

Hardware-Aware AI for HEP

Research Review Webinar
May 29th, 2024

Jeremy Love & Eric Church

Computational HEP

Jeremy.Love@science.doe.gov Eric.Church@science.doe.gov



U.S. DEPARTMENT OF
ENERGY

Office of
Science

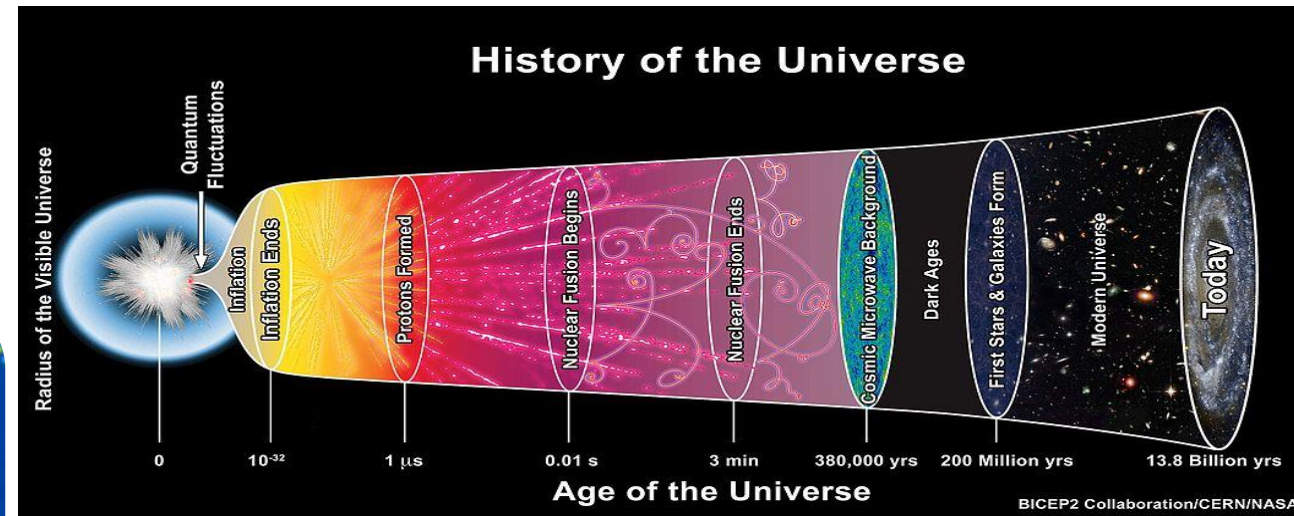
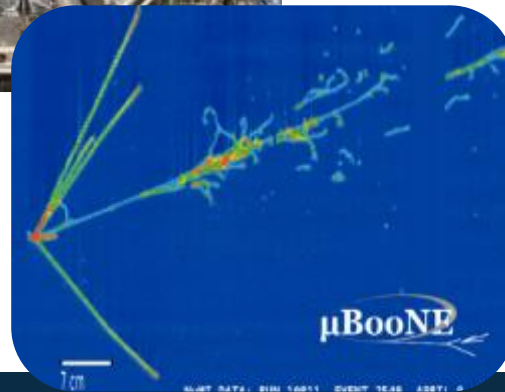
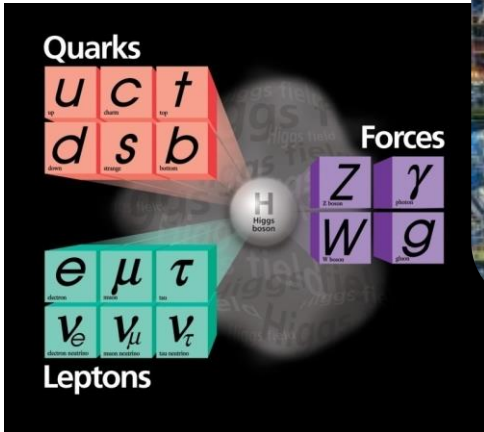
[Energy.gov/science](https://energy.gov/science)

