC collisions

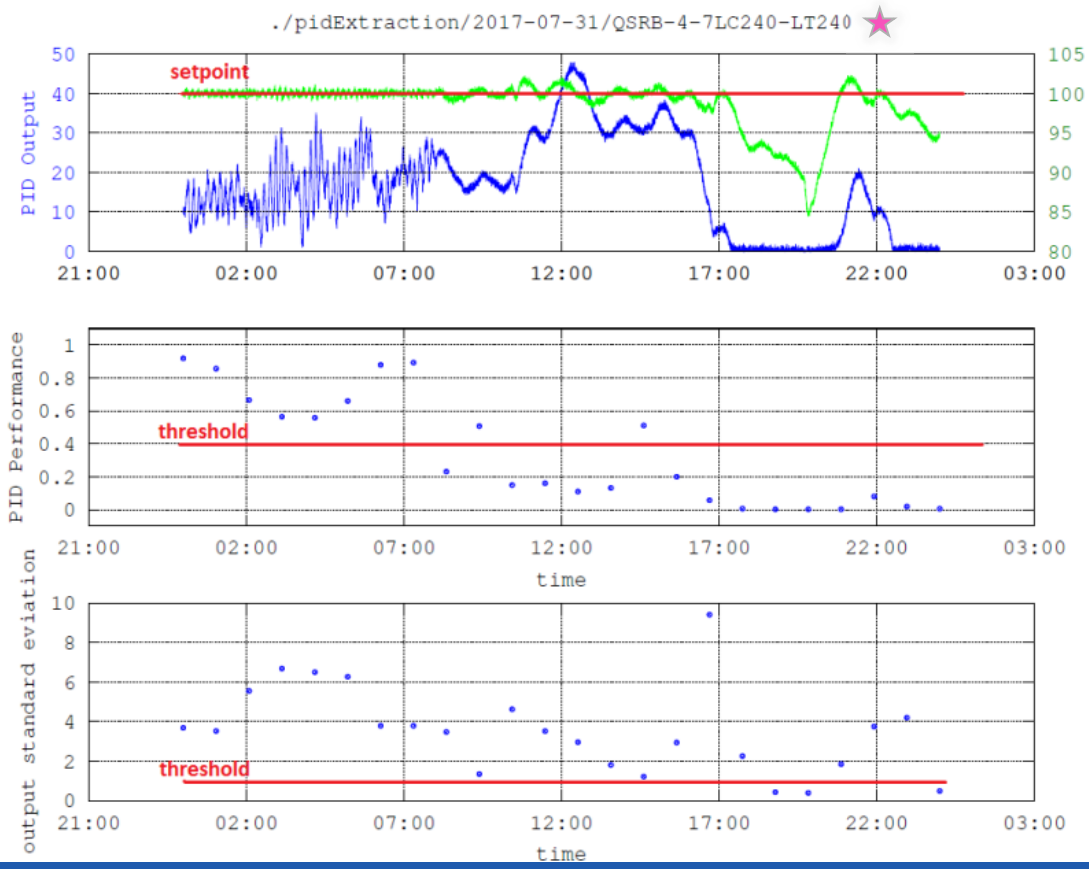




Example of “false positive”

- Liquid helium **level control** in a 4.5 K cryogenic refrigerator
  - ✓ Ensure the good cooling of superconducting magnets





