



Supervisory Agents

Speaker: Jordan “Jay” Roberts

Special Thanks: UVA Spin Group



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Outline

● Scope

● Project Requirements

● Update



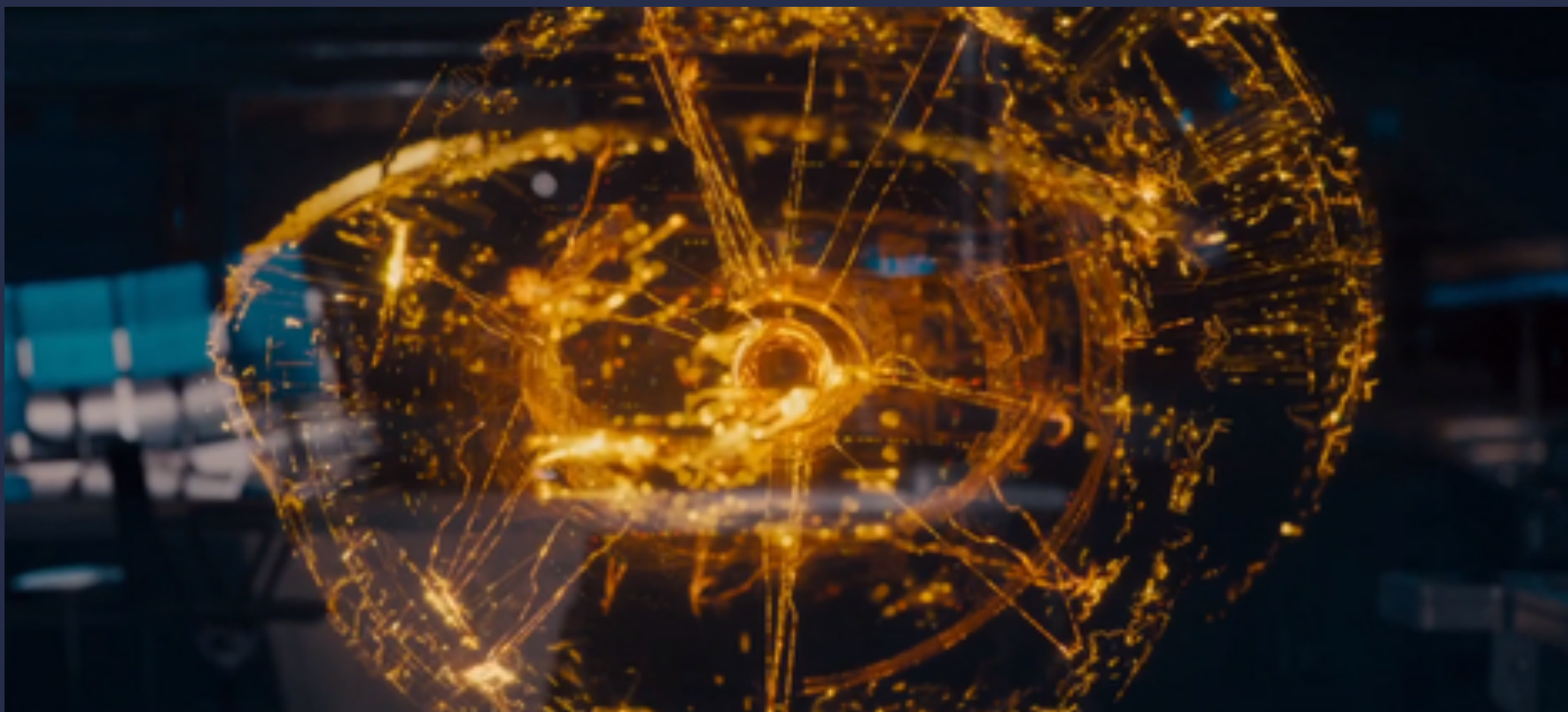
Vision


An experimental setup that monitors itself for anomalous behavior and provides domain level feedback for optimal performance.




A human-in-the-loop system of agents that performs in lab tasks under the management of a supervisory agent.

Different levels of control, Autonomous to Manual, that prioritize safety first.


Optimize performance and recover from faults.

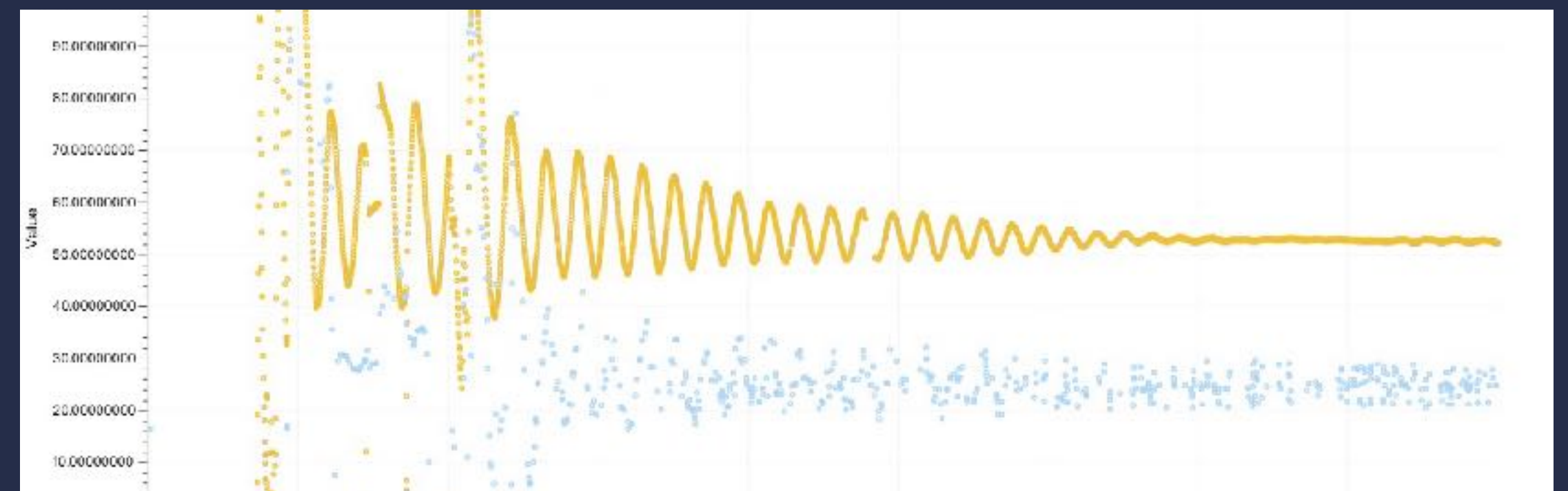


 **UVA_LAB** 8/5/25, 5:05 PM
!Update

 **MessageBotUVA APP** 8/5/25, 5:05 PM
 **Automated System Status Update** 

- Dewar Pressure: 9.14
- Inlet Pressure: 11.06
- Avg ColdHead Temp: 4.45
- Inlet Flow: 58.15
- Outlet Flow: 2.16
- Liquid Helium: 67.32%
- Helium Purity: 100.001%
- ColdHead Alert: False
- LN2 Alert: True
- Data Alert: False