Office of Science Statement of Commitment & other Guidance

- ◆ **SC Statement of Commitment** – SC is fully and unconditionally committed to fostering safe, diverse, equitable, inclusive, and accessible work, research, and funding environments that value mutual respect and personal integrity. <https://science.osti.gov/SW-DEI/SC-Statement-of-Commitment>
- ◆ **Expectations for Professional Behaviors** – SC’s expectations of all participants to positively contribute to a professional, inclusive meeting that fosters a safe and welcoming environment for conducting scientific business, as well as outlines behaviors that are unacceptable and potential ramifications for unprofessional behavior. <https://science.osti.gov/SW-DEI/DOE-Diversity-Equity-and-Inclusion-Policies/Harassment>
- ◆ **How to Address or Report Behaviors of Concern**– Process on how and who to report issues, including the distinction between reporting on unprofessional, disrespectful, or disruptive behaviors, and behaviors that constitute a violation of Federal civil rights statutes. <https://science.osti.gov/SW-DEI/DOE-Diversity-Equity-and-Inclusion-Policies/How-to-Report-a-Complaint>
- ◆ **Implicit Bias** – Be aware of implicit bias, understand its nature – everyone has them – and implicit bias if not mitigated can negatively impact the quality and inclusiveness of scientific discussions that contribute to a successful meeting. <https://kirwaninstitute.osu.edu/article/understanding-implicit-bias>

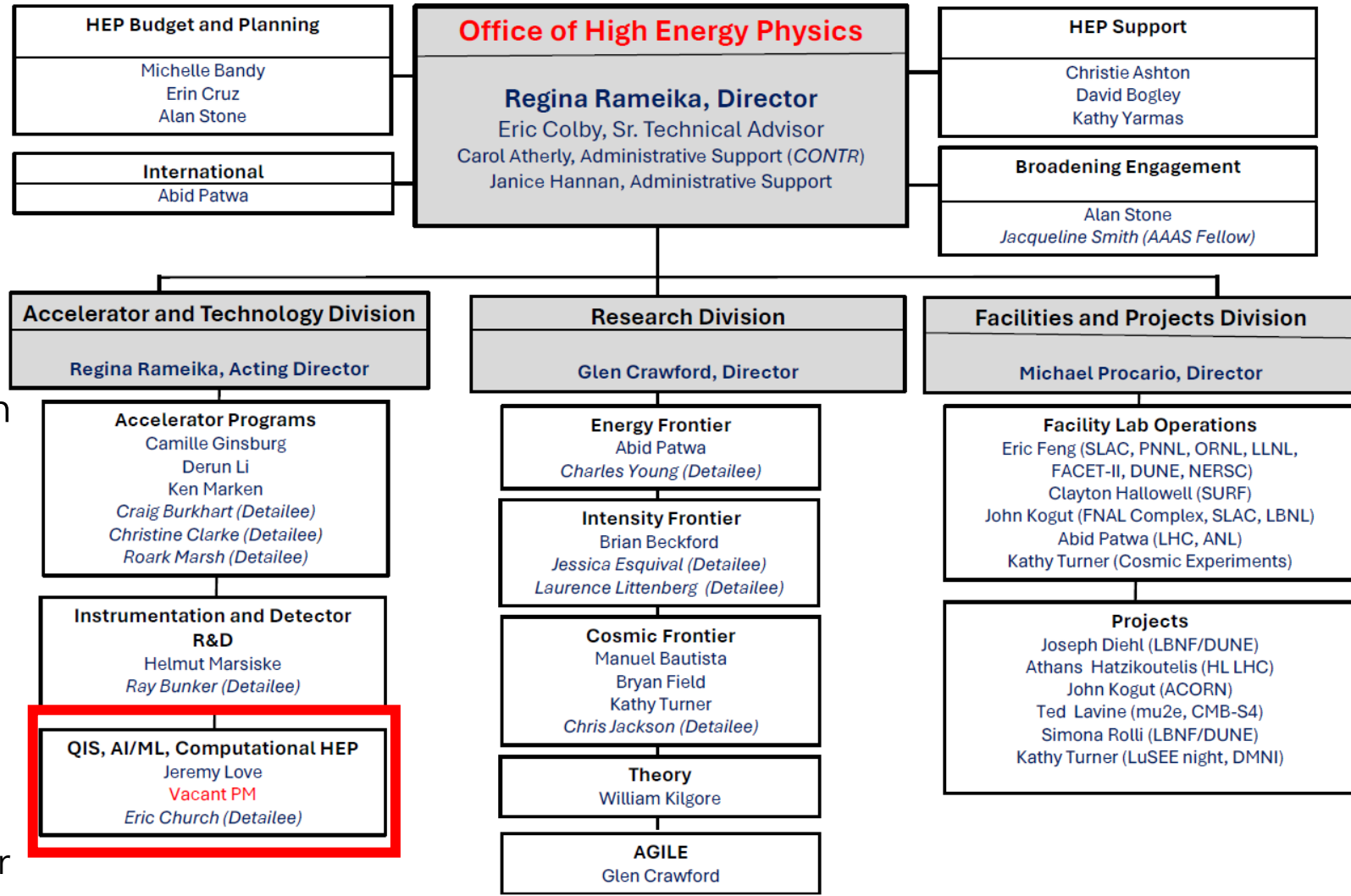
The Office of High Energy Physics (HEP) Program Mission

