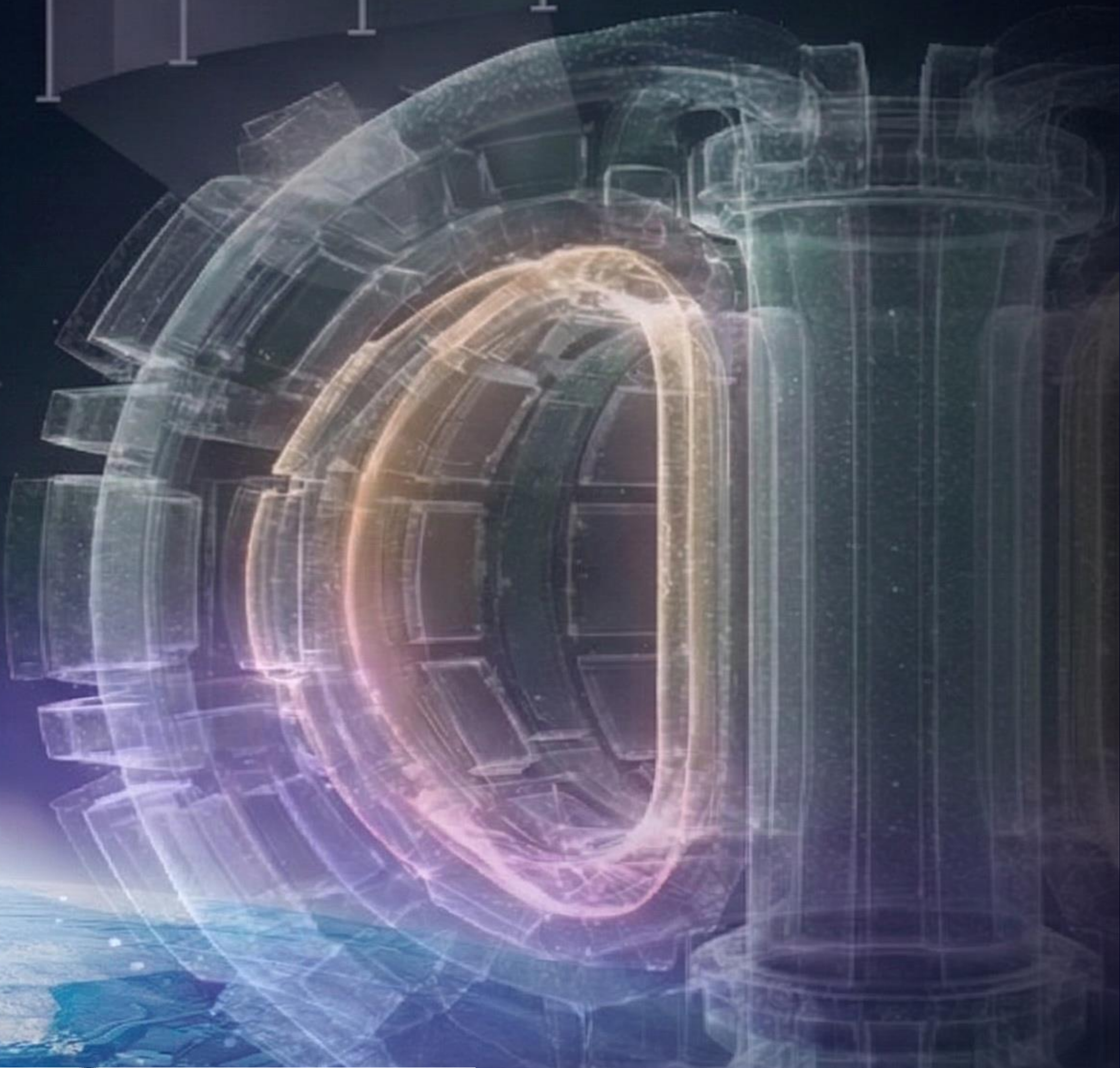
Practical Autonomy for Fusion Science



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ISC Hamburg

June 26, 2026

UC San Diego · SDSC San Diego Supercomputer Center · NVIDIA · AmSC American Science Cloud · General Atomics

The Goal of AI in Fusion is to Derisk The Path to Commercial Deployment

- **Fusion needs AI and AI "needs" fusion**

- **Fusion needs AI:** Trial-and-error does not scale.

- **The AI promise:** Move risk from costly physical iteration to in-silico optimization

- **Proof of Concept:** Use low-risk DOE fusion facilities as a proving ground

- **Metrics:** Risk reduction at high fusion performance, transferable tools for reactor design/operation

