Fermilab

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HEP in Genesis Mission

Nhan Tran
CPAD 2026

U.S. DEPARTMENT of ENERGY
Fermi National Accelerator Laboratory is managed by FermiForward for the U.S. Department of Energy Office of Science

FERMI NATIONAL ACCELERATOR LABORATORY

Prologue

- This talk is about HEP in the Genesis Mission
  - This talk is partially informational, interspersed with a examples and editorial comments
    - Several borrowed slides as a result
  - Outline:
    - Genesis Mission, Spotlights, Outlook

- With the rise of AI:
  - We have an opportunity to do things fundamentally differently
  - We need (?) to do things fundamentally differently
  - We should (?) do things fundamentally differently

This talk does not address societal or ethical aspects of AI (mostly for time purposes - but that does not mean it shouldn't be a part of the discourse

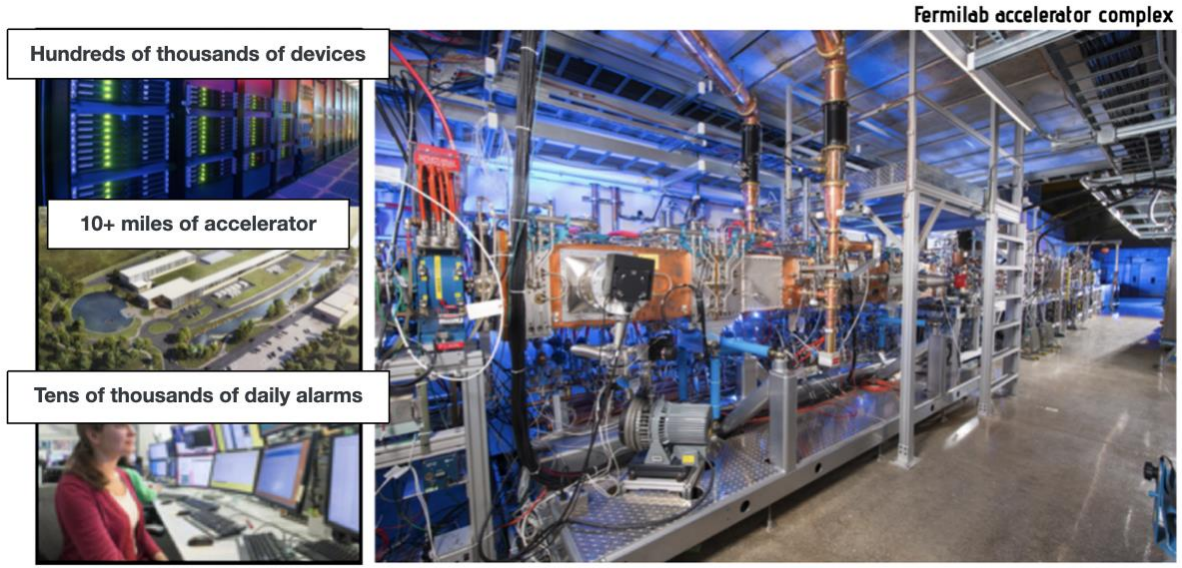
HENP value proposition for AI

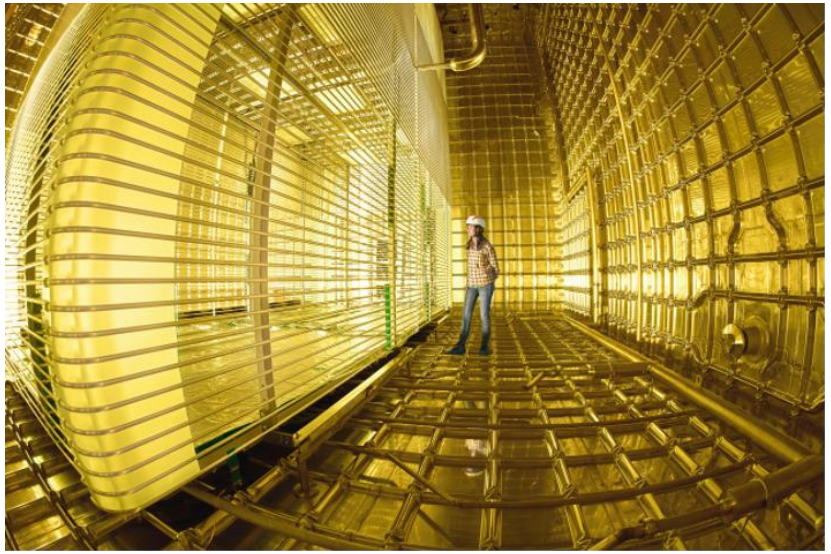
Facilities and experiments: complex operation in extreme scenarios