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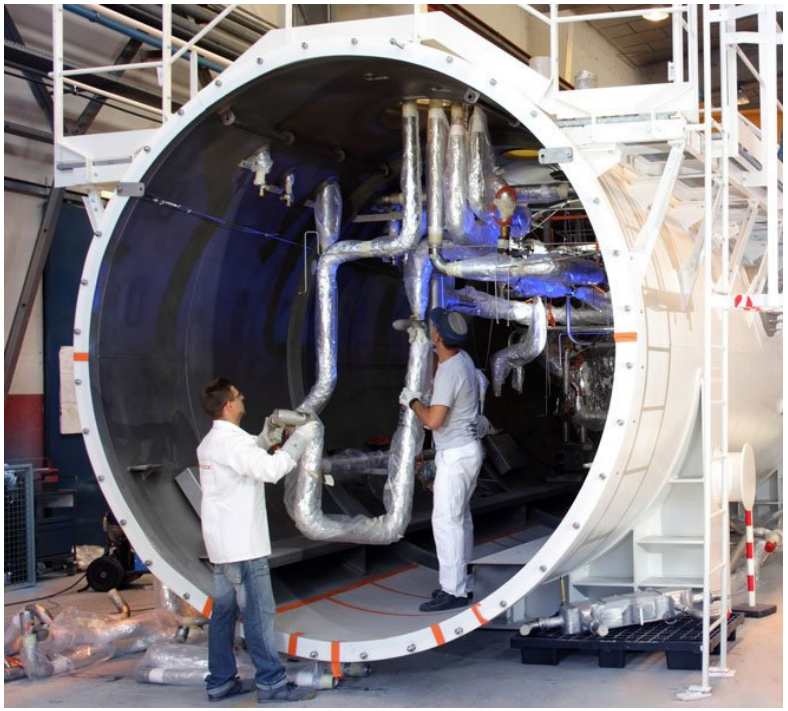
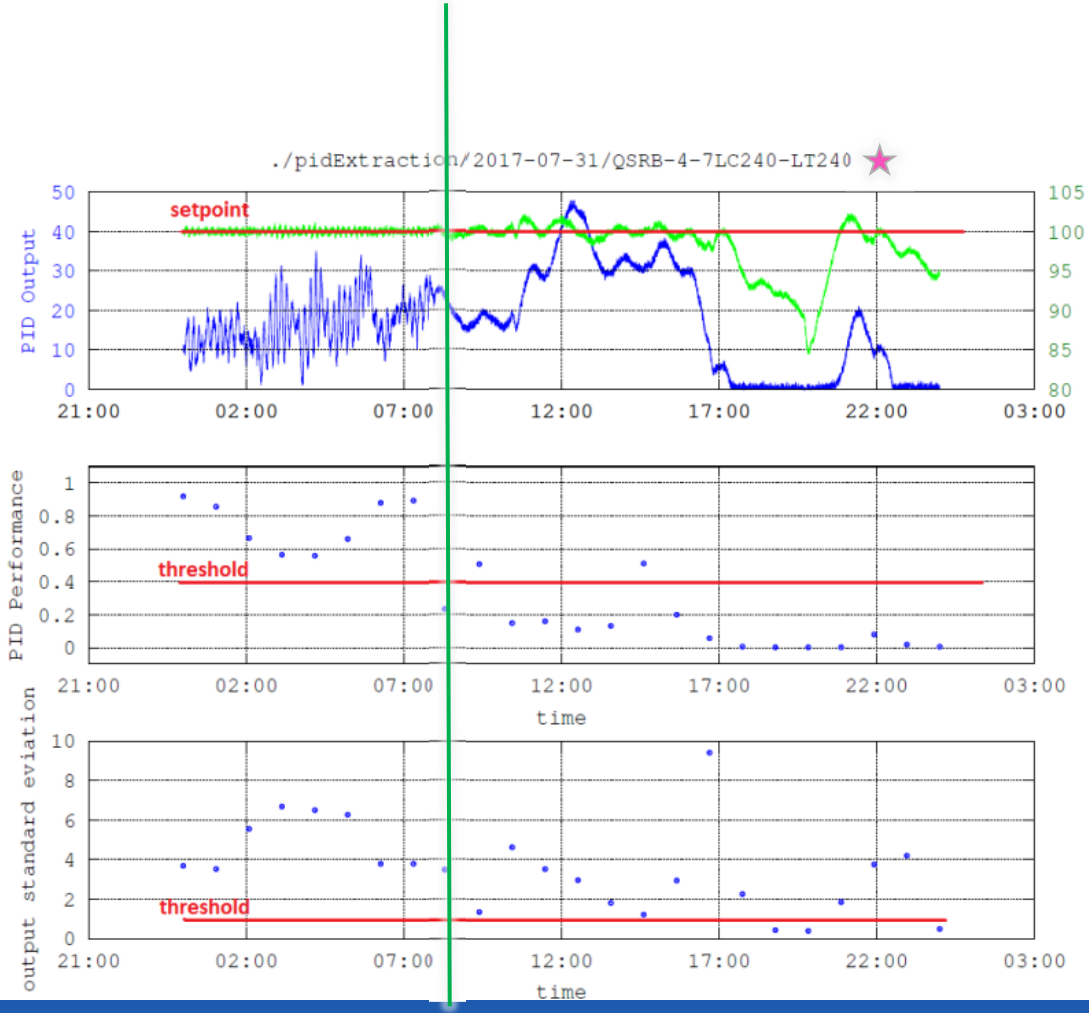