- ◆ DOE is a mission-oriented agency - mission includes **maintaining a vibrant U.S. effort in science and engineering as a cornerstone of our economic prosperity with clear leadership in strategic areas.**
- ◆ HEP's mission is to understand the universe at the most fundamental level:
 - **Discover** the elementary constituents of matter and energy
 - **Probe** interactions between them
 - **Explore** the basic nature of space and time
- ◆ DOE HEP supports ~85% of the U.S. HEP effort (in \$) at Universities and National Labs



DOE HEP Organization

- ◆ The Office of High Energy Physics is organized into three divisions
 - Research, Facilities, and Technology
- ◆ All three are needed to achieve the field's long-term goals
 - Technology Division - supports Crosscutting HEP subprograms in enabling technologies: Accelerator Programs, Instrumentation and Detector R&D, Quantum Information Science, and Computational HEP and AI/ML Initiative
 - Work in emerging technologies allow for new facilities and experiments, more efficient Operations, and previously impossible discoveries
 - Provide broader impact on other science programs and society



AI/ML Initiative



U.S. DEPARTMENT OF
ENERGY

Office of
Science

[Energy.gov/science](https://www.energy.gov/science)

Why Invest in HEP AI Research?

- ◆ Investment in AI/ML is a national strategic priority
 - Develop cutting edge tools and applications of AI/ML to maintain US expertise
 - Develop a technically capable workforce able to lead the economy of the future and speed-up societal benefits
- ◆ The [White House AI Executive Order](#) requested a report on "the potential role of AI, especially given recent developments in AI, in research aimed at tackling major societal and global challenges."
 - Delivered in April 2024 [PCAST Report "Supercharging Research: Harnessing Artificial Intelligence to Meet Global Challenges"](#)

“The cosmologists and particle physicists ... **are some of the earliest adopters—and developers—of AI**, so an epoch of advanced AI is an epoch of exciting discoveries in fundamental physics and cosmology.”

“Fundamental physics and cosmology are built on statistical analyses of data to test theory, so they require a deep understanding of the probabilities in the interpretation of data. **This requirement is driving the mathematical development of AI that can handle probabilistic rigor.** ... Assessing uncertainties is crucial for fundamental physics, and **probabilistically rigorous AI would be a game changer for many other fields of science as well, in addition to being invaluable for applications beyond science.**”

- ◆ Our community is recognized as early adopters and developers of cutting-edge AI techniques, and a uniquely statistically rigorous and data driven field.
 - AI/ML techniques are embedded throughout our programs
- ◆ Investments in the AI Initiative are an investment in HEP Research - not a zero-sum game
 - As early adopters, HEP also benefits from AI research by other sciences