Deep domain knowledge: surrogate and physics-inspired models

Trustworthy AI for Science: foundation models, robustness, generalizability

Data: uniquely massive, rich, high-fidelity data and simulation







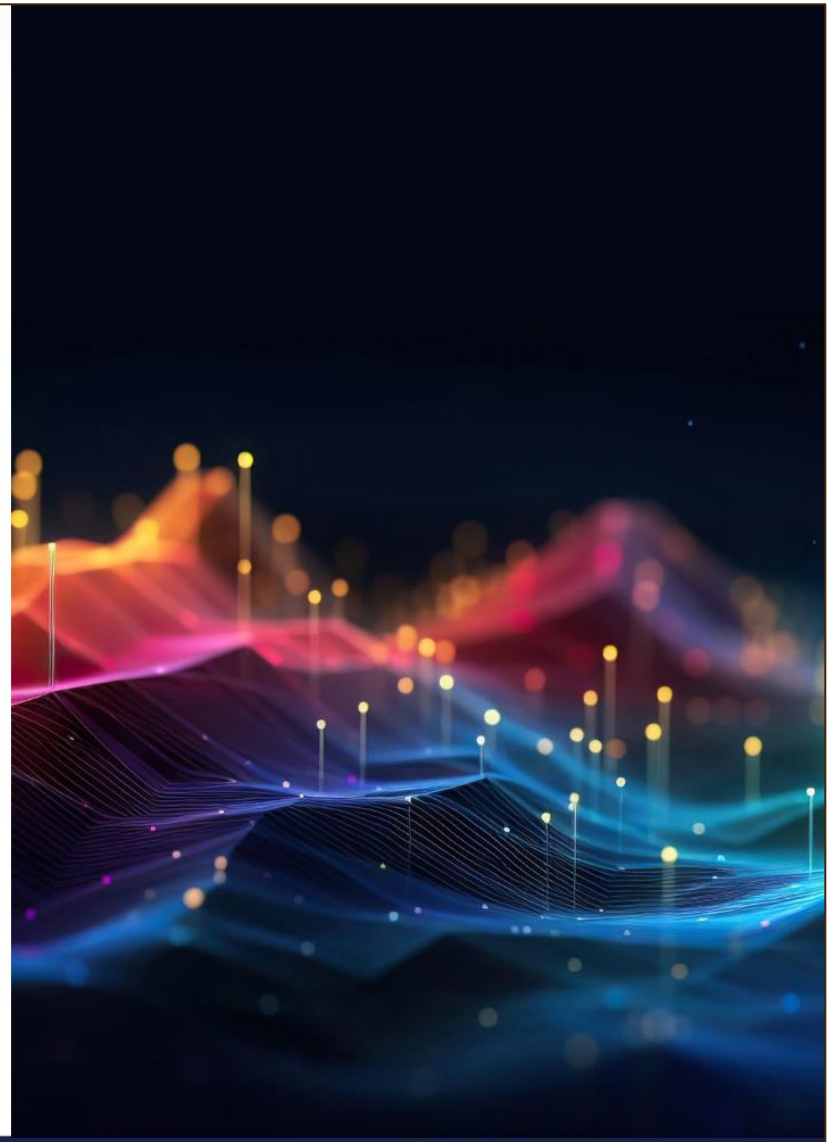
Genesis Mission

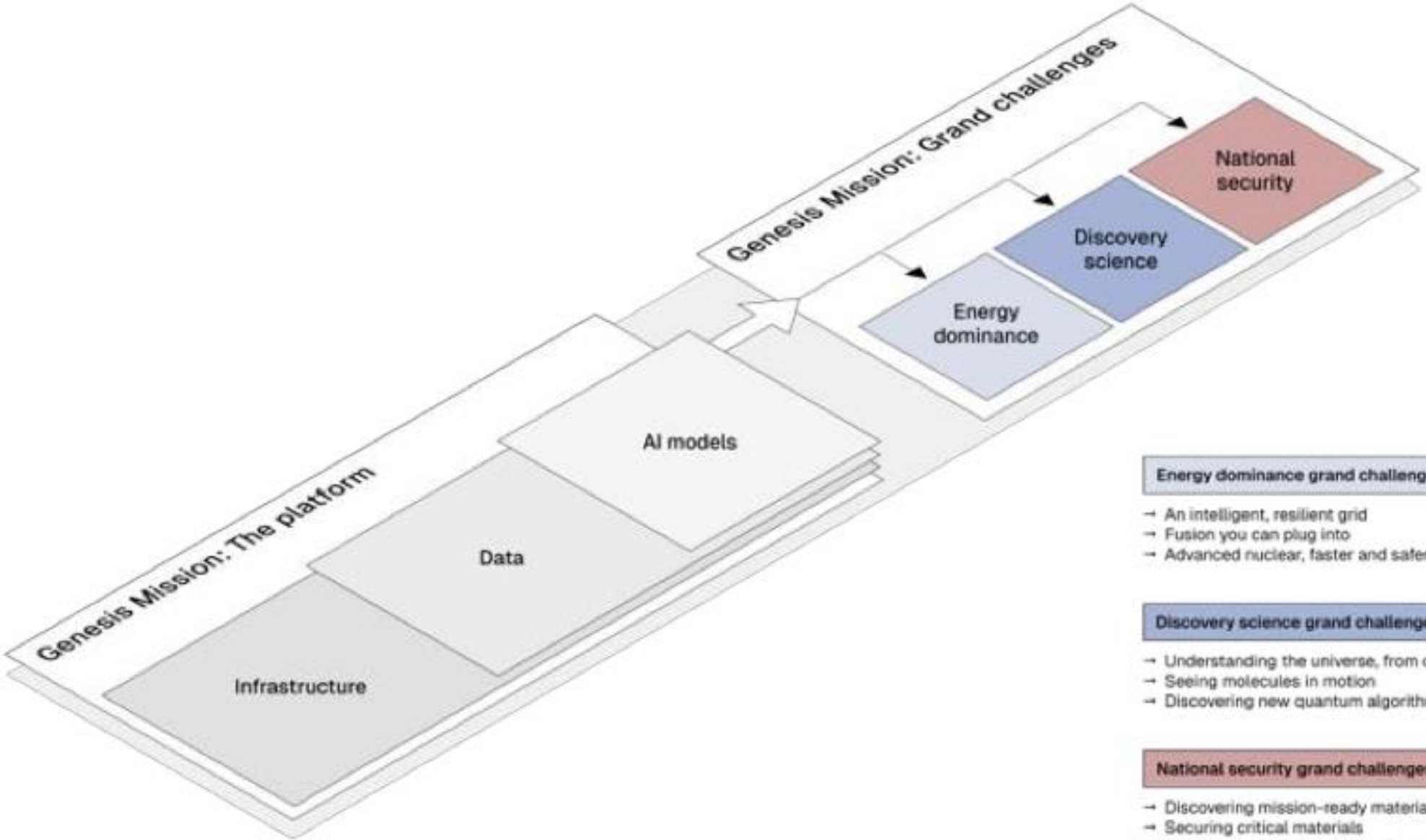
The Genesis Mission

The **Genesis Mission** is a historic national effort to catalyze new industries, create high-skill jobs, and usher a new golden era of American discovery by fully embracing AI and the ongoing computing revolution.

The Genesis Mission's **American Science and Security Platform** will connect the world's best supercomputers, AI systems, and next-generation quantum computers with the most exquisite scientific instruments in the nation, and its intelligence layer will be trained with the singular scientific datasets and expertise housed in the National Laboratories. Once complete, it will be the world's most complex and powerful scientific instrument ever built.

Through the Genesis Mission's **National Science and Technology Challenges**, the scientific community will develop and deploy the technologies necessary to demonstrate true AI advantage for science and energy.