 **UPDATE:** The purifier has been refilled!



Lead With Monitoring-End With Control

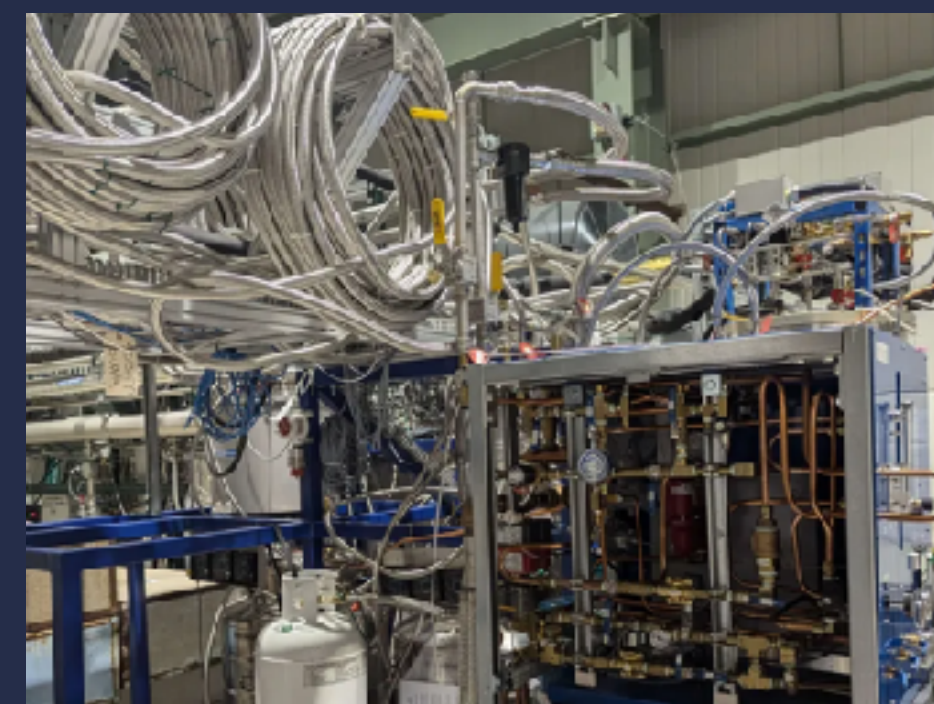
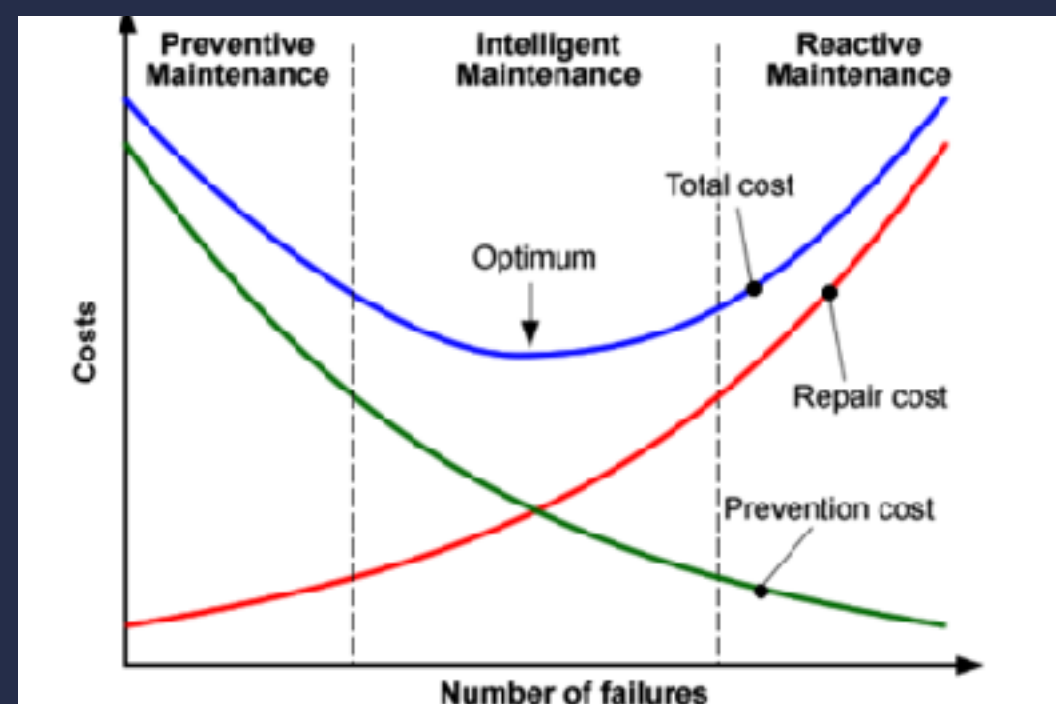
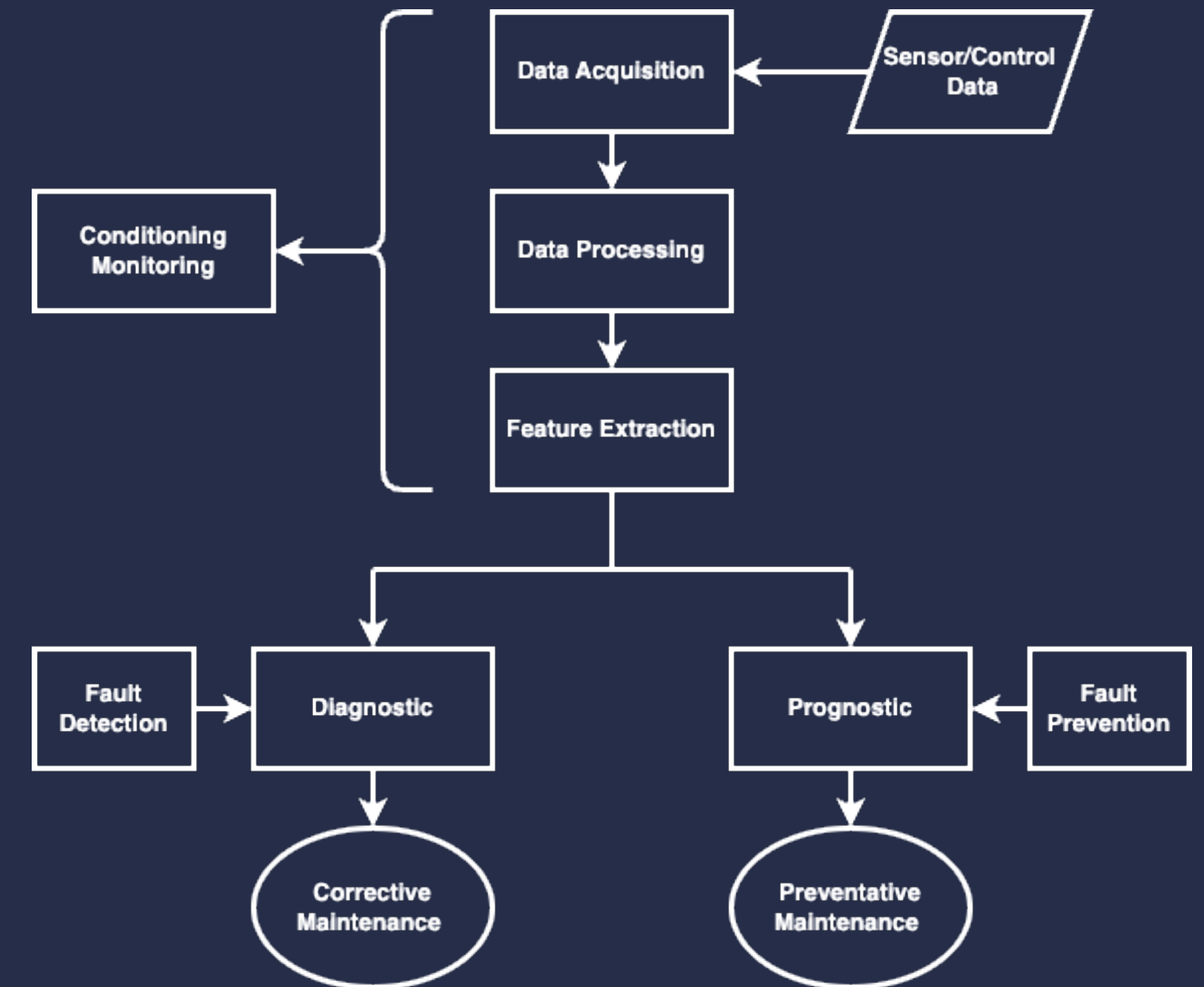
Modern experiments are complex systems with several coupled subsystems.

This problem is a current concern in industry with applications such as chemical processing or hydraulic systems.

Fault detection systems are driven from concerns of safety, efficacy, and costs. Decrease Mean Time to Repair.

Remote control is critical for systems that have access limits

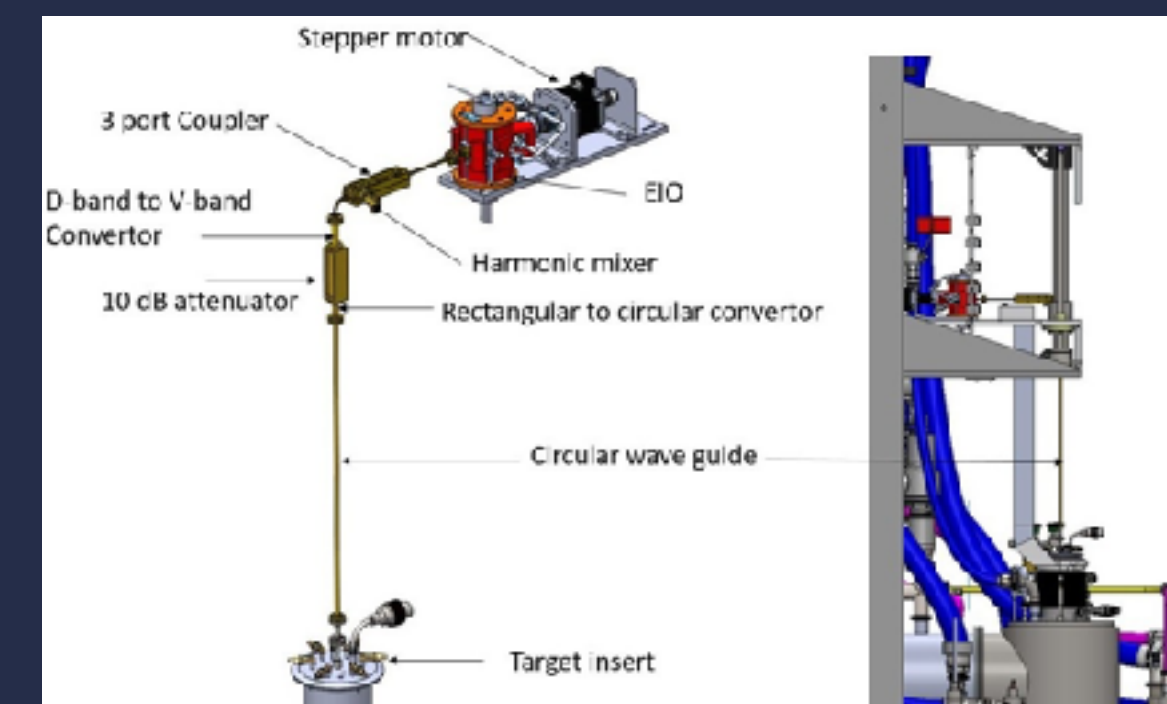
Classical solutions are statistical methods and rules based control, but a trend towards machine learning has been growing in the past decade.