JET UK: Camera data

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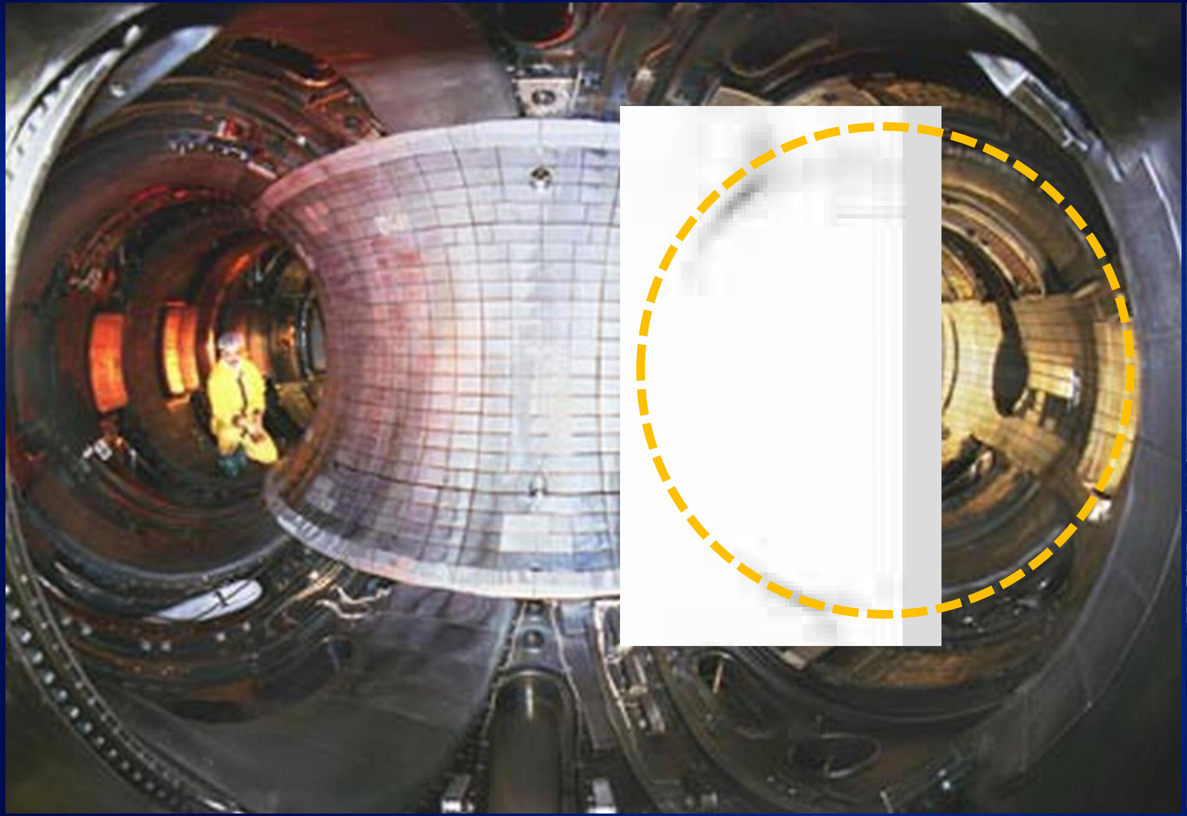
The Driver: Unacceptable Cost of Physical Iteration At Scale

~ 2-3 MJ

The Event: Unpredicted Plasma Disruption (TFTR ~1994)



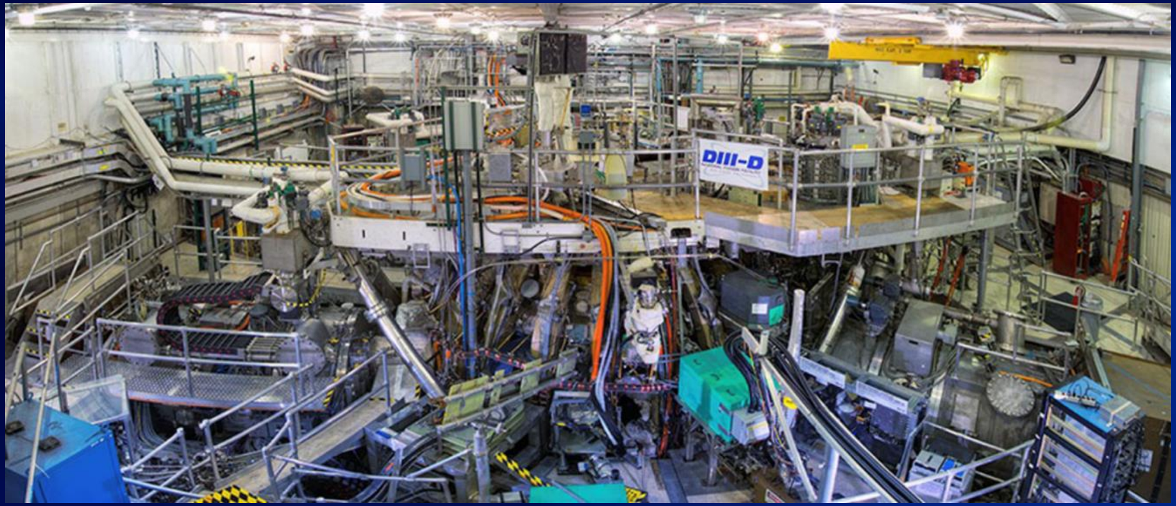
AUG (Germany)

Next-generation reactors will store 100-300x the energy of present facilities.
"Test-to-fail" no longer financially or operationally viable.

