Achieving Optimal Control of LLRF Control System with Artificial Intelligence

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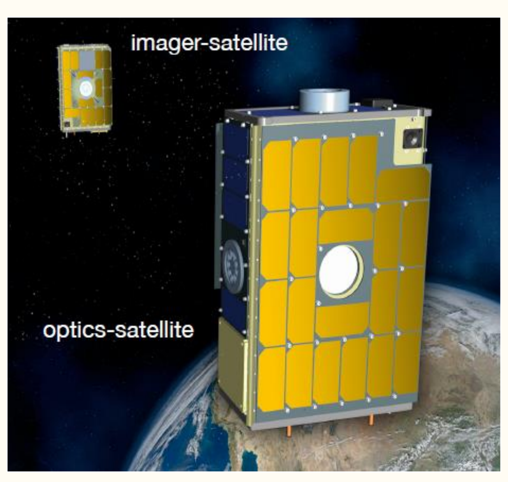
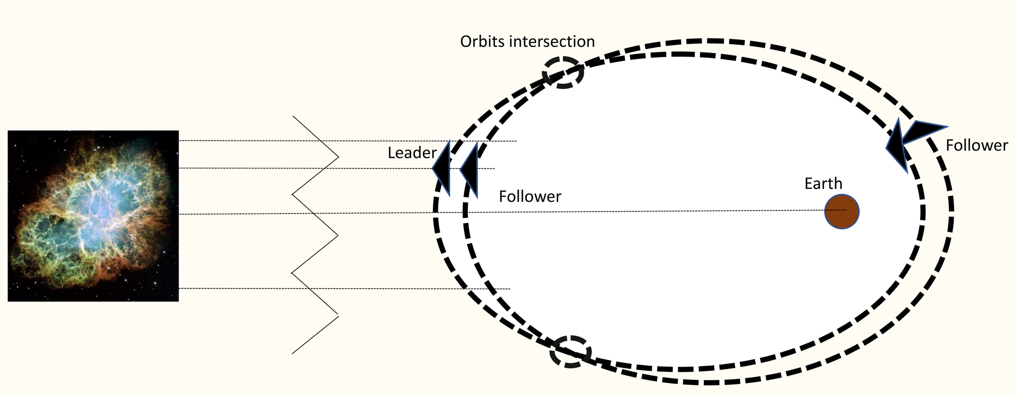
Space Dynamics Laboratory

Space Mission

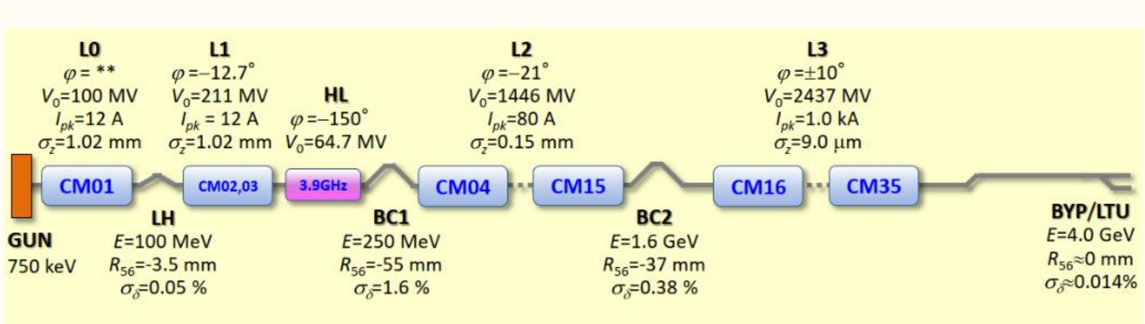
- Virtual Telescope for X-ray Observations
- Attitude formation control with sub-arcsecond accuracy
- Approximately 1 hour observing the Crab Nebula