Liquefier



Detectors



Controls

Why Does This Matter For Physics?

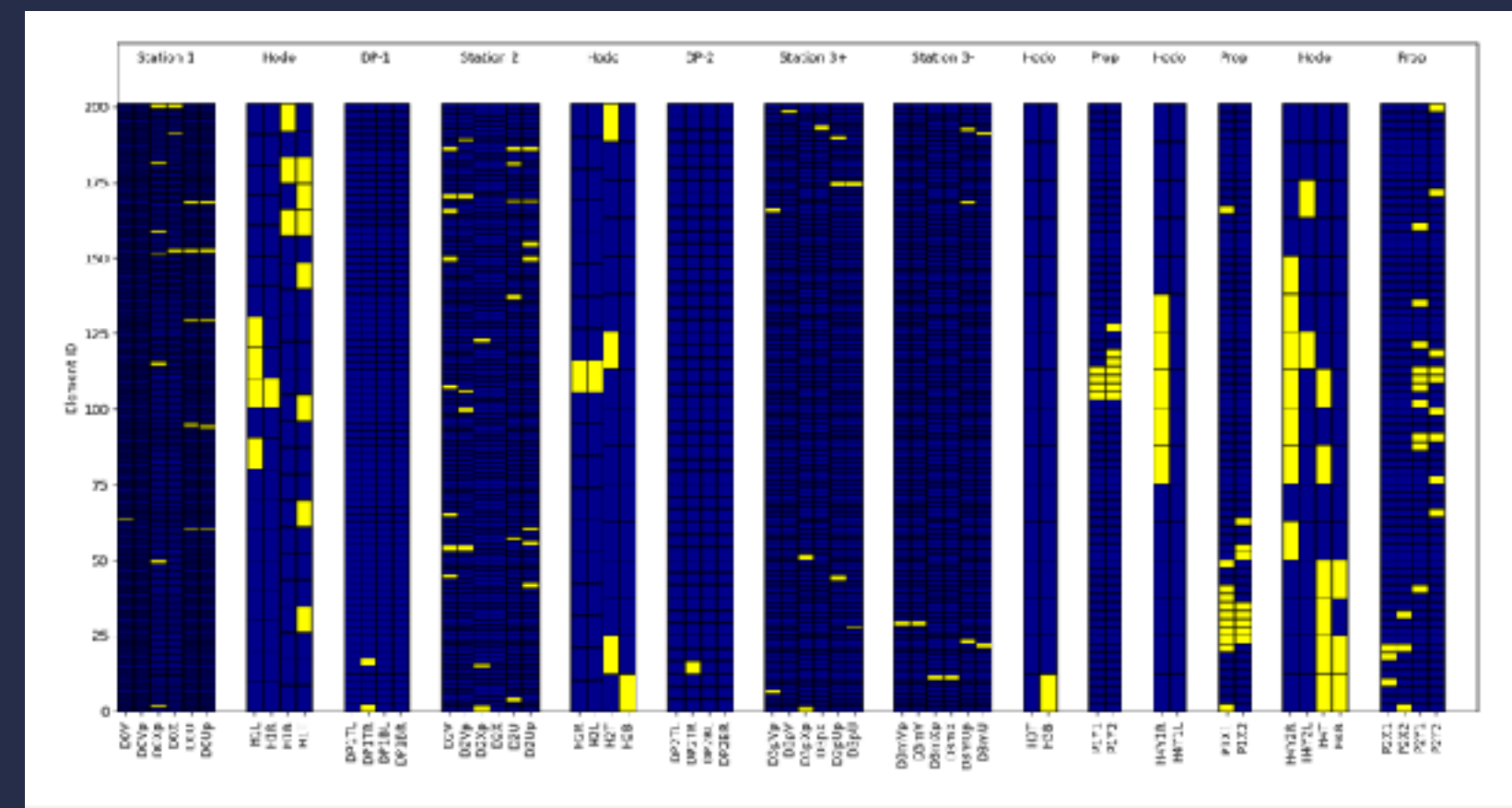
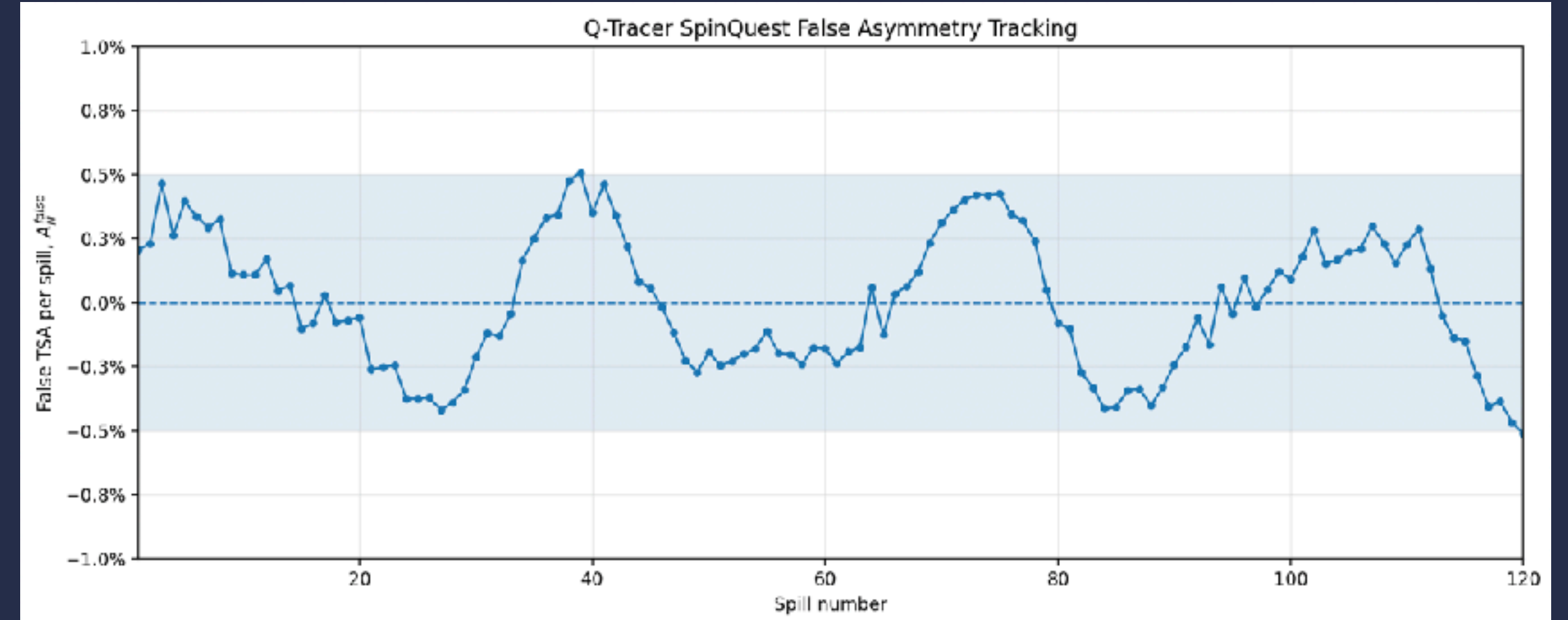
Real time anomaly detection to increase the figure of merit. Soft Sensors to detect False Asymmetries

Reliable control systems to maintain stable polarization and fast ramp up. Microwave and cryo control.