Energy dominance grand challenges

- An intelligent, resilient grid
- Fusion you can plug into
- Advanced nuclear, faster and safer

Discovery science grand challenges

- Understanding the universe, from quarks to cosmos
- Seeing molecules in motion
- Discovering new quantum algorithms

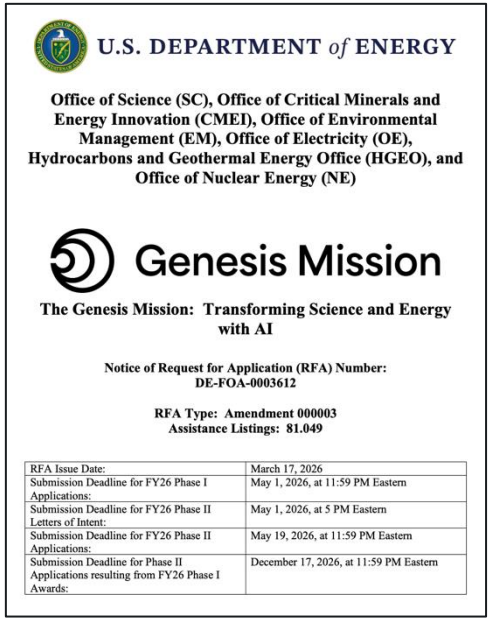
National security grand challenges

- Discovering mission-ready materials
- Securing critical materials
- Accelerating advanced manufacturing

The Genesis Mission timeline

Genesis Mission

Data	Compute/Storage	Models	Applications
HEP Data Pilots	American Science Cloud	Model Consortium	AI for Science and Energy
Fall 2025 (DOE labs only) **TREASURE**: tokenization for colliders **AI Universe**: data for cosmology foundation models **Knowledge Extraction**: agentic exploration and tools	Fall 2025 (DOE labs only) **ASCR-led:** **Compute and data platform** **Infrastructure Partners** connect compute with domain facilities, experiments, and capabilities e.g. Scientific User Facilities (IaaS, networking, etc.) Fermi Data Platform FemtoMind (LQCD)	Fall 2025 (DOE labs only) **ASCR-led:** **Model capabilities, e.g. Agents, multi-modal, evaluation, safety** **Seed model teams** were early application teams e.g. MOAT – Multi-Office Accelerator Team AXESS – Accelerating eXtreme Environment Specs-to-Silicon Q2C - Quarks to Cosmos	Spring 2026 (Lab, university, industry)



U.S. DEPARTMENT of ENERGY

Office of Science (SC), Office of Critical Minerals and Energy Innovation (CMEI), Office of Environmental Management (EM), Office of Electricity (OE), Hydrocarbons and Geothermal Energy Office (HGEO), and Office of Nuclear Energy (NE)

Genesis Mission

The Genesis Mission: Transforming Science and Energy with AI

Notice of Request for Application (RFA) Number: DE-FOA-0003612

RFA Type: Amendment 000003
Assistance Listings: 81.049

RFA Issue Date:	March 17, 2026
Submission Deadline for FY26 Phase I Applications:	May 1, 2026, at 11:59 PM Eastern
Submission Deadline for FY26 Phase II Letters of Intent:	May 1, 2026, at 5 PM Eastern
Submission Deadline for FY26 Phase II Applications:	May 19, 2026, at 11:59 PM Eastern
Submission Deadline for Phase II Applications resulting from FY26 Phase I Awards:	December 17, 2026, at 11:59 PM Eastern

SC HEP Portfolio Summary: 20 awards from 381 applications

- HEP's selected portfolio spans the HEP program utilizing existing and forging new collaborations for AI-driven scientific discoveries
  - **Enabling science** at HEP's flagship experiments ATLAS, CMS, DUNE, Rubin/DESC
    - Developing new AI methods for deeper insight from Exabyte-scale datasets
  - Accelerate the R&D cycle of technologies needed for the next generation of experiments
    - AI and agentic systems that can design, control, and realize more advanced technical solutions in **QIS, Microelectronics, and particle accelerators**
  - Partner with ARDAP, ASCR and NP to pursue discoveries in areas of mutual interest beyond traditional stovepipes
    - International researchers from CERN and French, Japanese, and British institutions
    - Three Genesis Mission aligned awards through US-Japan Program further broadens international partnership
  - HEP maintains some Phase-I alternate applications for future consideration.

HENP National Challenges and FY26 focus areas

7. Discovering Quantum Algorithms with AI

E. Quantum Advantage for Nuclear and Hadronic Systems (HEP, NP)
Use AI to determine the quantum computation advantage in nuclear and hadronic systems typically described through lattice quantum chromodynamics. Enable solutions using quantum algorithms that demand AI to tackle the challenges of chiral symmetry breaking, confinement, relativistic kinematics, and infinite degrees of freedom.

8. Realizing Quantum Systems for Discovery

B. AI for Control of Quantum Systems (HEP, NP)

Implement AI-based methods in control systems to dramatically improve the real-time control of practical quantum systems, including automating and optimizing calibration, tuning, noise mitigation, error correction, and readout processes, providing accurate, practical, and scalable quantum control to a wide variety of potential users.

C. AI for Quantum Imaging and Sensing (HEP, NP)

Integrate AI into multi-qubit quantum sensing applications for extreme sensitivity in both the laboratory and field environments to enhance and optimize the design, fabrication, and operation of sensors based on the quantum properties of superconductors, semiconductors, atoms, or other physical substrates.

U.S. DEPARTMENT of ENERGY

9. Recentering Microelectronics in America

G. Microelectronics in Harsh Environments (HEP)

Integrate AI into the design and validation of robust devices and facilitate the efficient operation of devices that process high data volumes in harsh environments where there is no possibility of replacement or service.

J. Low-temperature Electronics for Sensors and Computation (ASCR, HEP)

Low-temperature (mK up to 120K) electronics, including cryogenic CMOS and superconducting logic, promises efficient, high-speed, and low-cost computing to address Genesis Mission needs in edge computing and AI accelerators, but bottlenecks in design, density, scaling, fabrication, and integration have prevented practical realization of these benefits. Research proposals may focus on EDA for superconducting digital logic, analog and digital superconducting electronics for sensors or for classical control of quantum computers, superconducting neuromorphic, AI, and control circuits, distributed superconducting computing architectures, or cryogenic CMOS.

HENP National Challenges and FY26 focus areas

13. Enhancing Particle Accelerators for Discovery

A. AI-driven Accelerator Facilities (BES, HEP, IRP, NP)

Enable and deploy AI systems that provide real-time operational advice, automate control functions, enhance beam stability, reduce beam tuning time, predict equipment failure, detect faults, and optimize performance for both large and small-scale accelerator facilities currently operating or under construction. Scope includes the development and deployment of high-fidelity AI-driven "digital twins" of these particle accelerators to enable a sophisticated simulation and design environment and AI systems that can mitigate cost and risk of accelerator facilities under construction.