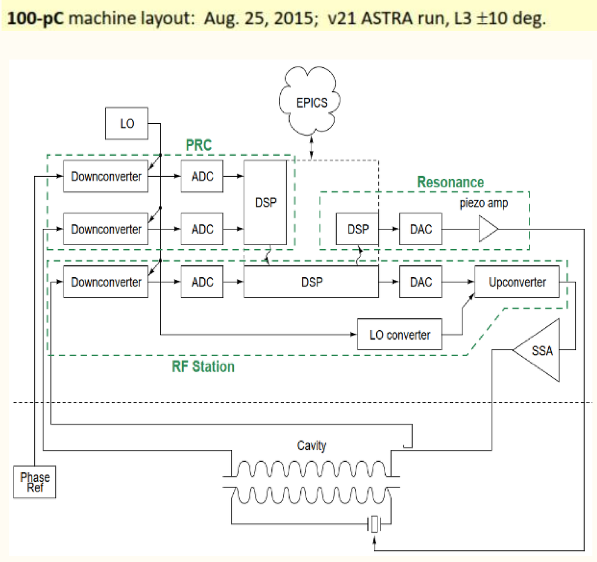
Orbit Design





LCLS-II LLRF & Resonance Control





Motivation

Detuning in superconductive cavities due to microphonics is a challenging problem due to the high-quality factor Q of SRF cavities and tight detuning specifications (around 10Hz of peak detuning). Traditional approaches involve mechanical modifications of the cryomodule/cavity environment and active resonance control techniques. In this research we explore novel control architectures using machine learning as a tool to improve control performance.