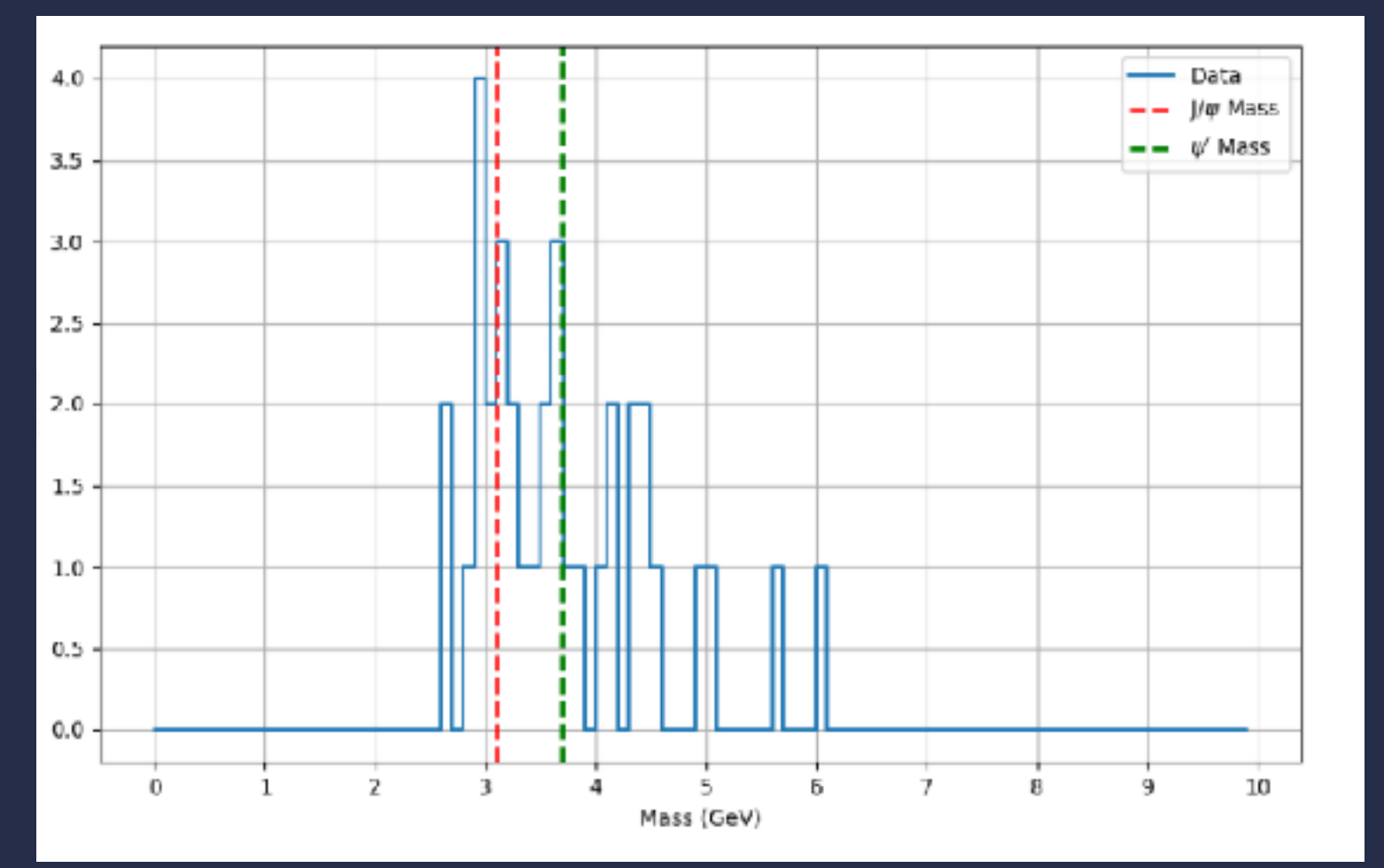
Minimize hall access and maximize planning for recovery.

Fast asymmetries in real time using AI.

To the best of our knowledge SpinQuest was the first experiment to implant fast AI driven spin asymmetry measurements in real time providing false asymmetry tracking during data collection.



$$A_N^{false} = \frac{1}{\langle P \rangle f \eta} \frac{\sqrt{N_L^\uparrow N_R^\downarrow} - \sqrt{N_L^\downarrow N_R^\uparrow}}{\sqrt{N_L^\uparrow N_R^\downarrow} + \sqrt{N_L^\downarrow N_R^\uparrow}}$$



Importance of Control

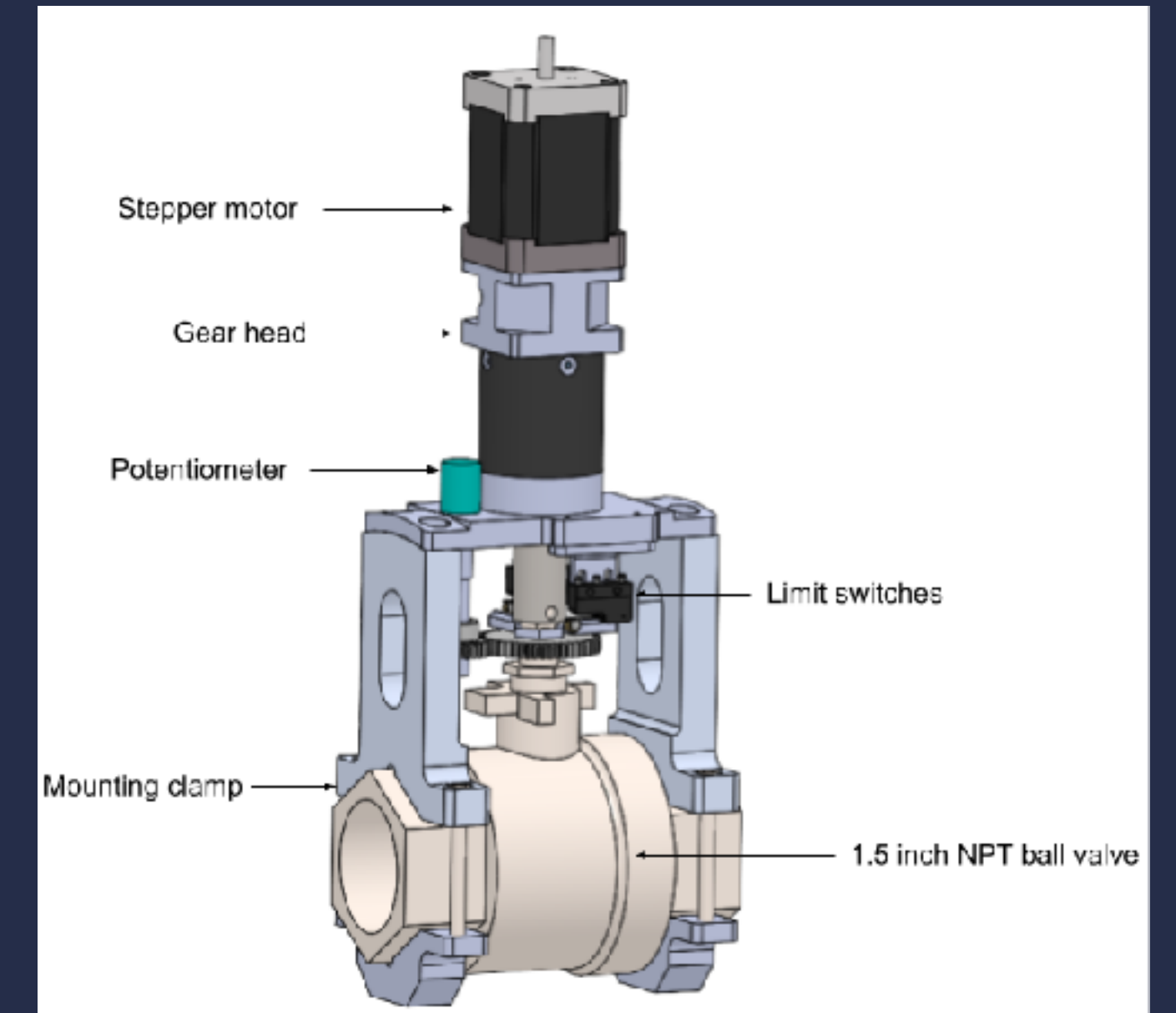
Paired with a robust monitoring system. Faults can be diagnosed and promptly acted on. With actuator the solution could be enacted remotely at different levels of autonomy.

The microwave is a prime example of a device controlled using a control loop. However, this can be extended to cryogenics. Flow Management.

Using incoming and historical data, we can perform optimal control or agentic control to optimize performance or obtain certain outcomes.

Digital twins could be used to predict the current state of the system and update its prediction based on incoming data in a bayesian formalism.

Sensor fusion can be used to combine data from multiple sensors to increase accuracy.



$$P(1/2) = \tanh \frac{g\mu B}{2k_b T}$$

Agents

Large Language Model: A model that is used for generalized natural language processing using a transformer architecture and large unlabeled training data. Excellent for summarization.

Transformers use attention mechanisms to develop context between tokens. Encoding/Decoding these tokens in parallel.

These models can be fine tuned using supervised learning to provide less general but domain specific generated response.

LLM: Query → Generate → Respond

Compound Systems: Query → Search →  → Generate → Respond

Agentic Systems: Query → Planing → Act → Observe → Respond

Tools → Act

Observe → Tools

Observe → Planing

Project Requirements

Cycle UHP helium for an extended period of time (multiple days).

✓ Recover and store helium.

✓ Run at a variety of flows (10 - 150 SLM) at a variety of pressures (1-15 psi).