14. Unifying Physics from Quarks to the Cosmos

A. Foundation Models of Particle Interactions and Cosmic Physics (HEP,NP)

Develop and curate the essential data of nuclear and particle experimental efforts, critical to train foundation models of particle interactions and cosmology to accelerate new breakthroughs in our understanding of the universe. Data and models may include the future Electron-Ion Collider, cosmic observations, underground and accelerator-based experiments as well as synthesizing different modalities of data from acros
understand nuclear astrophysics, dark energy, dark matter,
Universe. Successful scope will seamlessly span experimer
pinch points of analysis pipelines from detector-level throu
with the output of advanced theoretical calculations. Disco
maximized by addressing such technical challenges as spa
acquisition of high-dimensional petabyte-scale datasets wi
and interpreting the experimental signals using theoretica

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B. AI Accelerated DUNE Science (HEP)

Develop AI methods that significantly speed up and enhance the DUNE science program, reducing the time needed for the collaboration to publish neutrino oscillation measurements, significantly improving the sensitivity to neutrinos from core-collapse supernova, and developing new flagship measurements that will enhance the DUNE science goals.

C. Expedited Discovery from High Complexity and Petabyte-scale Datasets (HEP, NP)

Partner domain expertise with data science and industry to develop AI methods and techniques capable of drawing robust scientific insight from increasingly complex and/or petabyte-scale datasets. Enable deeper insights by directly connecting datasets with theoretical parameters for uncertainty-aware reasoning to leverage the high-dimensionality of particle physics datasets. Scope will address the critical slowdown problem in Lattice QCD, automate big-data analysis, achieve new levels of experimental precision and theoretical calculation, and significantly improve understanding of the universe and particle interactions. AI-assisted design to maximize experimental sensitivity to fundamental parameters of interest or that significantly reduces costs of proposed or current projects and can be implemented in the next three to five years, is also of interest.

More from DPF 2026

- Gina Rameika:
  - DOE HEP has always expected researchers to use the best tools possible
    - …
    - To take advantage of this rapidly developing frontier AI requires collaboration and partnerships requiring a **shift in the structure and support of HENP research**
- Jeremy Love:
  - Advance the HEP mission by using the best tools available, the frontier AI and computing of the Genesis Mission Platform
    - Requires a change in approach and a move toward **larger multi-institution and multi-disciplinary collaborative effort**

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Me, slide 3

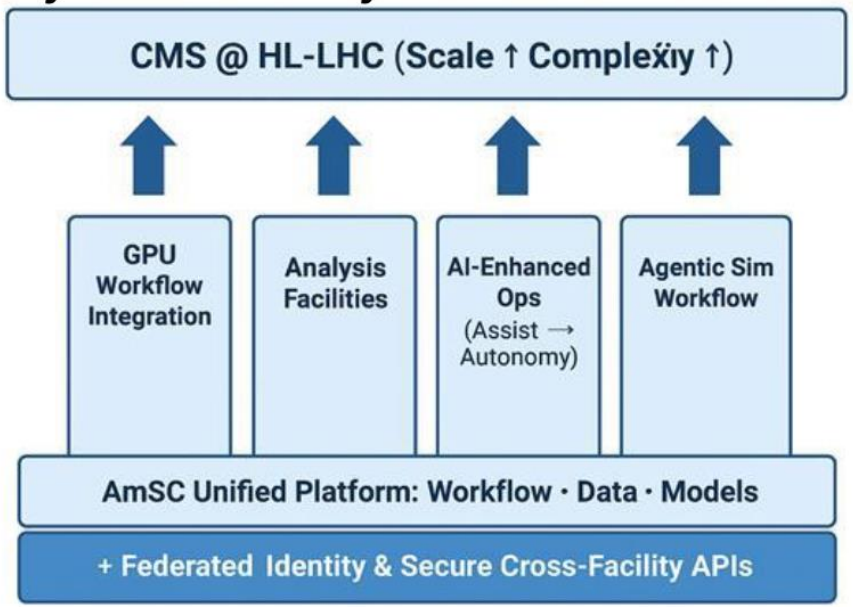
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Spotlights

HEP IP Pilot CMS

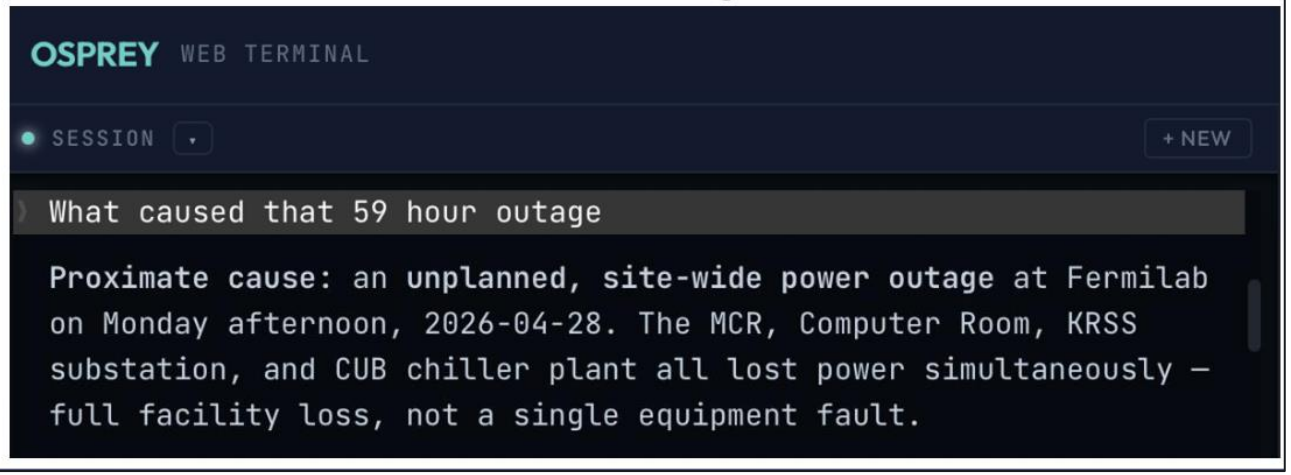
- CMS represents a complex globally distributed scientific workload
  - HL-LHC will bring order of magnitude increases in data volume and simulation throughput
- Utilize the Genesis Mission platform workflow and orchestration APIs, data services, model services, federated identity and security
- Focus on four initiatives:
  - GPU Enabled workflow integration with Genesis Mission
  - Analysis facilities on the Platform
  - AI enhanced computing operations
  - Agentic simulation workflow