Sensors

Gyroscope

Sensing the angular velocity with noises included

Star Tracker

Sensing the angle of the satellites

Cavity Probe

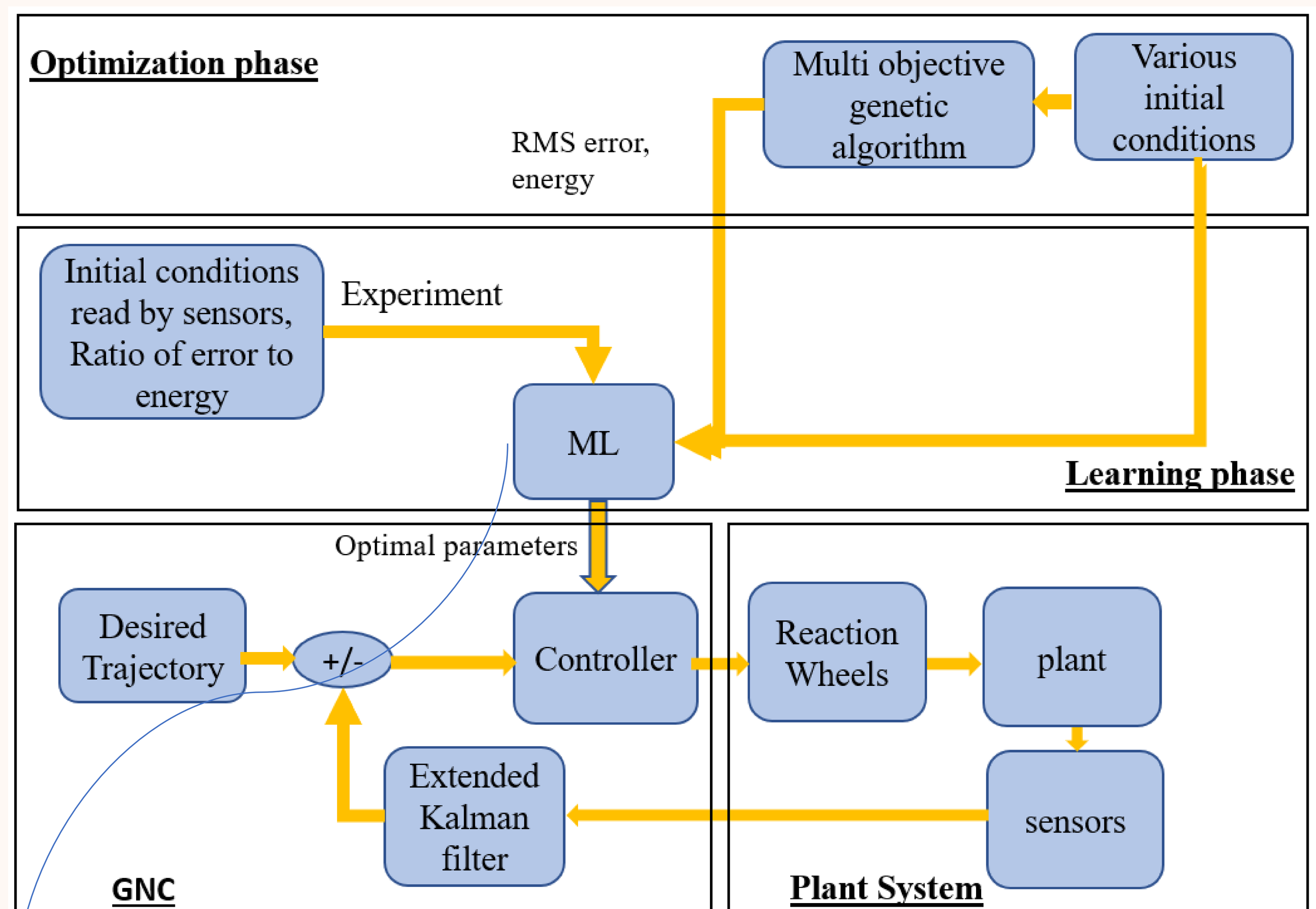
Controllers

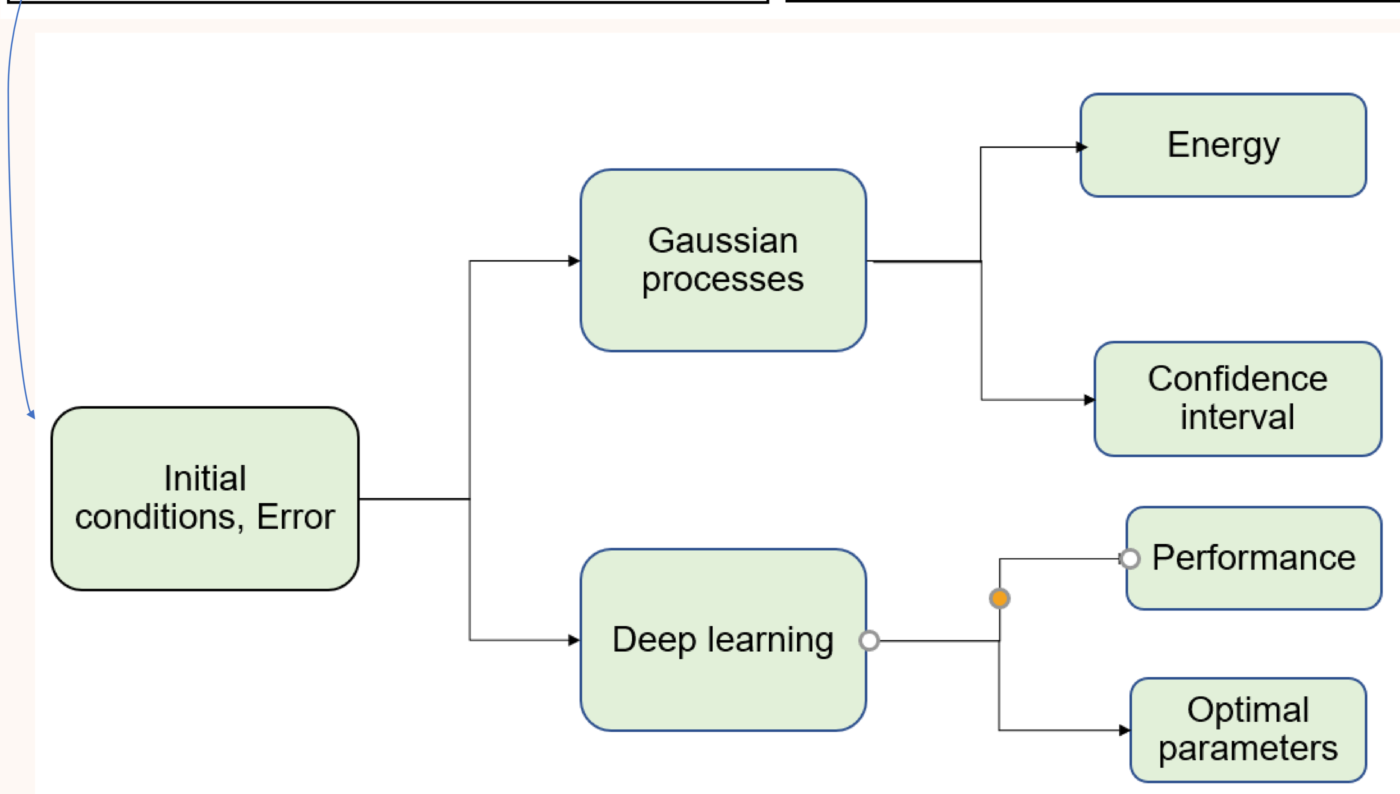
	Robust against dynamical disturbances	Linear vs Nonlinear
Sliding Mode Controller	Guaranteed	Nonlinear
PID Controller	Not Guaranteed	Linear and Nonlinear
Anti Gravity Gradient Torque	None	None