PID parameter modification at 8:30 am



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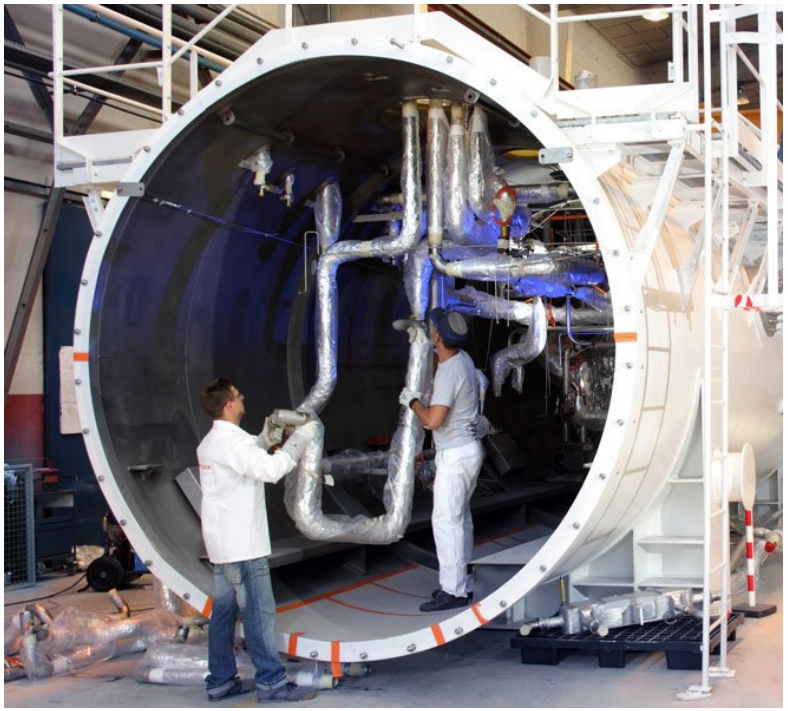
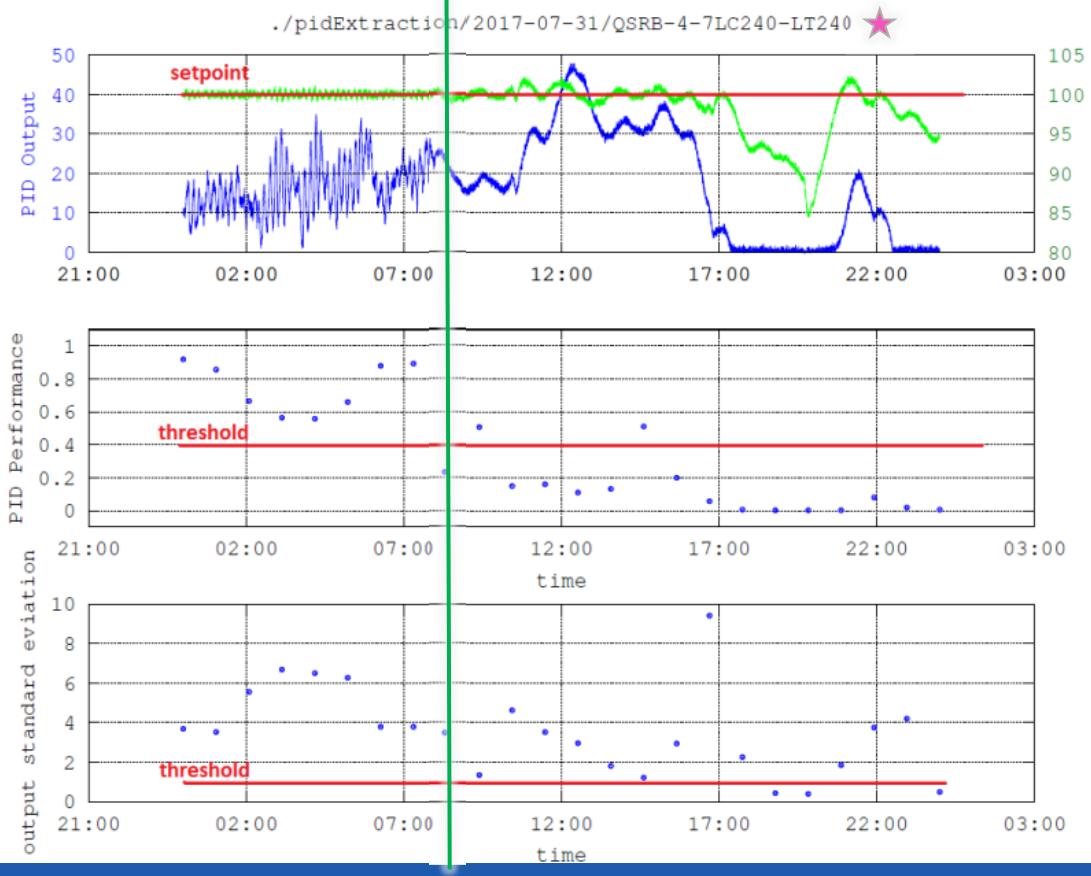


PID parameter modification at 8:30 am

NOK for process operation
OK for PID performance

OK for process operation
NOK for PID performance



Conclusion

- A proof of concept has been setup and validated for PID performance monitoring

- Need to pass to “production”
  - Better user interface should be provided to operators
  - Hadoop cluster can be setup to accelerate computation time

- Algorithm can be still improved
  - Take into account different regulation objectives for dedicated loops
  - Insert some penalties on the actuator movement