High Energy Physics (HEP) Office Hours

Technology Initiatives and HEP Core Research

Glen Crawford, Jeremy Love, Helmut Marsiske

May 21, 2024

Office of High Energy Physics

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 biases – everyone has them – and understand their nature. 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

HEP Office Hours

https://science.osti.gov/hep/officehours

- **Introduction to HEP and Program Mission:** March 19, 2024
- **Funding Opportunities for Early Career Researchers:** April 16, 2024
- **Technology Initiatives and HEP Core Research:** May 21, 2024
- **How to Navigate the DOE Funding Process:** June 18, 2024

Tell Your Friends!

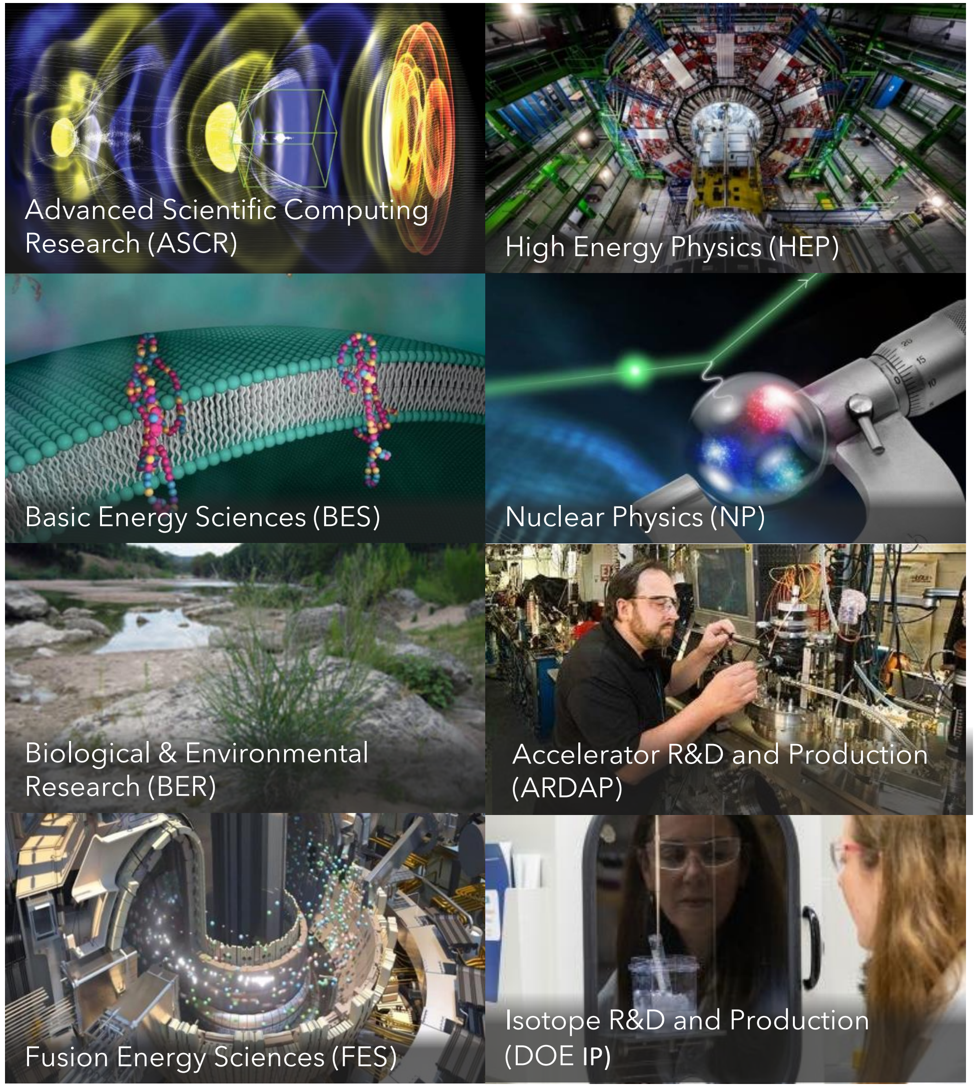
Join us on the **third Tuesday of each month**, 2-3 pm Eastern Time, for virtual office hours to learn about our programs and ask questions. Researchers, educators, and research administrators from all institutional types are encouraged to join. A primary goal of the virtual office hours is to broaden awareness of our programs; no prior history of funding from DOE is required to join. Program managers will be available to answer questions. **Registration is required for attendance.** Please use an institutional email address to complete the registration process.