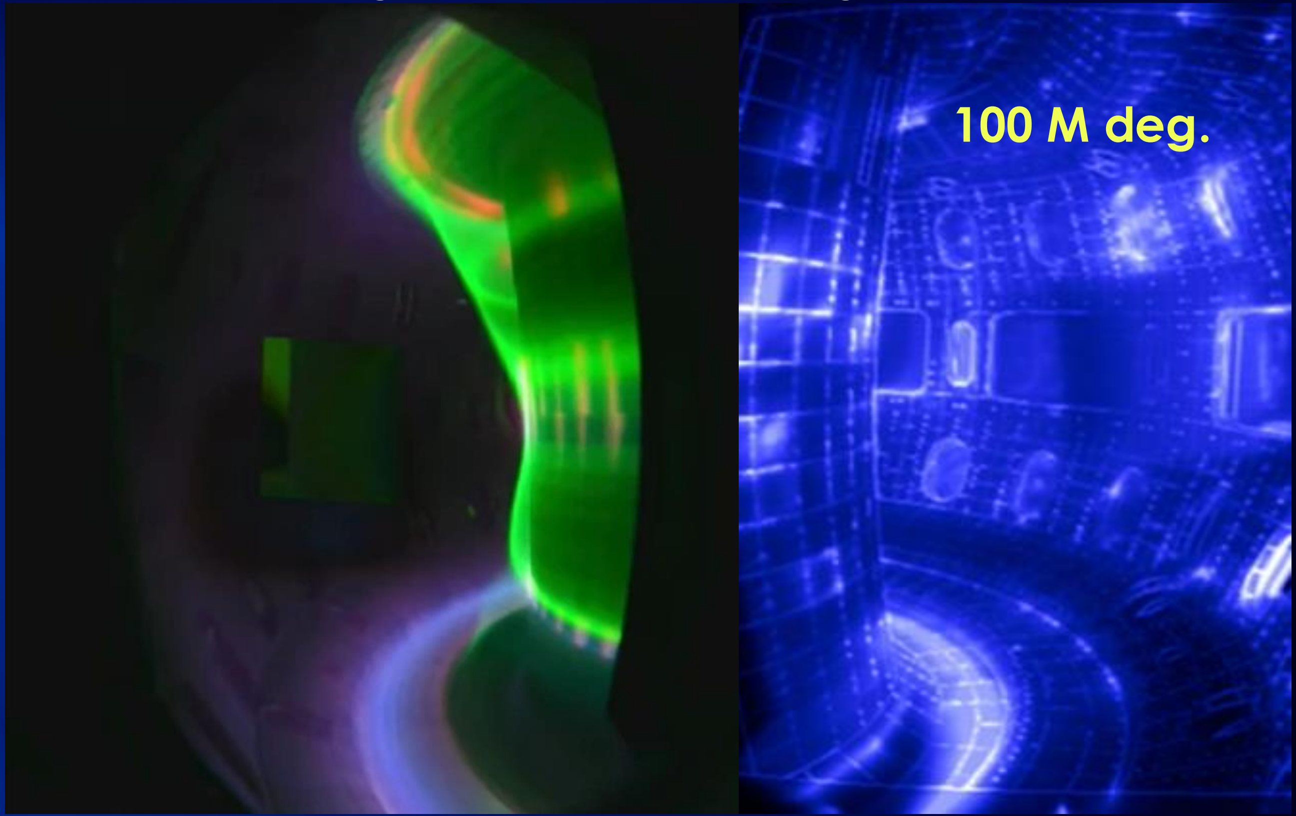
ASDEX Upgrade PPPL

GENERAL ATOMICS

DIII-D National Fusion Facility Serves as a Relatively Low-Risk, Agile Testbed For Demonstrating AI Advantage and Practical Autonomy



High-Fidelity Internal Diagnostics



- Over 830 collaborators world-wide
- Unmatched control and diagnostics
- High operational cadence; data collection
- Resilient to off-normal events

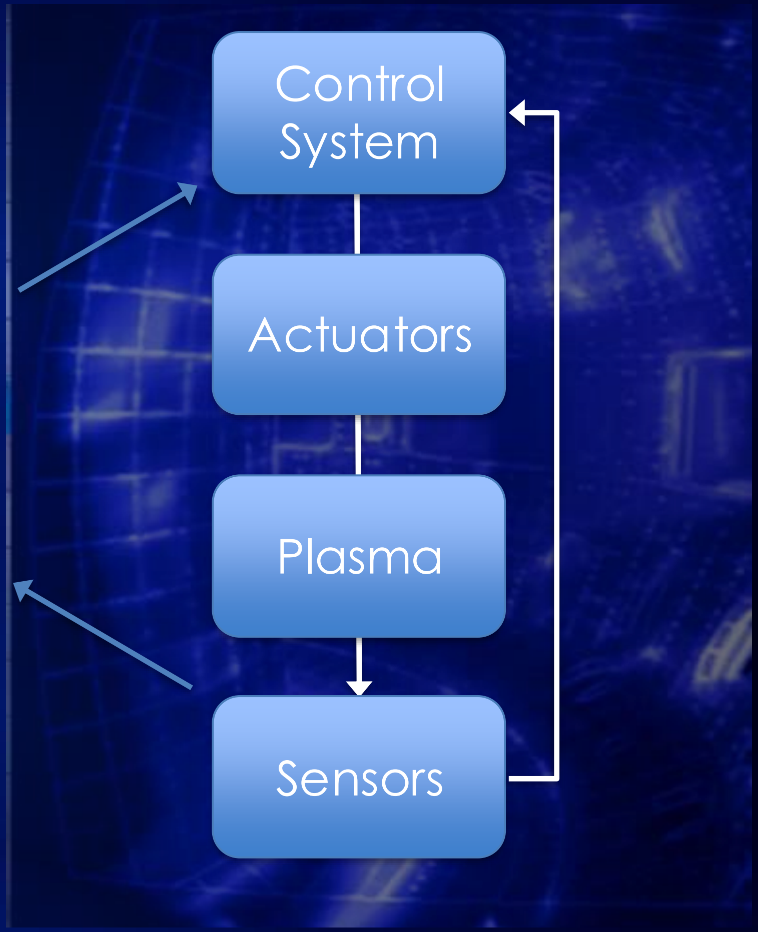
"Practical" means humans remain in the loop for safety and facility protection

DIII-D GENERAL ATOMICS

The Blueprint: Architecting Practical Autonomy on DIII-D

Control Room

Physical DIII-D



The Blueprint: Architecting Practical Autonomy on DIII-D

Virtual DIII-D	Control Room	Physical DIII-D
Control System		Control System
Actuators		Actuators
Plasma		Plasma
Sensors		Sensors