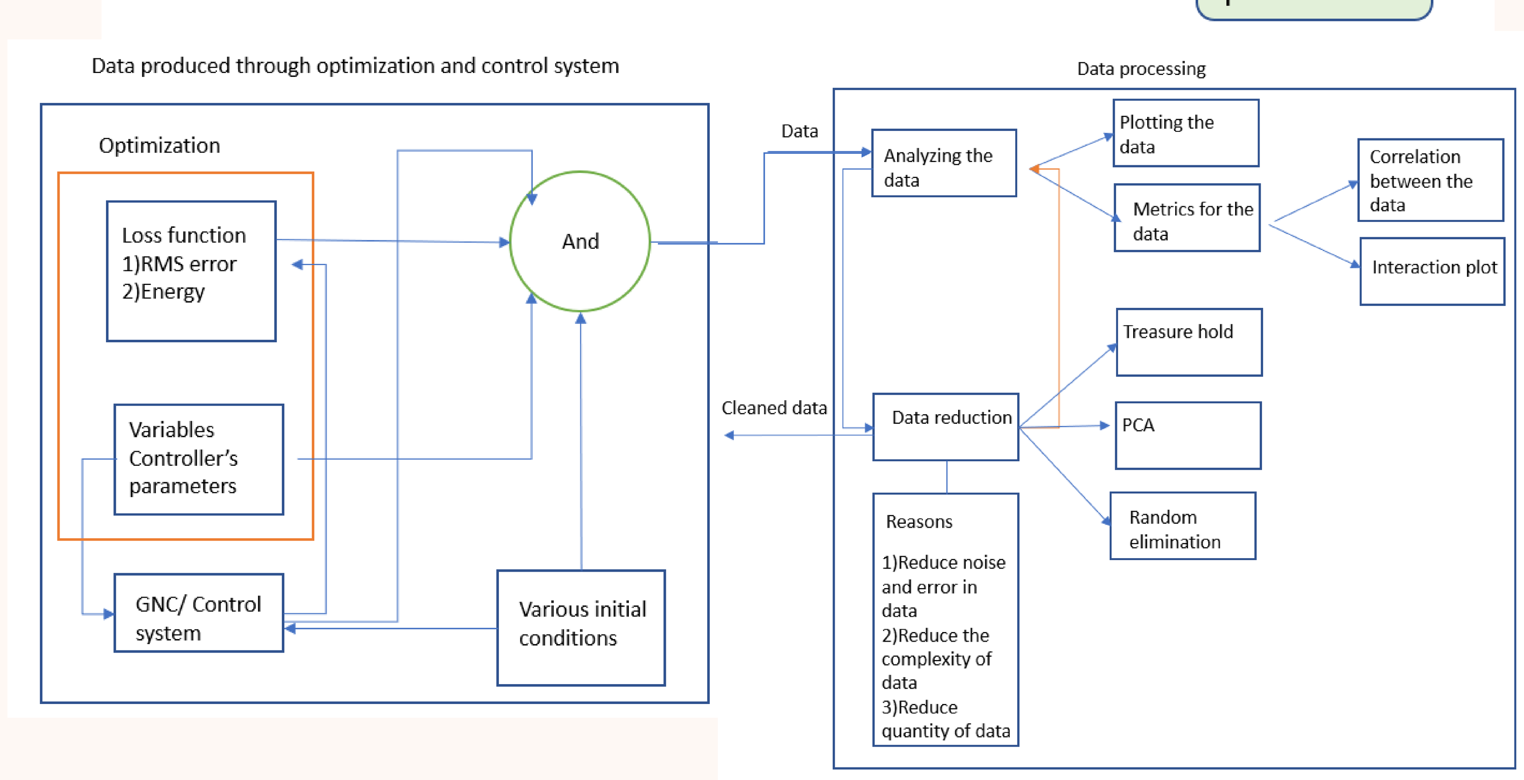
Actuator

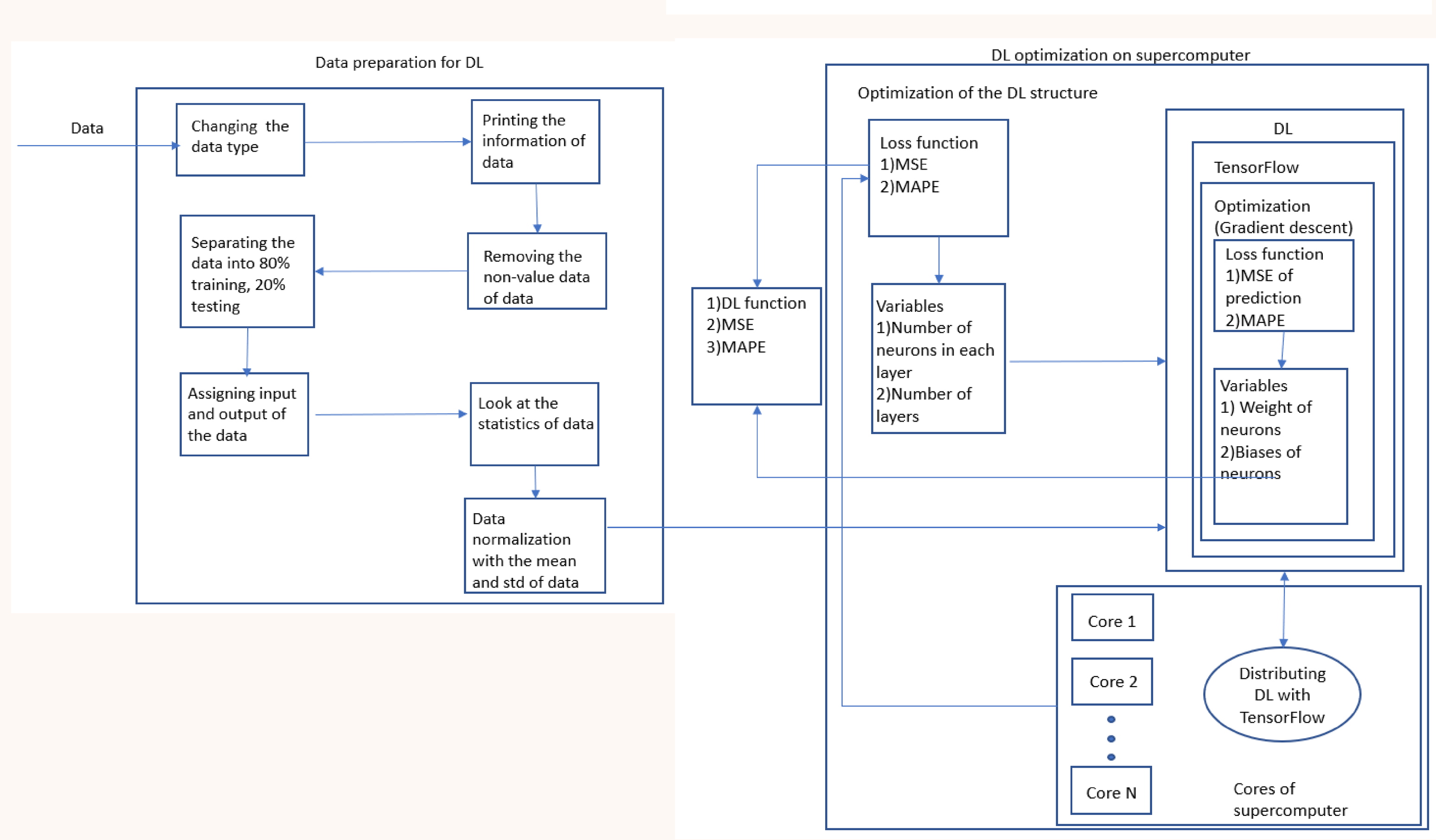
- Reaction wheels
- Thrusters
- Piezo electric
- Stepper motor