AI Initiative in HEP

- ◆ For decades physics papers from all HEP subprograms have utilized and developed cutting edge AI/ML techniques
 - Pattern recognition, ML-assisted simulation, data classification, uncertainty quantification, real-time applications, etc.
- ◆ DOE HEP is pursuing research into AI/ML topics in two broad thrusts
 - **Programmatic AI/ML** - Furthers each subprograms pursuit of the P5 Science Drivers through integrated/embedded in the frontier programs.
 - Applications within a given frontier where primarily ML techniques are the best ones suited to accomplish the research.
 - This is approximately 85% of HEP's current AI/ML activities.
 - **Core AI/ML** - research into AI/ML topics from an HEP perspective and blue-sky R&D necessary to enable future HEP breakthroughs across frontiers
 - Go well beyond what is standard practice either through development of new methods, systems, or applications; or studying fundamental AI techniques and their limitations

Core AI/ML Research

- ◆ Core AI/ML strategic focus:
 - **AI for HEP** – AI research that furthers HEP priorities of pursuing the P5 science drivers
 - Innovative applications of AI tools and techniques or demonstrations and development of new capabilities not currently available to HEP researchers and go well beyond **Programmatic AI/ML**
 - **HEP for AI** – AI research that makes use of unique aspects of the HEP (datasets, theory, etc.) to improve understanding of the theoretical capabilities and limitations of fundamental AI techniques
 - **HEP AI Ecosystem** – Production of open datasets, software ecosystems, or access to shared computing resources that enable broad democratic participation in AI research for HEP
 - Including democratic participation from historically underserved communities
- ◆ Supported through dedicated FOAs and strategic projects
 - Data Science and Machine Learning for Scientific User Facilities FY20
 - Artificial Intelligence Research in High Energy Physics FY22
 - Hardware-Aware AI for HEP FY24/FY25
 - University Comparative Review beginning in FY25
 - Early Career Research Program since FY24

Hardware-Aware AI for HEP LAB 24-3305

HEP POC: Jeremy Love

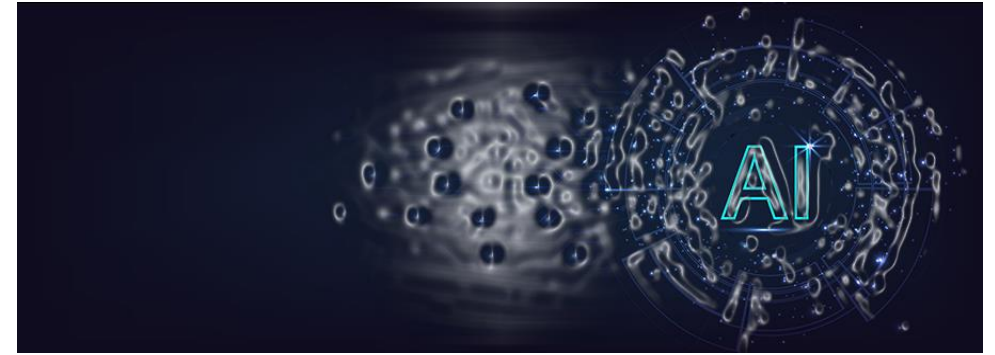
Lab Call Issued : May 1

- ◆ University PIs may submit proposals in this area for a [Research review through the SC Open Call FOA-3177](#)

Pre-applications/LOIs due: June 26

Full applications due: July 24

<https://science.osti.gov/hep/Research/Artificial-Intelligence-AI>



- ◆ DOE HEP intends to hold a review for new ambitious research projects where detailed knowledge of HEP hardware systems informs the AI techniques and methods required for implementation
- ◆ Applications are sought in two broad categories
 - **Smart Detectors** - Intelligence on detector in readout and control electronics
 - **AI for Operations** - AI/ML for improved experiment and facility operations and control
- ◆ Multi-institution team applications are allowed. See lab call for details.
- ◆ Limited to [two applications per lab](#) (as lead institution). No restriction on number of submissions as subawardee. No restrictions on number of submissions per PI.