GENERAL ATOMICS

The Blueprint: Architecting Practical Autonomy on DIII-D

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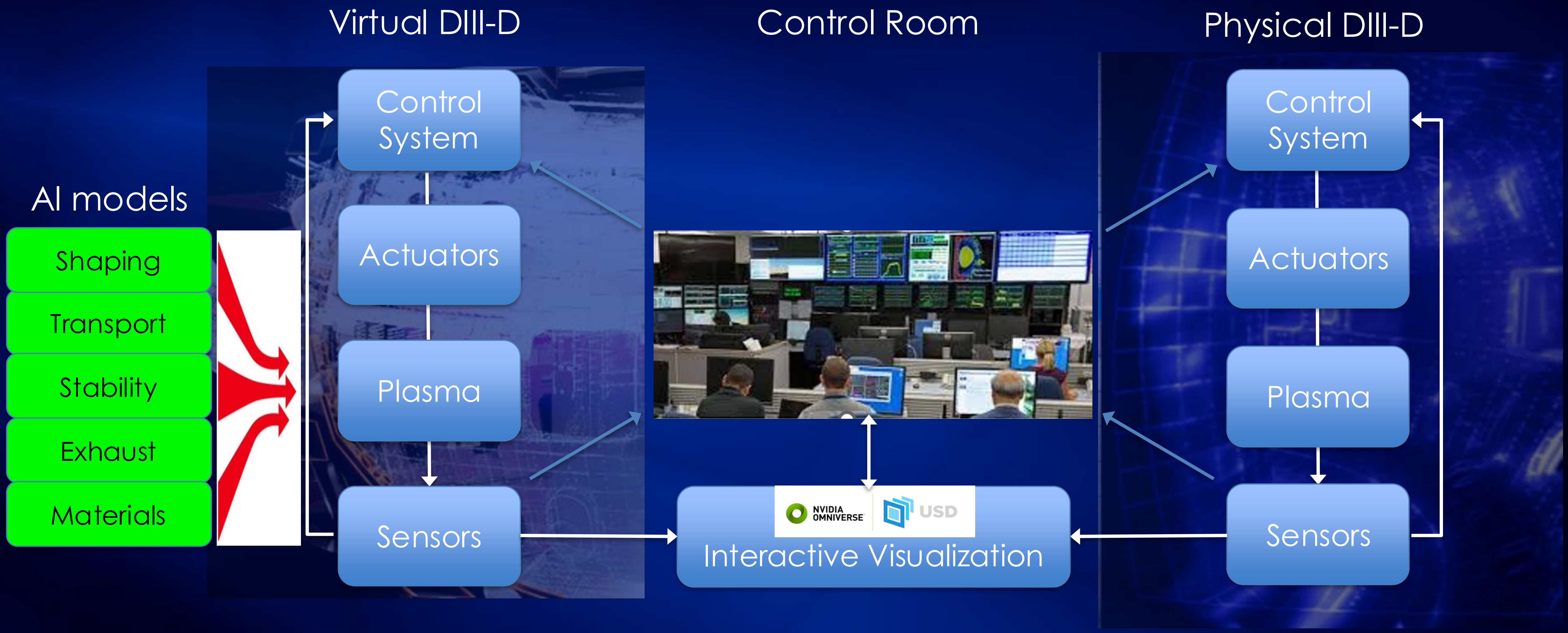
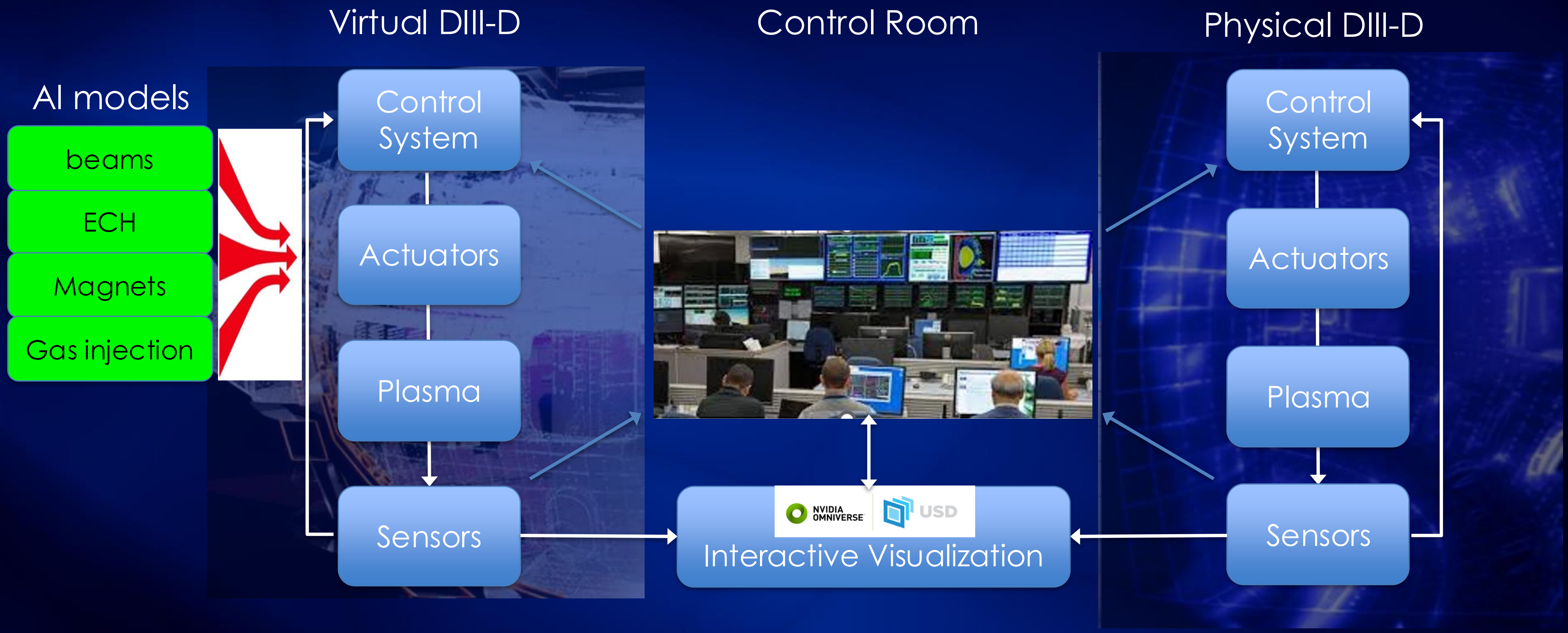
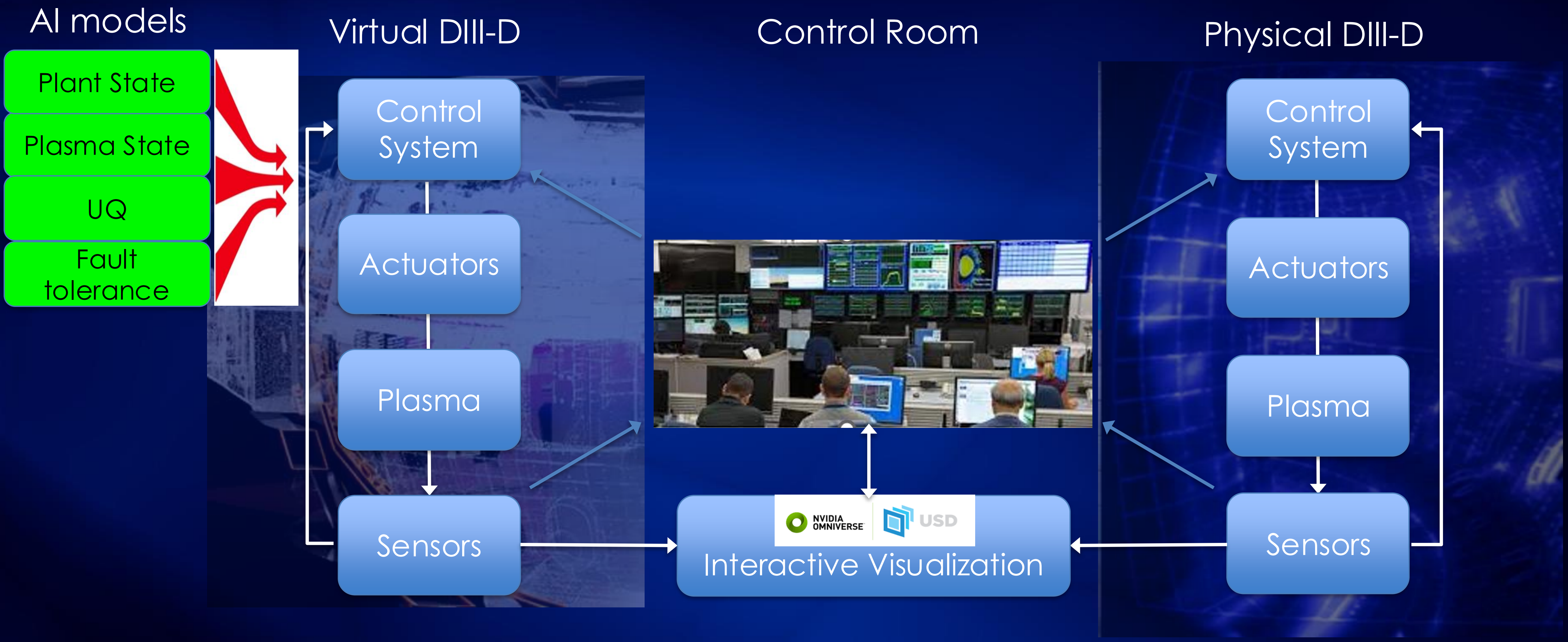