Artificial intelligence framework









Simulation

1) VTXO model

Quaternion models, Sensors, actuators, GNC, and noises

2) LLRF

The CryoModule-On-Chip (CMOC) is a simulation engine developed at LBNL to model LLRF and beam-based feedback systems for Linac- driven FELs.

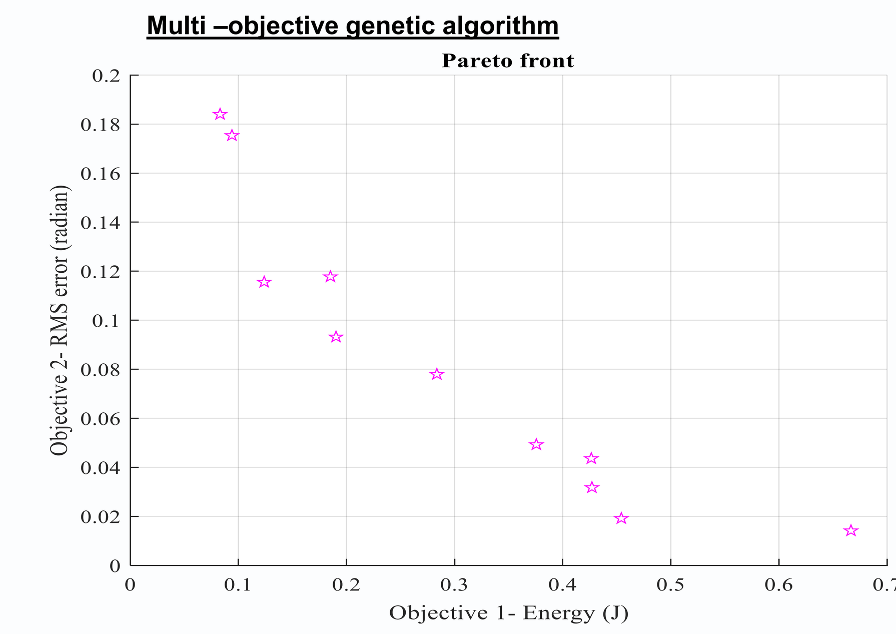
cavities (with electromagnetic eigen-modes), of RF stations (RF source + Cavity + FPGA Controller)

cryomodules (Piezo tuners + RF Stations + mechanical modes)

Linac sections (cryomodules + bunch compressor)