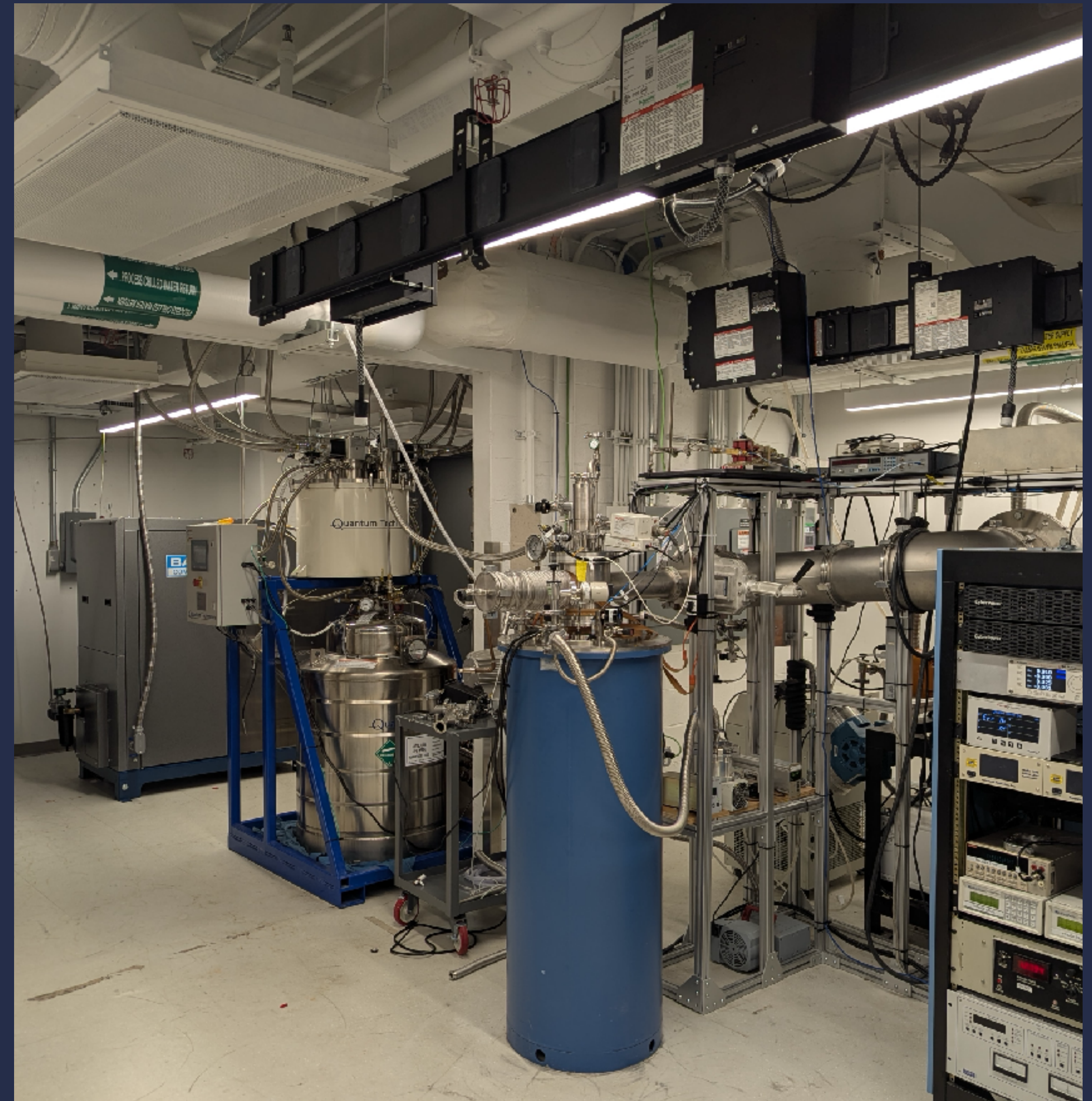
✓ Continuous monitoring of the system.

Control of: Microwaves, fridge valves, pumps, and QT.

✓ Storage and retrieval of data.

Optimize control and monitoring.

Aiming for a cooldown in July.



Purifier: Prototype

We designed a low cost solution that can handle the flow and contamination level.