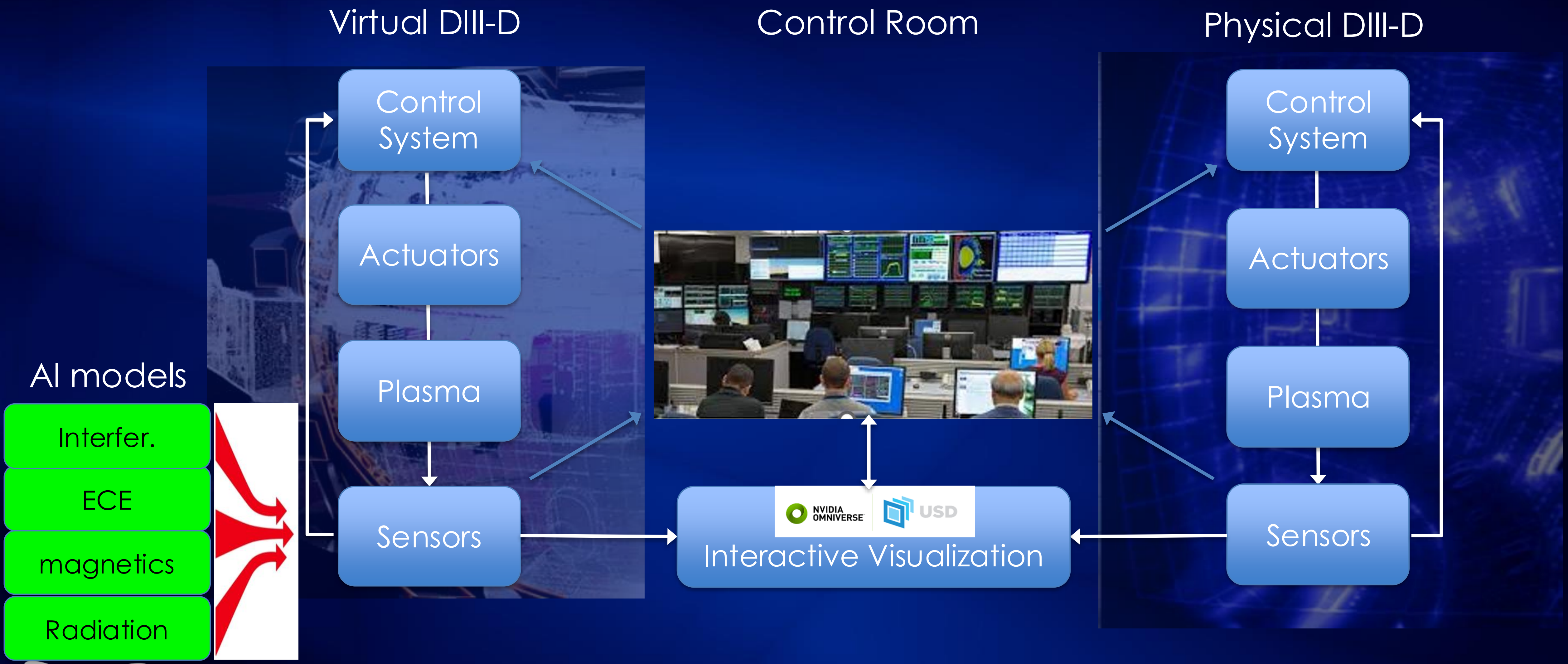
The Blueprint: Architecting Practical Autonomy on DIII-D