| Application Track | Award Floor (Annual) | Award Ceiling (Annual) | Award Duration |
|-------------------|----------------------|------------------------|----------------|
| Lab Application | \$350,000 | \$3,000,000 | 3 years |
| University Review | \$100,000 | \$350,000 | 3 years |

Hardware-Aware AI for HEP

- ◆ HEP Hardware for this opportunity are an HEP specific detector or sensor technology deployed in HEP experiments and facilities or under development for future HEP applications including Application Specific Integrated Circuits (ASICs) and readout electronics that provide real-time operation of facilities, experiments, and observatories.
- ◆ **Smart Detectors** – Informed by the [Advanced Detector BRN](#) seek applications that move intelligence as close to the sense element as possible.
- ◆ **AI for Operations** – Continuation and broadening of the Data Science and Machine Learning for Scientific User Facilities
- ◆ Applications targeting a specific accelerator, experiment, observatory, etc. are encouraged to obtain letters of collaboration from an appropriate representative to assure reviewers that the stated impact of the project will be realized and there is a willingness to adopt and support the system after the project period.
- ◆ Multi-disciplinary partnerships with non-traditional HEP institutions and PIs are encouraged
 - Especially when those individuals or institutions bring unique and necessary expertise to the project
- ◆ Topics considered out of scope:
 - Widely available computational hardware and accelerators such as CPUs, GPUs, FPGAs, or Quantum Processors as well as emulations of those systems are not considered Hardware systems as defined for this call.
 - These computing platforms may be used but details of these computational hardware alone is insufficient
 - Proposals for applications that rely on detailed knowledge of HEP Hardware for offline or post-shifter/operator applications

Smart Detectors

- ◆ **Smart Detectors** – Applications that move intelligence as close to the sense element as possible to distribute intelligence across HEP Hardware systems
 - This may include applications for real time readout or control in ASICs or FPGAs but is not required to do so
- ◆ AI research is sought into algorithms or development of intellectual property blocks that improves the ability of HEP Hardware systems to meet their functional requirements and improve operations robustness
 - Data processing or improved control and configuration of HEP hardware systems
 - May target analog or digital circuits in ASICs or commercial off the shelf computational hardware as appropriate for the application
- ◆ Non-traditional trigger or data selection architectures with distributed or emergent intelligence are in scope.
 - Applications for ML-based algorithms used as input to traditional architectures with centralized decision making are not in scope.

AI for Operations

- ◆ **AI for Operations** -- AI systems that increase the productivity of facilities and experiments
 - By improving the efficiency and minimizing downtime, automating control of complex systems, reducing time to optimal conditions
 - Improve the quality of data recorded through enhanced monitoring, lowering the expertise of expertise needed to interpret HEP Hardware systems status data, perform complex actions, and reduce the level of human intervention necessary
- ◆ All HEP accelerators, experiments, experimental facilities, test facilities, observatories, user facilities, etc. are considered HEP Hardware systems
 - Proposals for real-time AI applications up to a human shifter or operator of the HEP Hardware system are considered in scope
- ◆ AI applications that help human shifters accomplish operations tasks and build confidence in autonomous systems are in scope
- ◆ Applications should propose the appropriate computational hardware for the system under development