Multi-Office Accelerator Team

- Designed developed and deployed OSPREY agentic platform
  - Integrated with control system infrastructure, optimization packages, electronic logbooks, data archives, machine information databases, etc.
- Deployed at 11 accelerators across 6 DOE labs
- FNAL logbook integration allowed OSPREY to diagnose downtime 200x fast than shifter
  - Detected extended no-beam intervals and cross-referenced with elog





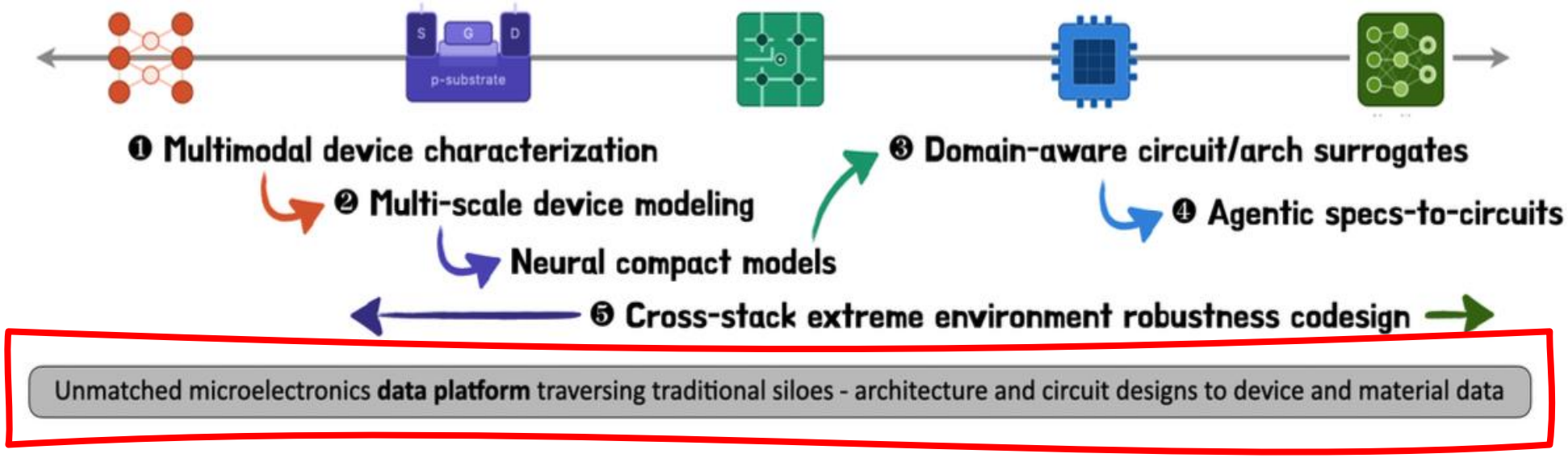
AXESS:
Accelerating eXtreme Environment Specs-to-Silicon

(Genesis Mission seed team, now ramping up for Phase 2)

- Develop DOE-specific Microelectronics design tools to speed-up research and development in extreme environments where commercial tools fall short
- Use decades of ASIC circuit designs from applications in extreme environments with characterization and testing data – initial focus on cryogenic environments

	Defense	Space	Material discovery	Quantum	Fusion	HPC	Particle/ nuclear physics
Ultra-fast	✓	✓	✓	✓	✓	✓	✓
Cryo/Temp		✓	✓	✓	✓	✓	✓
Radiation	✓	✓			✓		✓

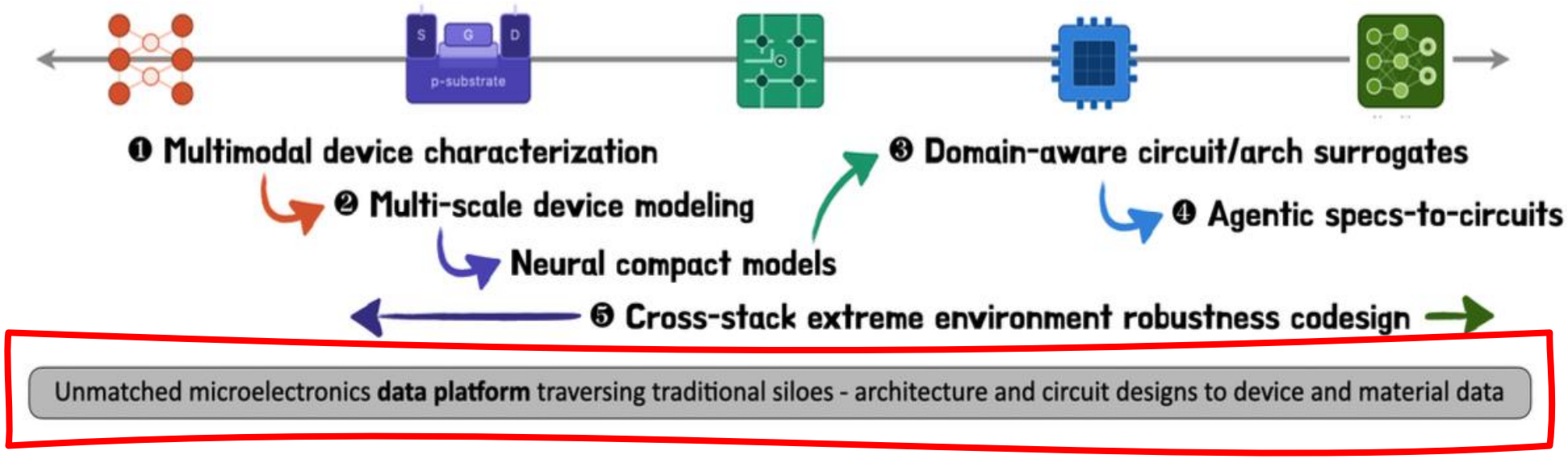
Vision: Significantly accelerate and enable extreme environment design with unprecedented reliability and precision based on DOE measurement and simulation capabilities



United data and modsim ecosystem with AI-ready data

Foundational Surrogate Models across different levels of the microelectronics stack