The Blueprint: Architecting Practical Autonomy on DIII-D

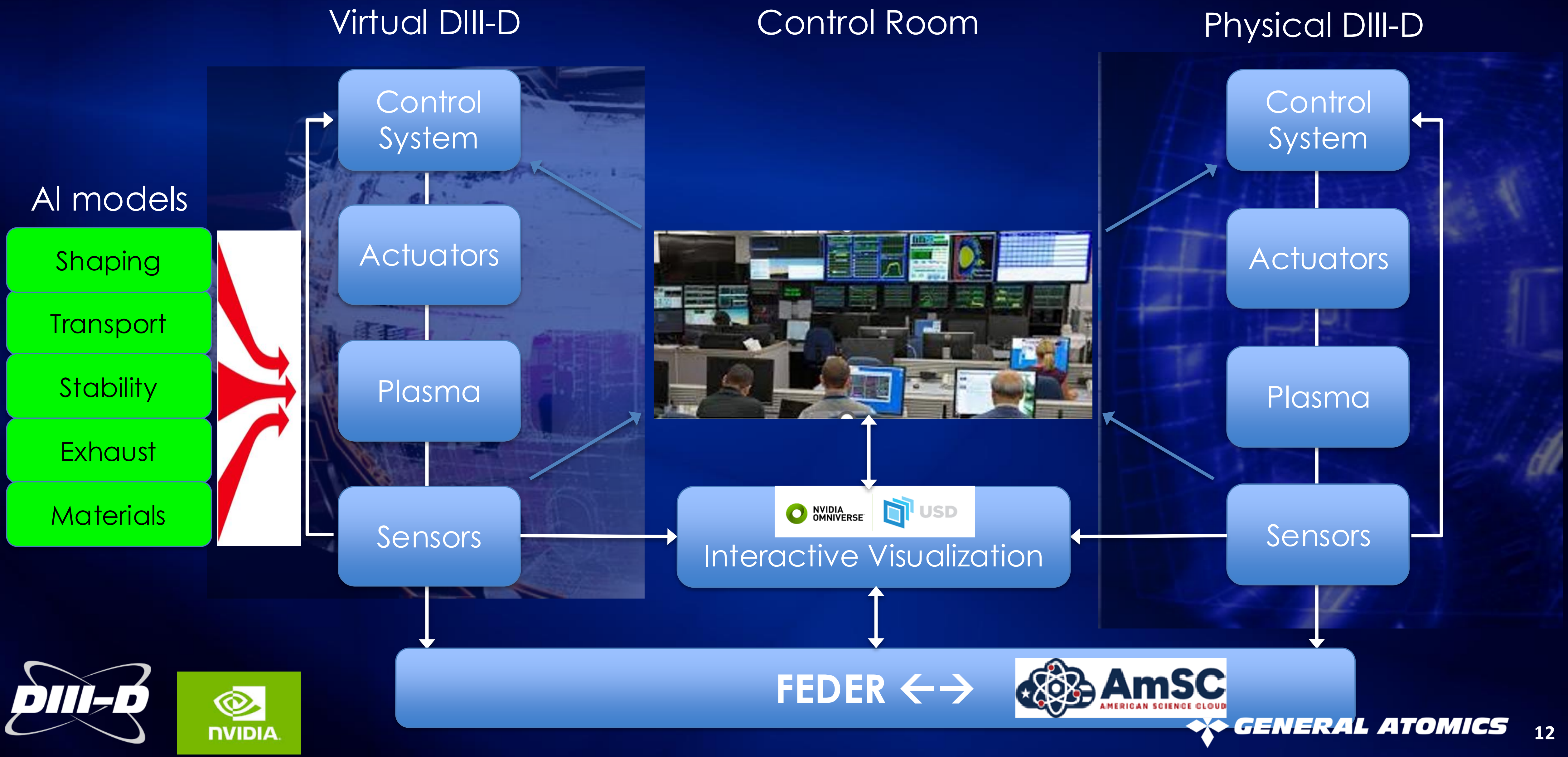


The Blueprint: Architecting Practical Autonomy on DIII-D