Frequently Asked Questions



U.S. DEPARTMENT OF
ENERGY

Office of
Science

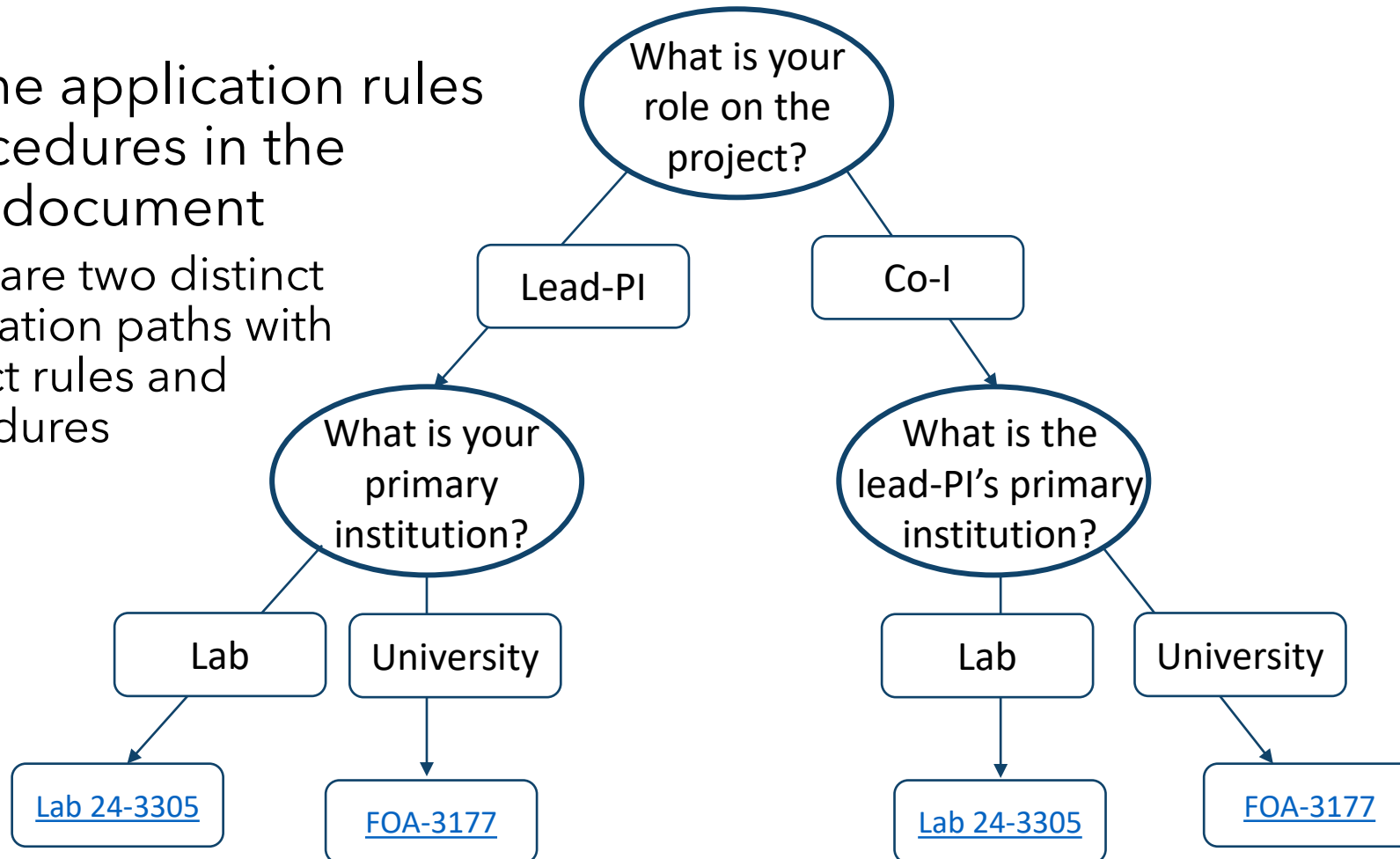
[Energy.gov/science](https://www.energy.gov/science)

Application Paths

- ◆ There are two distinct application paths for this research opportunity
 - There will be a concurrent review of the applications received through both paths
- ◆ DOE Labs
 - Apply through the call LAB 24-3305
 - May submit two applications
 - Both can be in one of the topic areas should the lab choose to do so
 - The Lead-PI of the application is expected to charge 20% of their effort to an award
 - No restriction on participation in other applications
 - No restriction on co-Is or subaward PIs
 - Joint appointment lead-PIs must have 50% of their effort lab supported
 - May participate in other Labs or University applications as subawardee
- ◆ Due dates are identical for both paths
 - Pre-applications/Lols requested by **June 26th**
 - Expect to encourage all in scope Pre-apps and Lols received, they are used to begin identifying reviewers
 - For full consideration applications due by **July 24th**
- ◆ Universities and other eligible institutions
 - Apply through the Open Call FOA-3177
 - [Topics and process described on research review page](#)
 - No restriction on number of applications
 - Emphasis should be on quality not quantity
 - No restrictions on PI time
 - May participate as subaward in Lab and other University applications