Agentic tools to **automate design optimization and data generation/discovery**

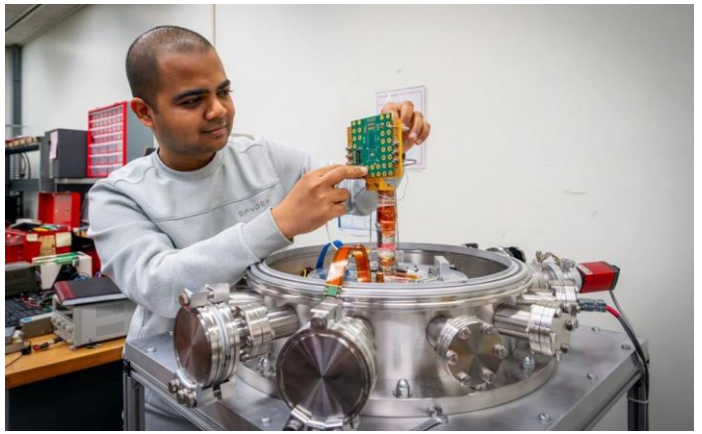


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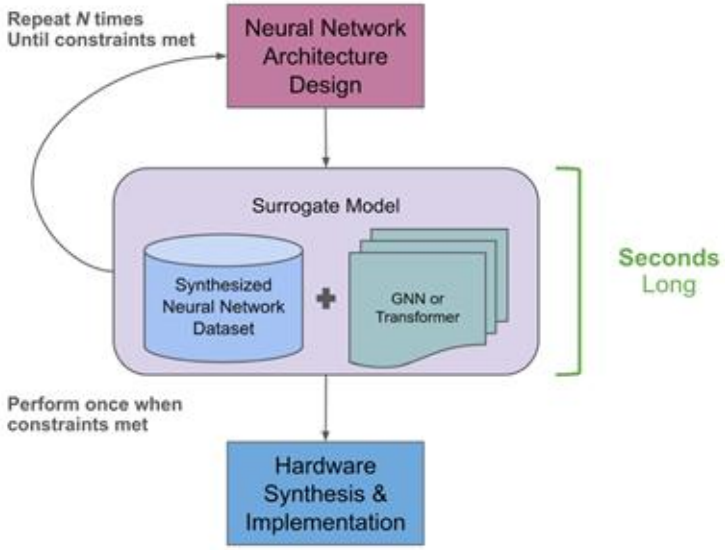
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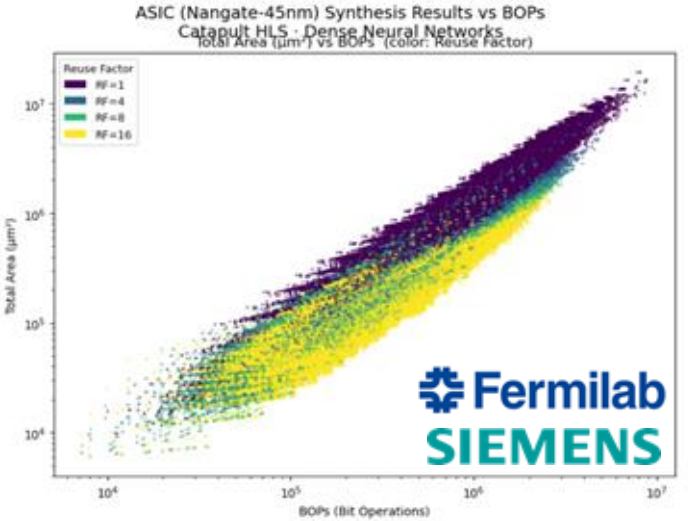




Architecture Cost and Performance Surrogates

- Challenge: ASIC synthesis takes **hours** per NN accelerator design, repeated N times in architecture search
- Surrogates (GATv2 / Transformer) predict area, latency, throughput in **milliseconds**
  - **Enables accelerated agentic-codesign**
  - Send only winners to full EDA/CAD flow
- Achievement:
  - Trained on ~500K designs across Nangate 45nm and GF22FDX
  - Accuracy: **$R^2 \approx 0.999$** for latency and area
  - Cross-node transfer: 45 nm → GF22FDX with ~10% target-node data





References

A. R. Das *et al.*, "Scaling Out hls4ml for ASICs: A Surrogate Model for Neural Network Accelerator Synthesis Metrics", Fast Machine Learning for Science, 2026



Outlook – a shared mission



Forbes

MONEY > INVESTING

Why Meta Paid $14.3B For Scale AI And Alexandr Wang's Data Empire

By Jon Markman, Contributor. Analyzing tech stocks through the prism of c... Follow Author

Published Jun 16, 2026, 12:27pm EDT

What Scale AI does well: *Claude*

- Data labeling and annotation at massive scale — armies of human labelers (including domain experts) to annotate text, image, video, and audio data for training AI models
- RLHF (reinforcement learning from human feedback) pipelines — a critical ingredient for aligning and fine-tuning LLMs
- Evaluation and benchmarking — building test sets to measure model quality/safety
- Synthetic data generation for cases where real labeled data is scarce

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Data

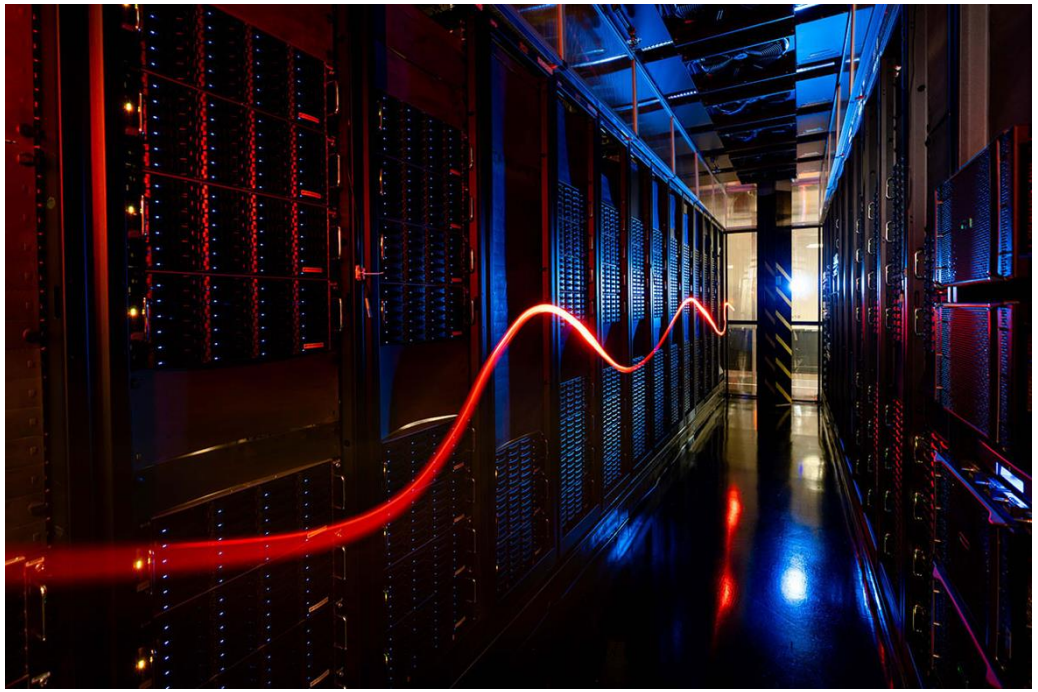
HEP has long had historical strength in data