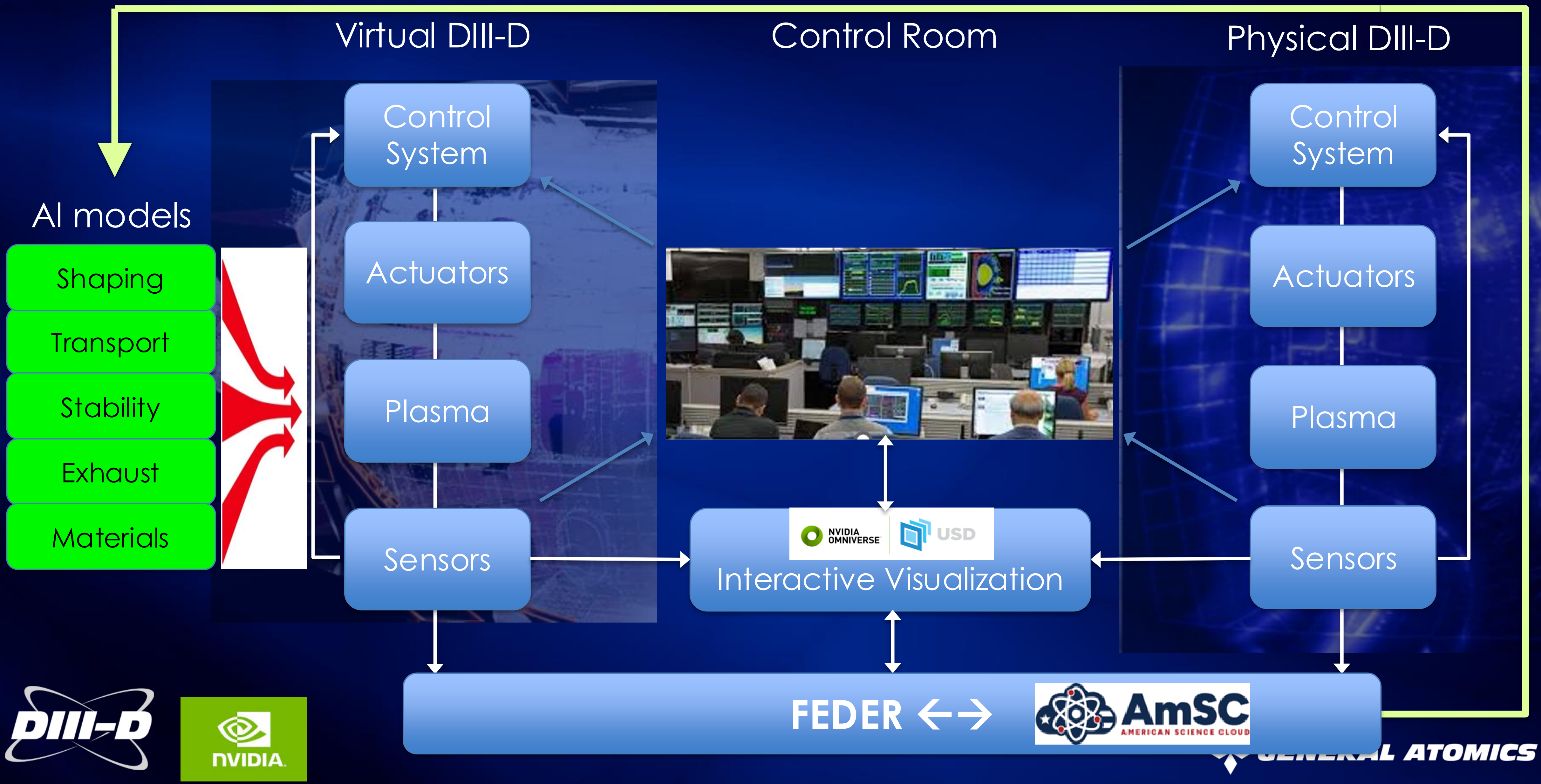


DIII-D NVIDIA GENERAL ATOMICS

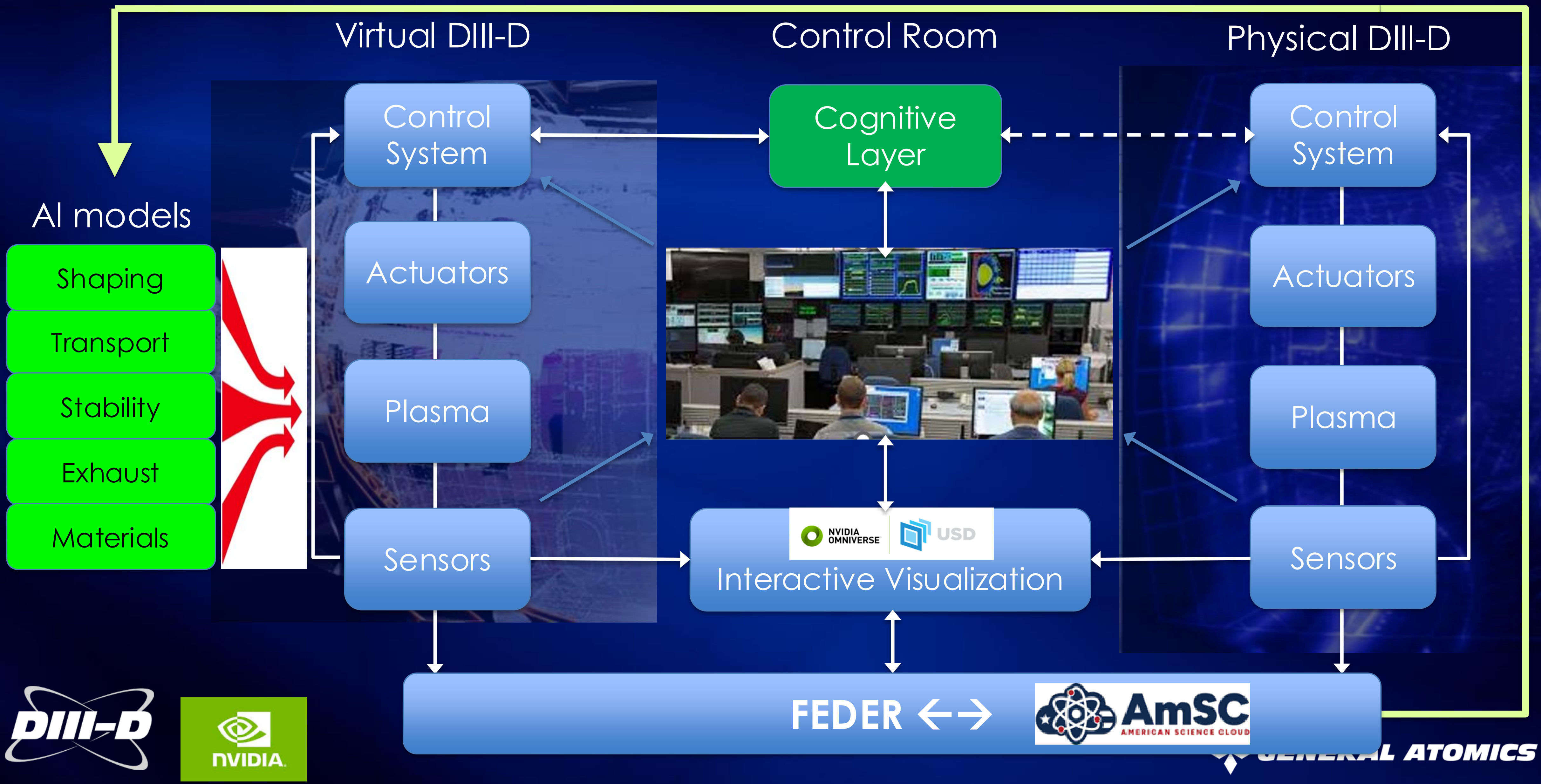
The Blueprint: Architecting Practical Autonomy on DIII-D