Where to Apply:

- ◆ Follow the application rules and procedures in the relevant document
 - There are two distinct application paths with distinct rules and procedures



Questions on Application Topics

- ◆ Is **X** topic AI?
 - AI for this opportunity are computational systems that respond to data and take action, without human intervention, to achieve a goal and the development of those systems. It includes validation and interpretation work beyond dataset cultivation, training, and algorithm optimization to allow trustworthy autonomous action by the computational system.
 - Projects that develop systems and tools to build toward fully autonomous trustworthy systems will also be considered.
- ◆ What does the Computational Hardware statement in the call mean?
 - Knowledge of computational Hardware CPUs, GPUs, FPGAs, ARM, Quantum Processors, etc. is insufficient for an application to be in scope. Any of these computational platforms may be used as part of a solution, but the application must target an HEP Hardware system to be in scope.
- ◆ Do I have to use a specific computing platform?
 - No. There is no expectation on the targeted computing system. PIs should propose to use the appropriate computing system for the application.
- ◆ I work on **X** accelerator/experiment/facility/observatory is it HEP Hardware?
 - The intention is to include all accelerators, experiments, facilities, observatories, etc. that are used to address HEP research questions.
- ◆ I work on **X** detector technology that is not currently included in an HEP accelerator/experiment/facility/observatory is **X** HEP Hardware?
 - If **X** is in development or under consideration for a future accelerator, experiment, facility, observatory, etc. that will be used to address HEP research questions it is included as HEP Hardware.

Questions on Application Topics

- ◆ Is **X** technique applied to **Y** technology in scope?
 - If **X** is AI and **Y** is an HEP Hardware system, the application is in scope.
- ◆ I am funded to work on **X** AI technique applied to **Y** HEP Hardware, can I apply for **Z** AI technique applied to **Y** HEP Hardware?
 - Yes. However, **Z** must be applied for new capabilities/problems solved/etc. for **Y** HEP Hardware.
 - In general, support is provided for researchers to work on an application with the most relevant AI/ML approach. Researchers are expected to the best approach and so **Z** is viewed as part of existing support if it is addressing the same research questions.
- ◆ Can I apply for trigger or real-time data selection systems?
 - Applications for ML-based input to traditional architectures with centralized decision making are not in scope.
 - Non-traditional trigger or data selection architectures with distributed intelligence are in scope.
- ◆ Are Quantum systems and Quantum Machine Learning in scope?
 - Real-time control of HEP relevant quantum systems is in scope.
 - Applications for Quantum Machine Learning are not in scope but may be relevant to the [QuantISED 2.0 FOA](#).

Questions on Application Topics

- ◆ Are Digital Twins of HEP Hardware systems in scope?
 - If the application is real-time it is in scope.
- ◆ What does real-time mean for this review?
 - Directly impacting data taking or operations efficiency. Performance of the AI system would affect the quality or efficiency of data being collected. Generally, this is up to a control room shifter or on-call expert.
- ◆ I only have experience in AI or HEP Hardware systems can I apply?
 - Partnerships are encouraged. In particular, teams with the relevant expertise to accomplish the research. Individuals are not expected to be experts in all aspects of a project but the team should have all expertise needed.
- ◆ Are Renewals allowed for awards from the Data Science and Machine Learning for Scientific User Facilities Call?
 - No renewals applications are allowed. All applications must be for new research activities.
- ◆ Will the review prioritize blue-sky R&D vs algorithm development vs fabrication projects?
 - The review will be structured to identify meritorious proposals of all three types and build a balanced portfolio of forward-looking R&D activities as well as projects that will deliver positive impact on the field during the anticipated three-year period

Questions?



U.S. DEPARTMENT OF
ENERGY

Office of
Science

[Energy.gov/science](https://www.energy.gov/science)