But, this needs to be revisited:

- Multiple modalities - research, operational, construction, project data
- **Big and small - smaller R&D efforts, test stands**

Dedicated efforts for data curation and system redesign

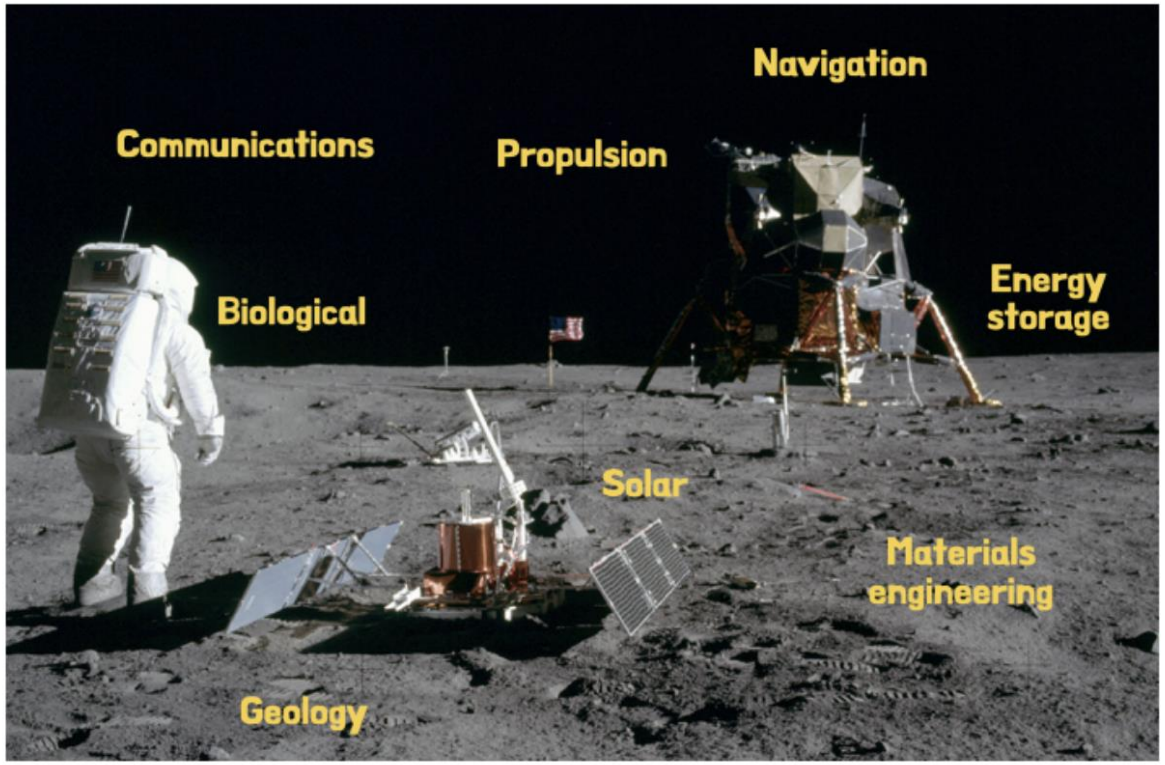
Could Genesis be the catalyst to do this?



Moonshots and benchmarks

"What get measured, gets improved."

Credit: Christian Herwig

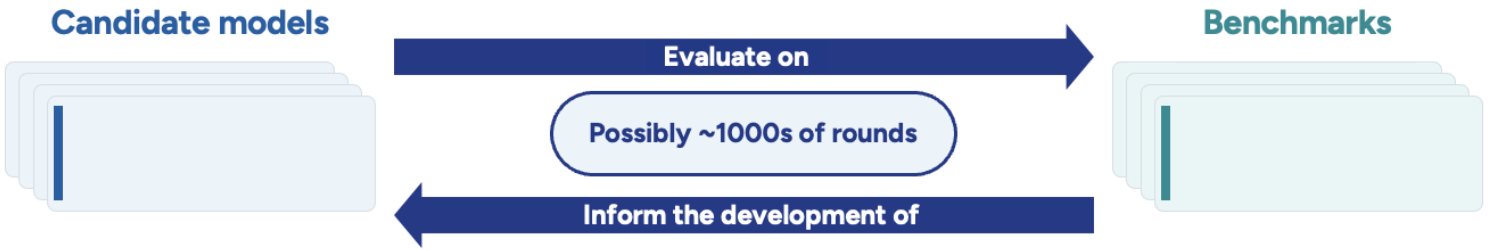


Defines meaningful scientific challenges
Specifies common metrics for comparison
Unites multidisciplinary experts and scientific workloads

Benchmarks

Why benchmarks?

The model-development loop: build many candidate models, measure them against a suite of benchmarks, and let the scores steer the next round.