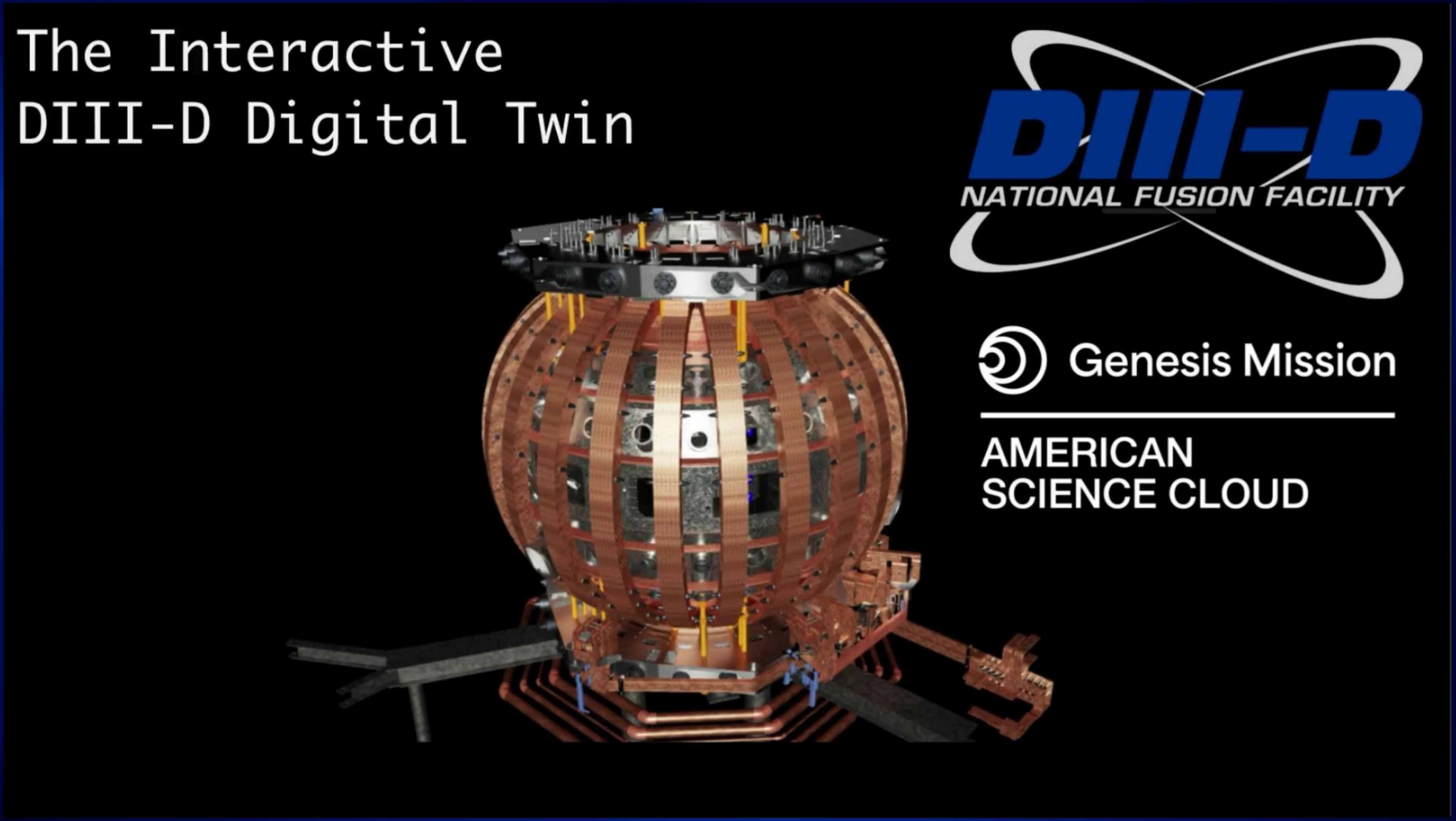
The Blueprint: Architecting Practical Autonomy on DIII-D



The Blueprint: Architecting Practical Autonomy on DIII-D



DIII-D Submission to DOE for July 4th Genesis Event



Underlying the Digital Twin and Agents is a Data Layer That Integrates With AmSC

DIII-D facility
Physical asset · sensors · pulses

Digital twin
Orchestrates models · pulse sims

AI models & agents
Surrogates · UQ · downselection

FEDER data substrate · Ontology + knowledge graph · FAIR, federated, provenance-tracked · curated multi-machine data (DIII-D · C-Mod · MAST)

AmSC American Science Cloud · compute + orchestration foundation everything runs on (ALCF · NERSC · OLCF)

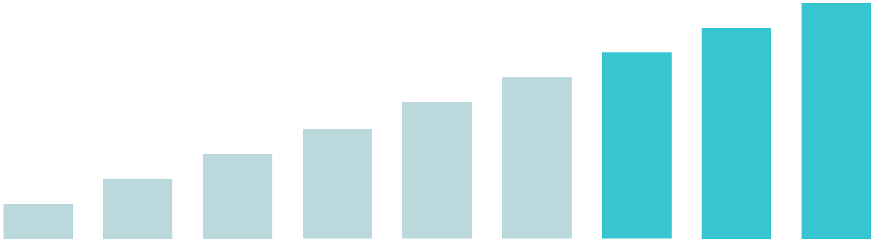
Common infrastructure for autonomous operations must address fundamentally different goals across scientific domains

cheap · parallel · replicable facilities and experiments

LOW-RISK SCIENCE

Optimize throughput

100× more data per campaign



vs

limited · expensive · irreversible; failure damages the instrument

HIGH-RISK SCIENCE · FUSION

Optimize risk

↑ performance

at **today's data throughput** — not 100× more pulses

The Solution is Co-Design: Inject Multiple Domain specific requirement and metrics early

Shape the horizontal abstraction with high-stakes domains

Discuss verification with real physics exemplars several domains

Push domain specific metrics into the roadmap

Final thoughts: Co-Design of Common Infrastructure with Science Domains Is Essential

FUSION IS A KEY USE CASE

- Expensive asset, no parallelism, no test-to-fail
- The goal is risk reduction, not 100× data
- Focus is on validating models on a safety-critical instrument

DIII-D Testbed for Autonomous Ops

- An agile, fast-cycling facility (DIII-D) that can falsify model extrapolations in a run day
- A deployed stack: surrogates, agent-orchestrated twin runs, streaming, AmSC integration
- FEDER FAIR substrate integrated with AmSC
- Multi-machine data curation for generalization