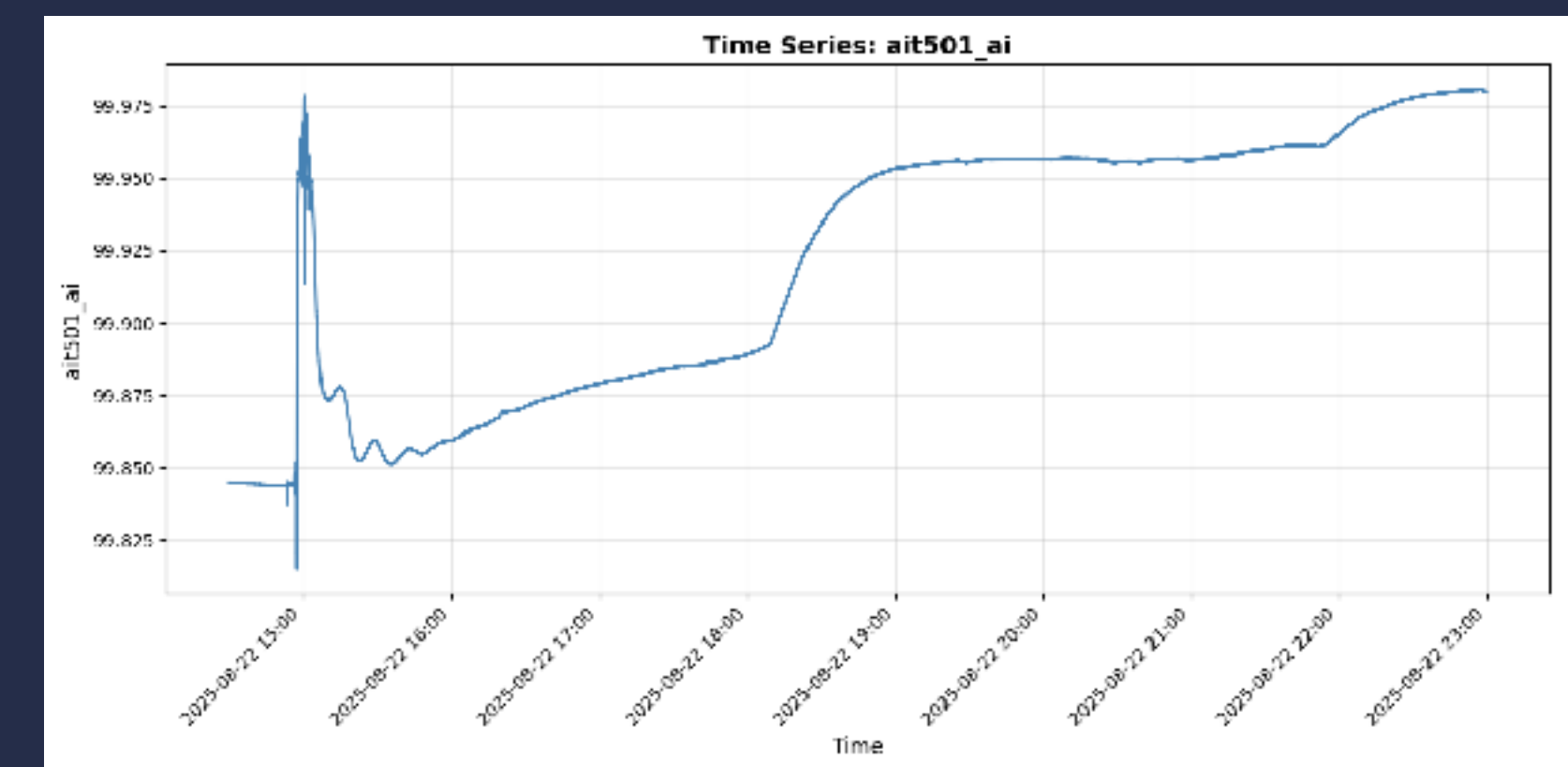
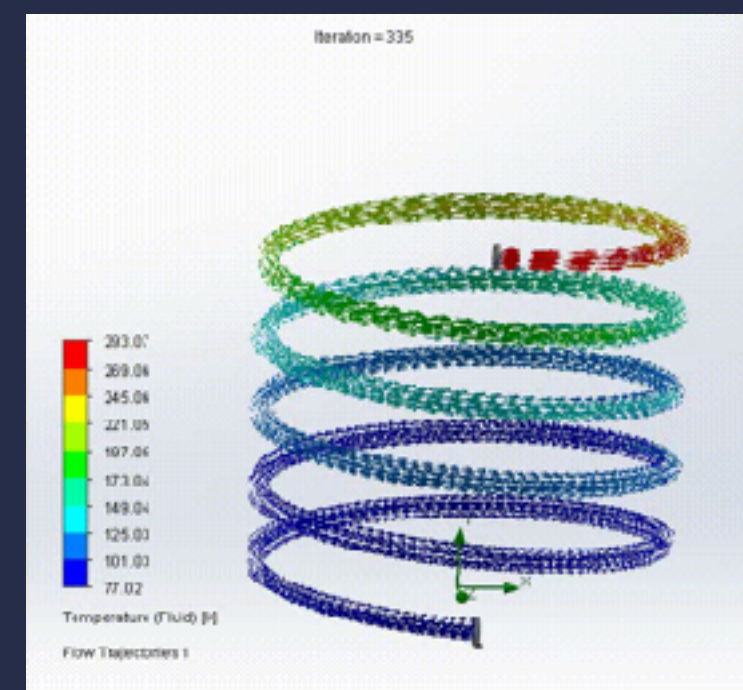
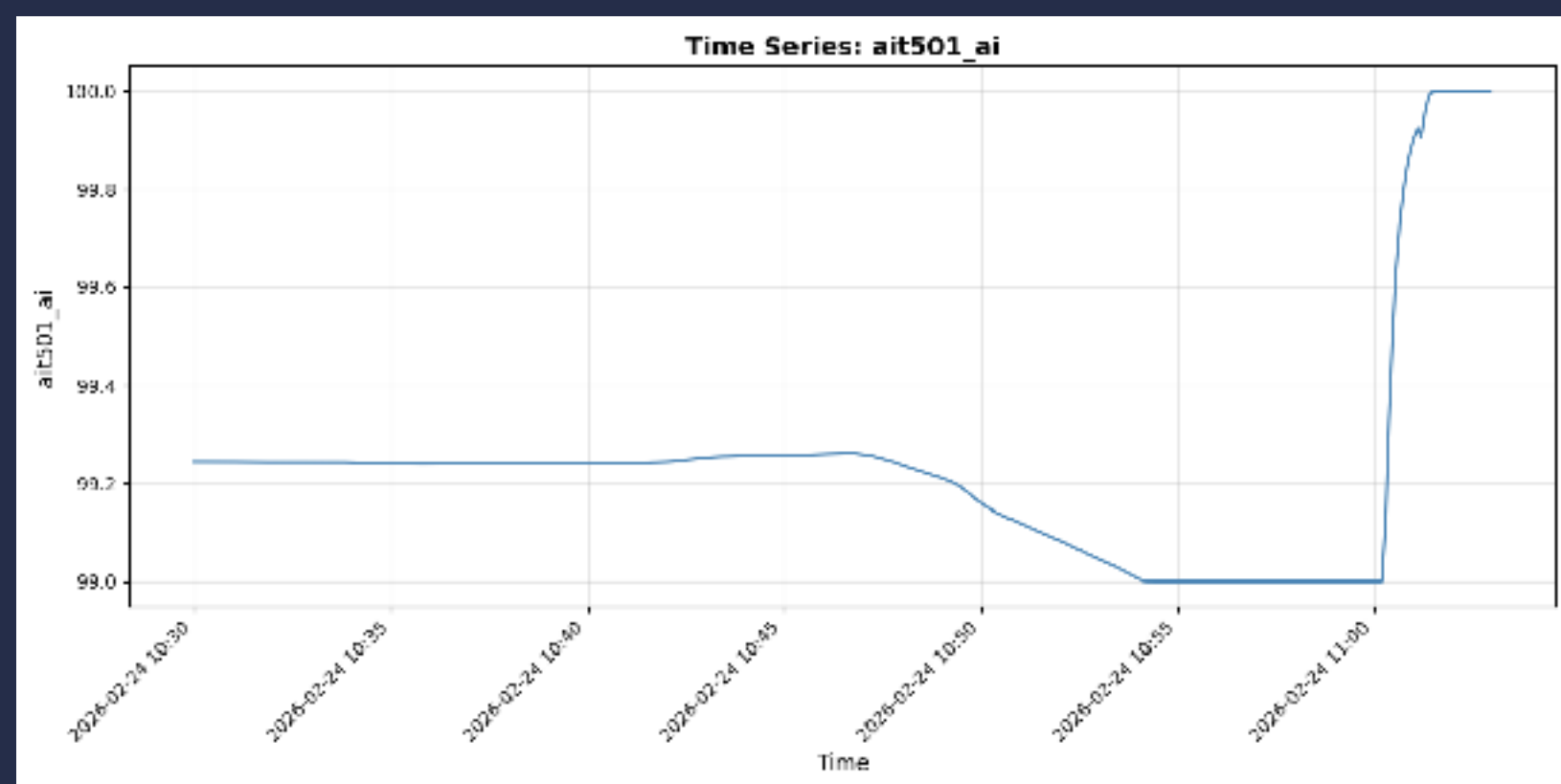
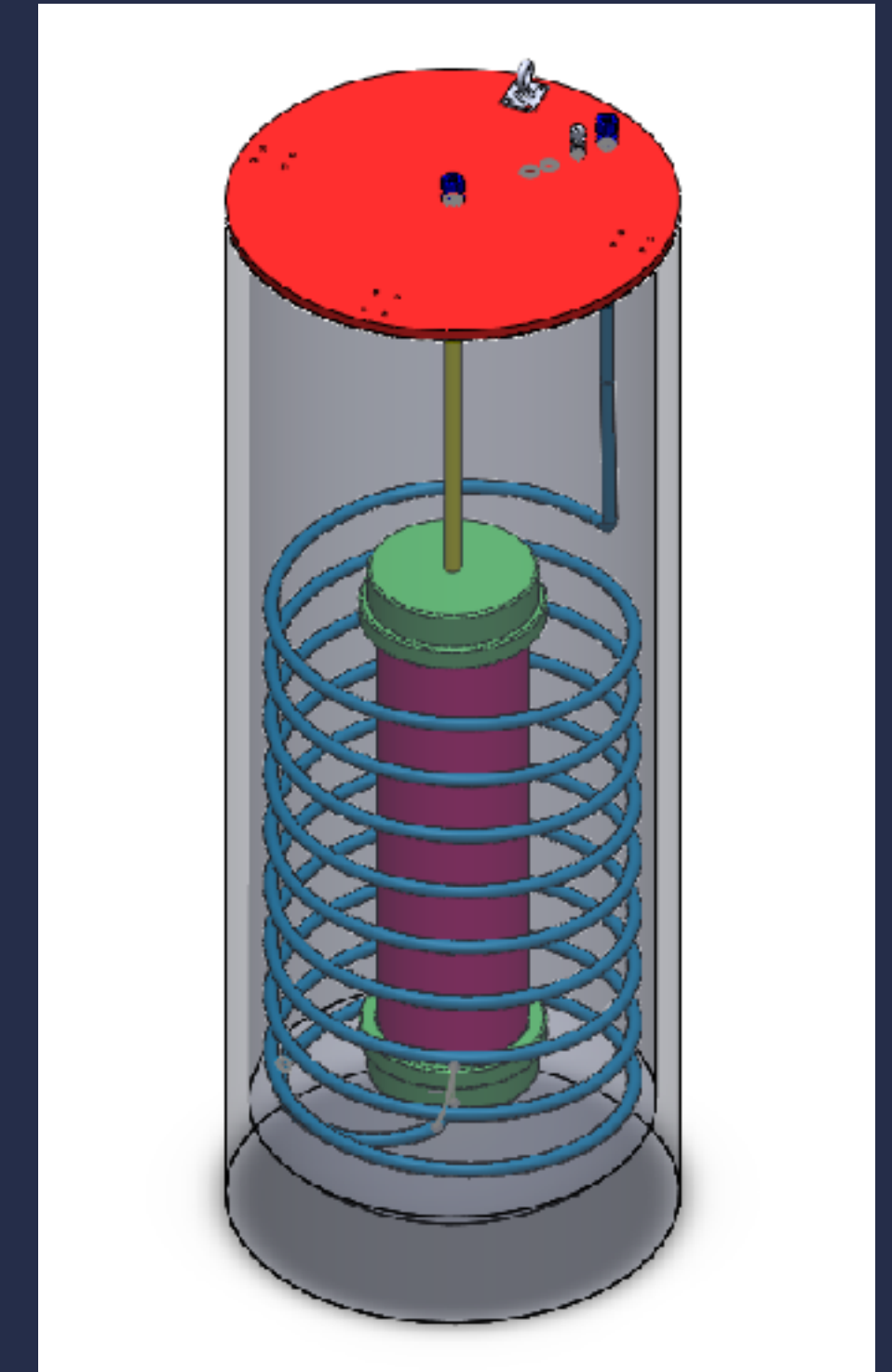
Used Polanyi potential theory to model the adsorption process of carbon to calculate the size of the bed required.

Used a coil heat exchanger to bring the high flow helium down to In2 temperatures.

A vaporizer to increase the exit temperature.

A gas dryer to remove moisture.