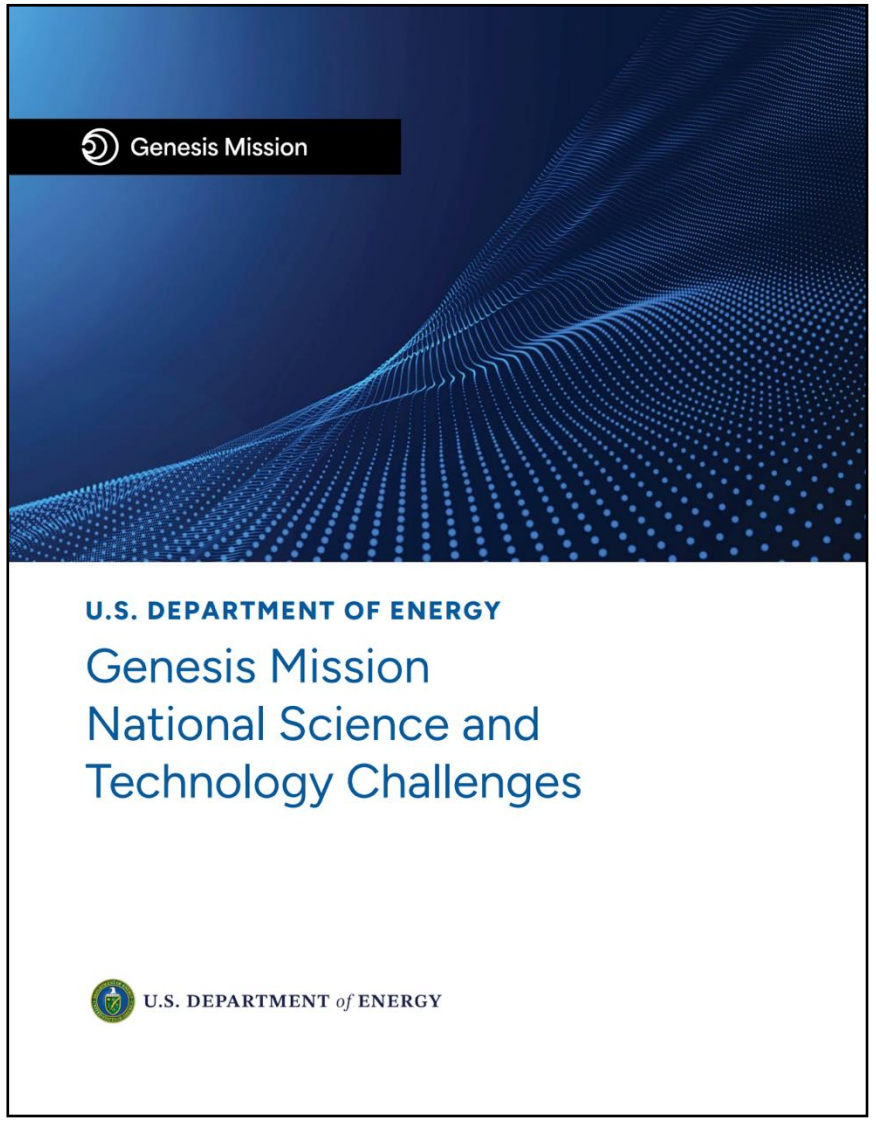
AI Frontier Labs build benchmarks constantly to power this loop and iterate thousands of times a day — you should too.

Build one scientific benchmark (or more) for your science and run the same loop!

Benchmarks

- Genesis is a good opportunity to define **the** benchmark problems needed to meet the national challenges

- Admirable benchmarking efforts exist in the community but need to be:
  - Holistic - to capture all aspects of scientific life cycle
  - Dynamic - continually adapted as progress is made
  - Championed



Parting thoughts

- AI is the big technological leap of this generation
  - Understand what it can (and can't do) (vs. time)

- With the rise of AI ***and Genesis Mission***:
  - We have an opportunity to do things fundamentally differently
  - We need **(!)** to do things fundamentally differently

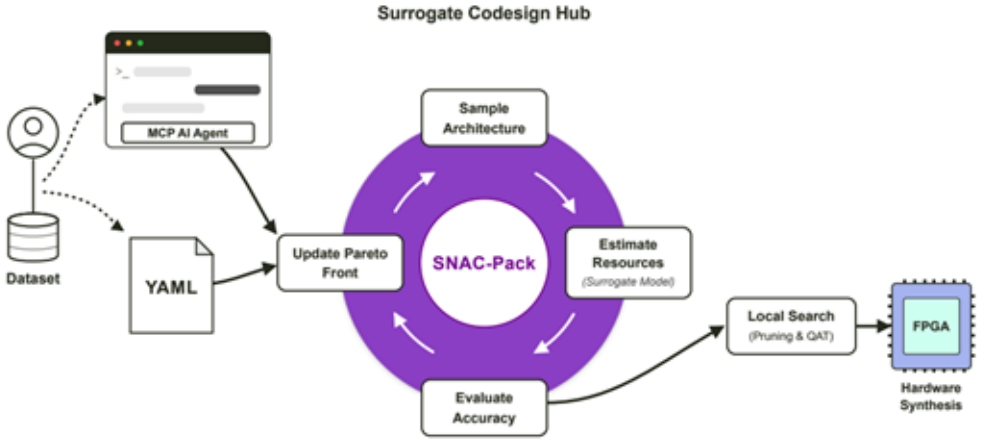


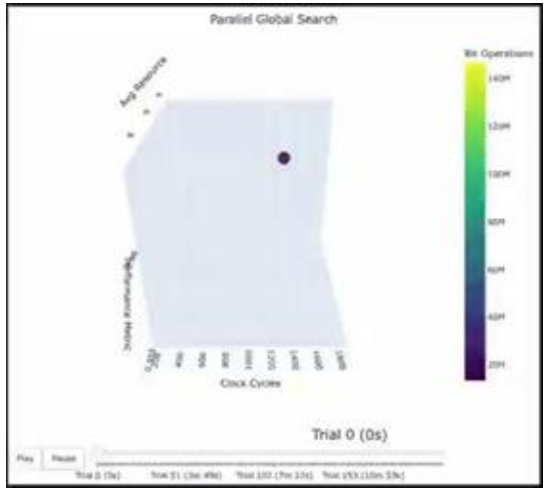
- **You** are the resource, understand what the frontier labs are doing
  - Data is (still) the foundation
  - Knowledge is encoded in our simulations, models, and domain expertise
  - Benchmarks define priority tasks and meaningful progress

Extra

Agentic Codesign Workflow

- SNAC-Pack embeds surrogate models in an agentic co-design loop
- Queries the surrogate instead of synthesizing every candidate
- Refines promising candidates with pruning and quantization-aware training
- Achievement:
  - **~500× faster design phase** for qubit readout hardware accelerator
  - Faster, smaller FPGA implementation: **~33% lower latency**, **~54% fewer LUTs**





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AMD

References

J. Weitz *et al.*, "Surrogate Neural Architecture Codesign Package (SNAC-Pack)", arXiv:2605.16138, 2026

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