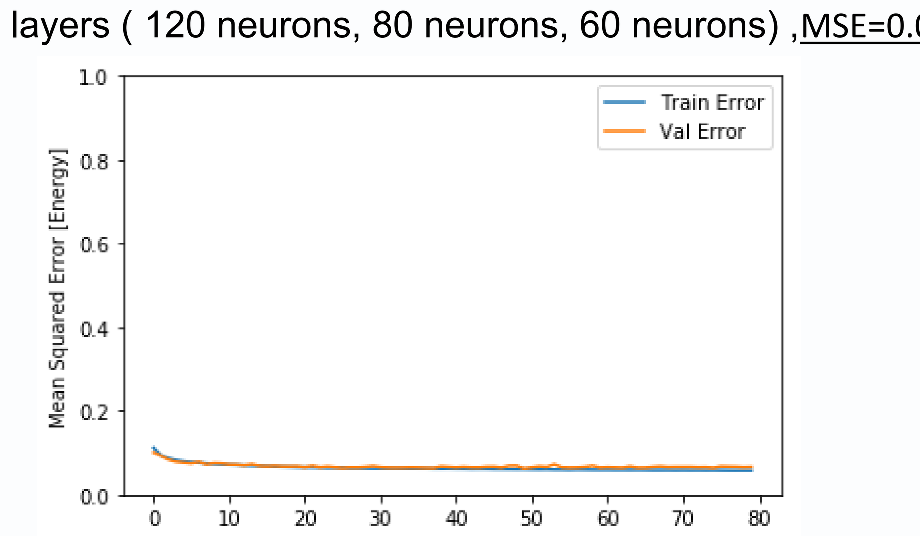
beam instrumentation, loop delays and sources of noise

Optimization

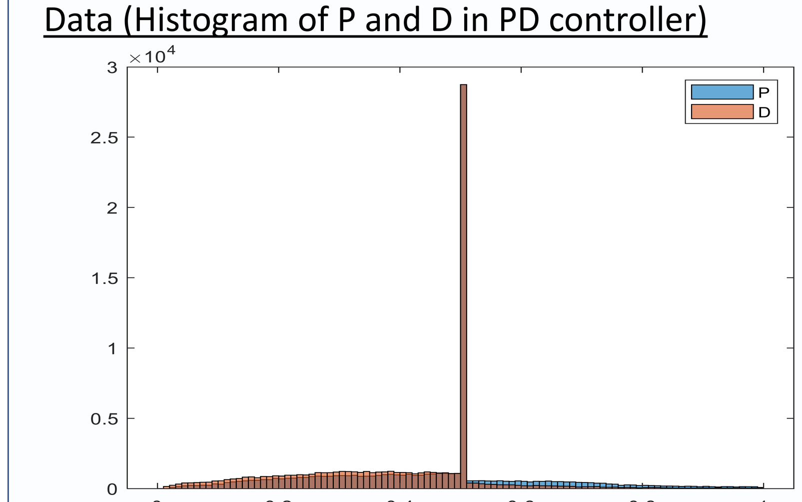


Deep learning

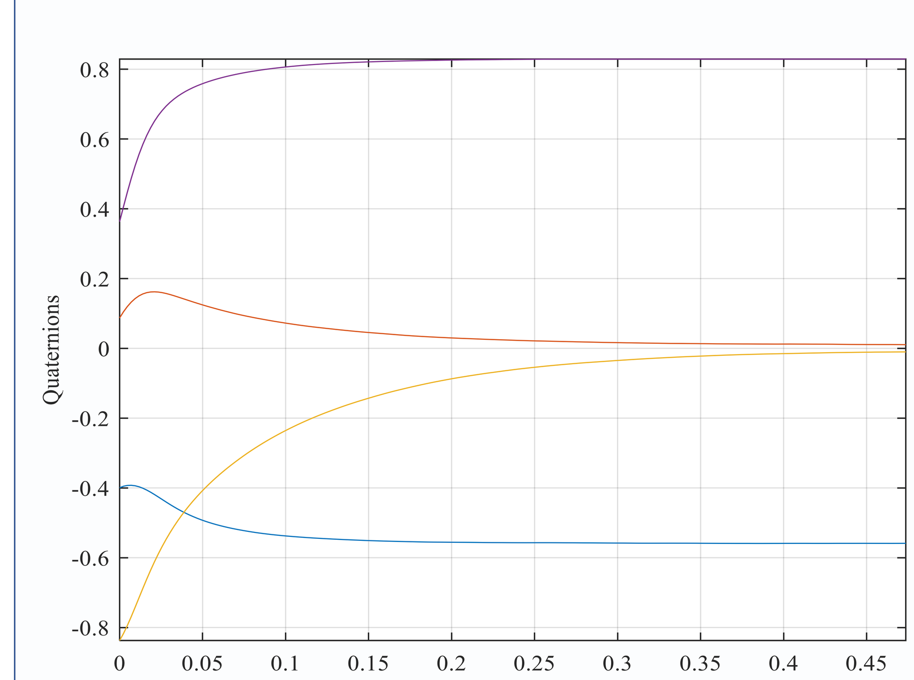
4 layers (120 neurons, 80 neurons, 60 neurons) ,MSE=0.07