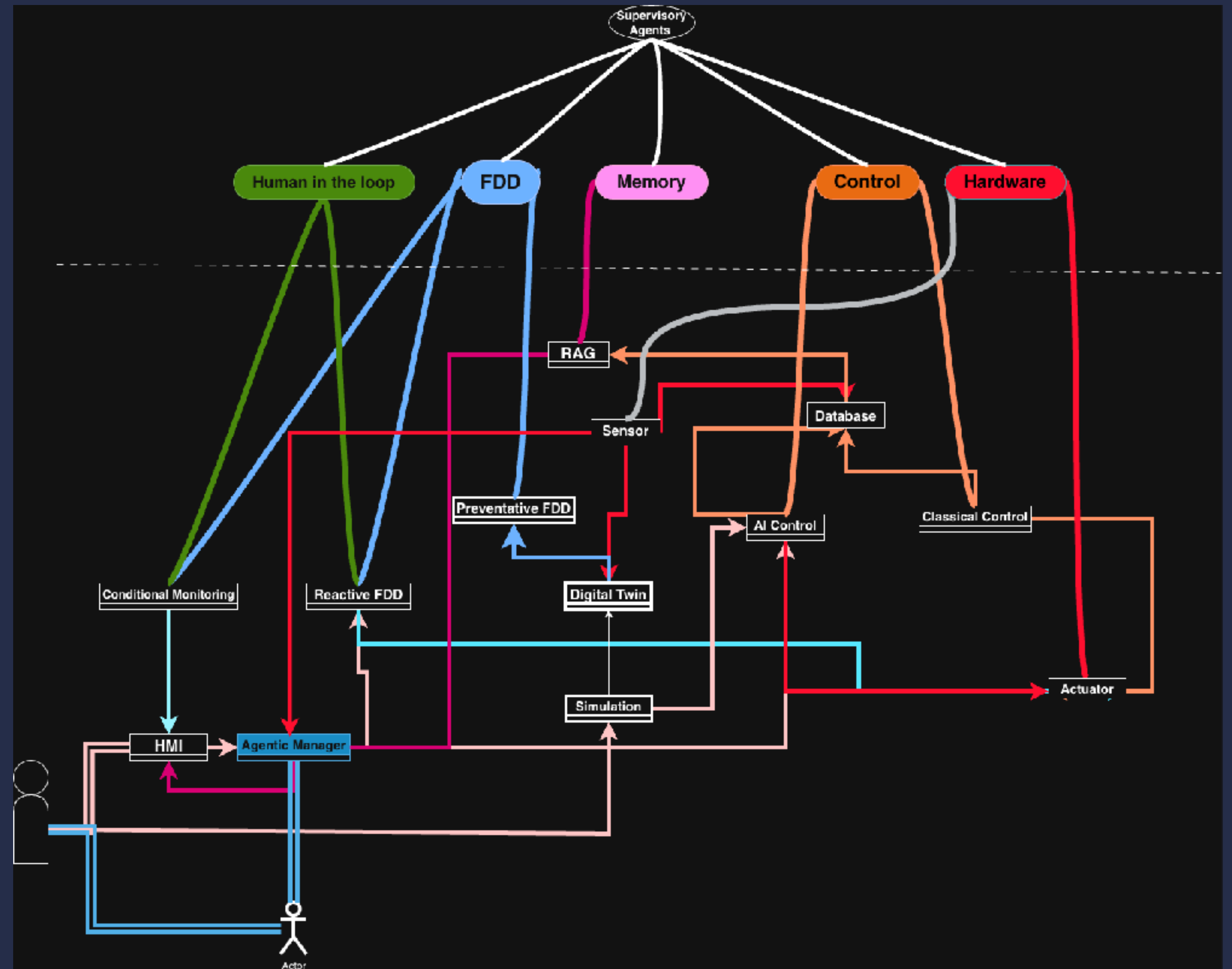
Automate filling and regeneration



Optimize Monitoring and Control: Supervisory Agents

What has been currently done:

- An ASME-Compliant Helium-4 Evaporation Refrigerator for the SpinQuest Experiment ([arXiv:2511.09689](https://arxiv.org/abs/2511.09689))
Target: ASME Journal of pressure vessels
- The SpinQuest Microwave System for Dynamic Nuclear Polarization ([arXiv:2604.10447](https://arxiv.org/abs/2604.10447))
Target: IEEE Journal of Microwaves
- Polarized Target Nuclear Magnetic Resonance Measurements with Deep Neural Networks ([arXiv:2603.10146](https://arxiv.org/abs/2603.10146))
Target: EPJA



Retrieval-Augmented Generation

Create a knowledge base along side our database.

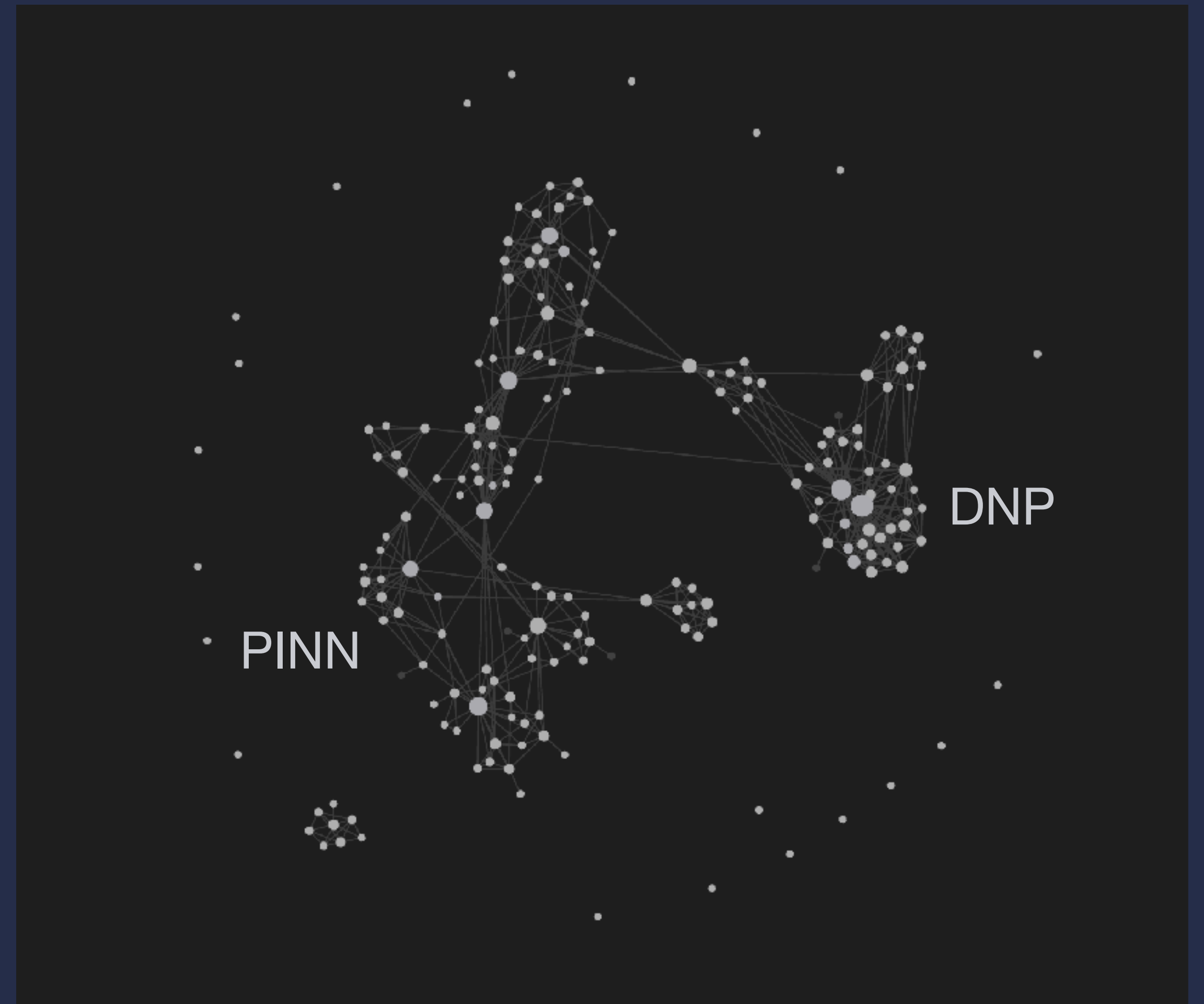
Vector Database: stores and index data as a vector embedding.

Use retrieval algorithms (similarity or distance metrics) to fetch the most relevant data.

Use an LLM to ground the response.

Key is to have full observability and traceability.

Credit: Andrej Karpathy LLM wiki



Control: Microwave and Refrigerator

Simulate how certain variables from the microwave or flow to the refrigerator effect polarization and stability.

Train models to optimize for different polarization regions and targets.

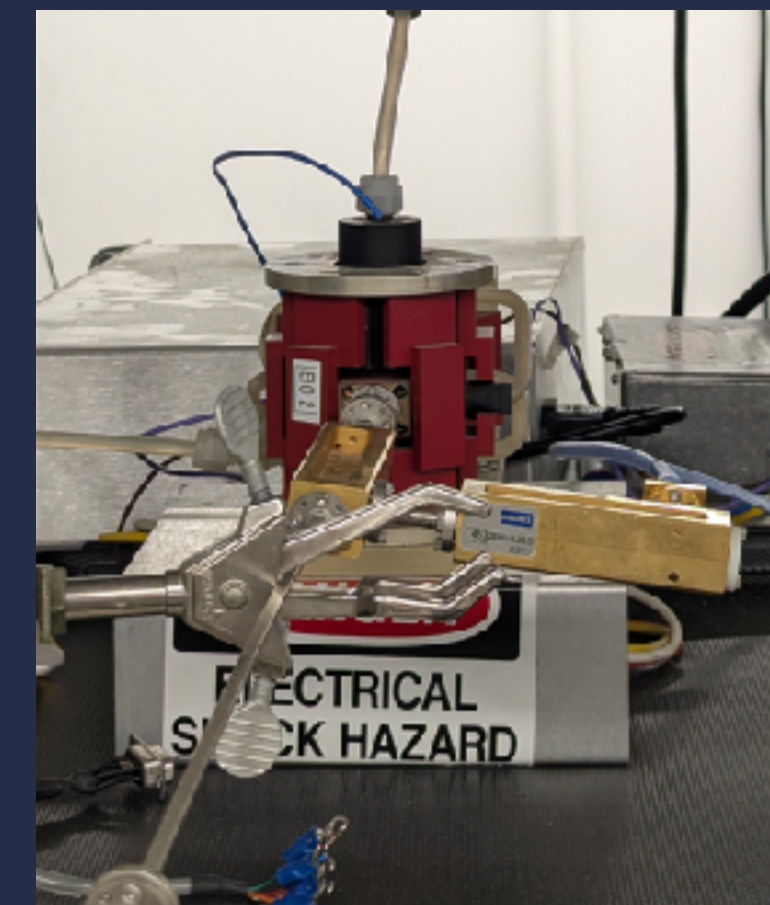
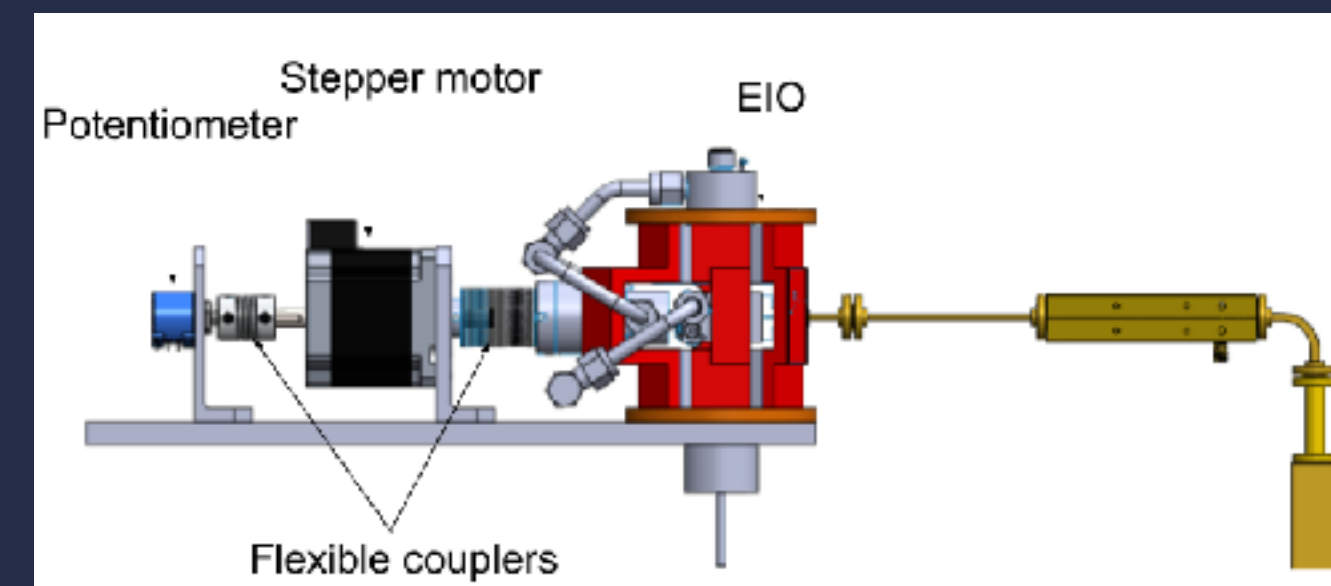
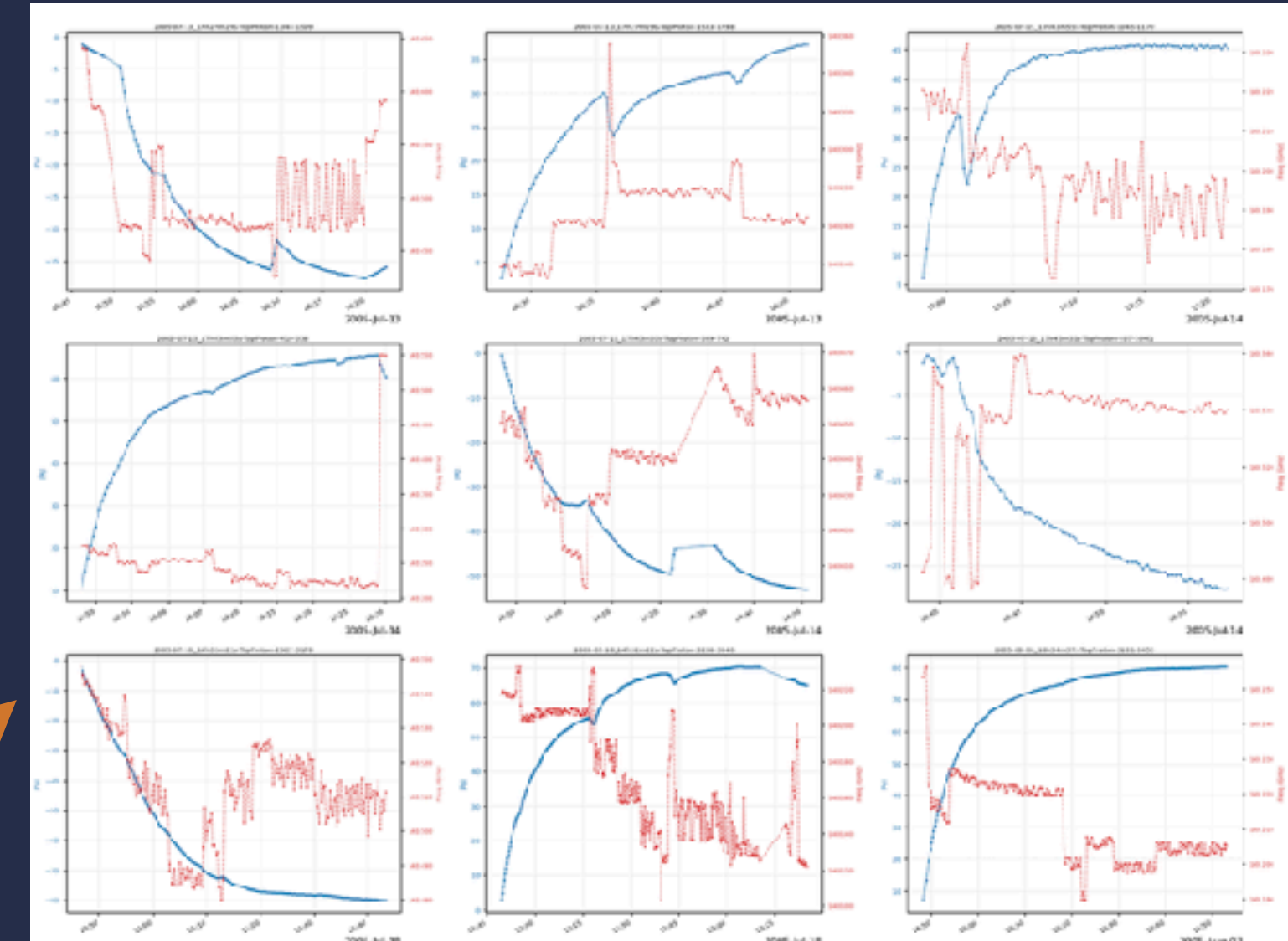
Expand microwave sim by including attenuation and voltage.

Expand to a digital twin with sensor feedback.

Rate Equations: Simplified Jeffries Formalism

$$T_{1e} \frac{dP_n}{dt} = \left(-\frac{T_{1e}}{T_{1n}} - \frac{C\alpha}{2} - \frac{C\beta}{2} \right) P_n + \left(\frac{C\alpha}{2} + \frac{C\beta}{2} \right) P_e$$

$$T_{1e} \frac{dP_e}{dt} = \left(\frac{\alpha}{2} - \frac{\beta}{2} \right) P_n + \left(-1 - \frac{\alpha}{2} - \frac{\beta}{2} \right) P_e + P_0$$



OpenModelica



NVIDIA OMNIVERSE™



Conclusion

UVA Polarized target lab is aiming to do a cool down in July to test the newly made purification system.

We are striving to improve on our monitoring system by expanding into machine learning and NLP.

We hope to use the lab as a test bench to prototype and test new monitoring and control techniques. Primarily fault detection and diagnosis.

We aim to expand this to larger labs and experiments.

We are working on using a RAG system to provide domain level feedback from monitoring.

We are exploring new ways to control the microwave through digital twins and ML.

Thank You