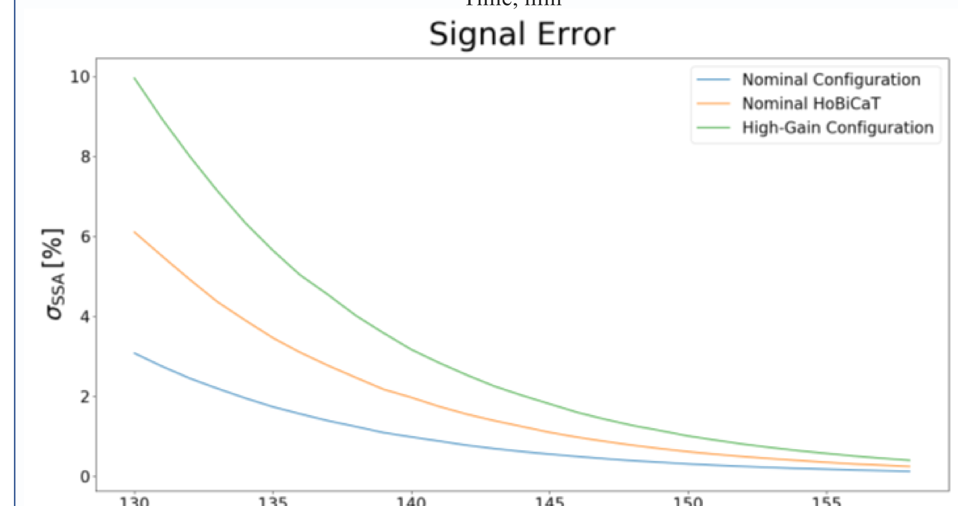
Data (Histogram of P and D in PD controller)



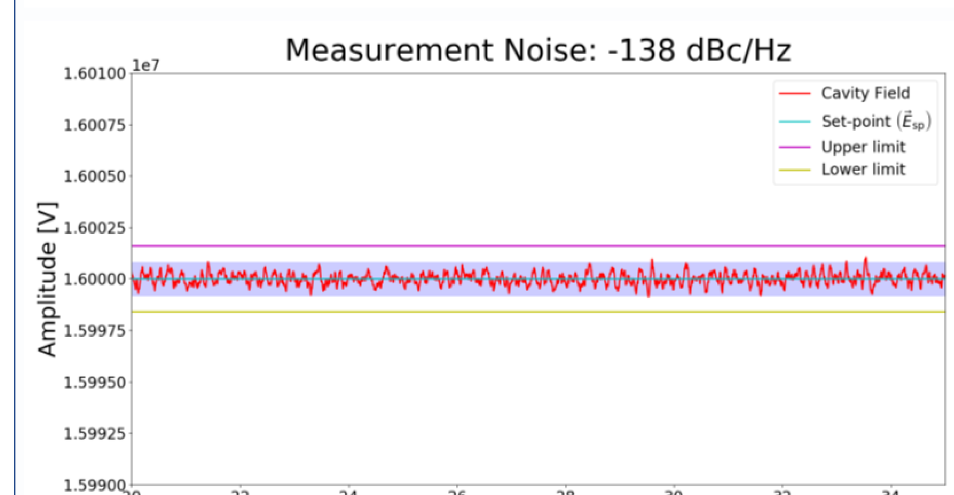
Results



Signal Error



Measurement Noise: -138 dBc/Hz



Future work

1) Producing data for the microphonics problem
2)Applying AI based controller
3)Include an optimal estimation of the LLRF to the control system and apply sensor fusion algorithms