There are also office hours for Advanced Scientific Computing Research (**ASCR**), Basic Energy Sciences (**BES**), Biological and Environmental Research (**BER**), Fusion Energy Science (**FES**), Nuclear Physics (**NP**), Accelerator R&D and Production (**ARDP**), and Isotope R&D and Production (**IP**); see SC program websites

Office of Science (SC) Research Programs and Offices

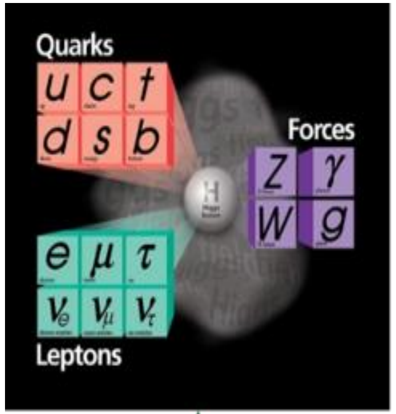
- Advanced Scientific Computing Research
- Basic Energy Sciences
- Biological & Environmental Research
- Fusion Energy Sciences
- High Energy Physics
  - Accelerator R&D and Production
- Nuclear Physics
- Office of Isotope R&D and Production

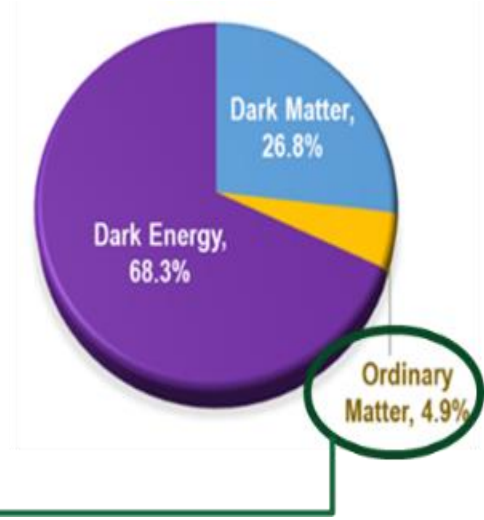
- DOE Office of Science is the nation's largest supporter of basic research in the physical sciences and the steward of 10 (out of 17) DOE national laboratories



Office of High Energy Physics (HEP) Mission

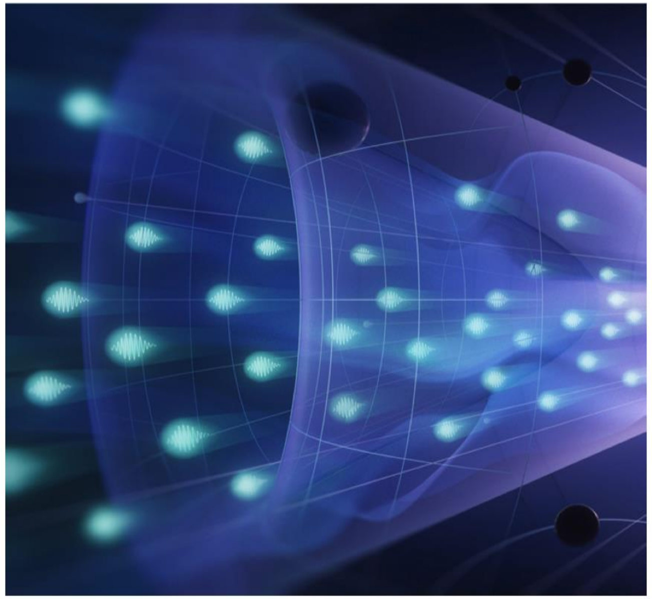
- Understanding how the universe works at its most fundamental level by
  - Discovering the elementary constituents of matter and energy
  - Probing the interactions between them
  - Exploring the basic nature of space and time





In pursuit of its mission HEP conducts cutting-edge discovery science by
- Executing Equipment and Facility Projects
- Operating Facilities and Experiments
- Conducting a Research program

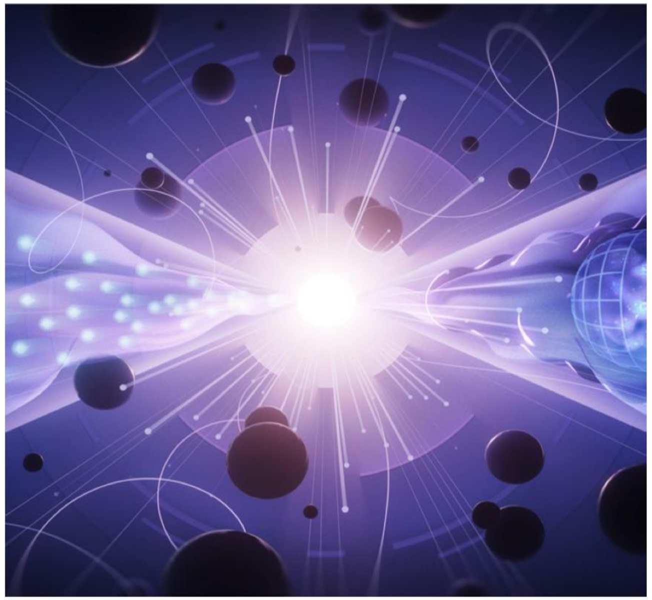
2023 Particle Physics Project Prioritization Panel (P5)
HEP Science Drivers



Decipher the Quantum Realm

Elucidate the Mysteries of Neutrinos

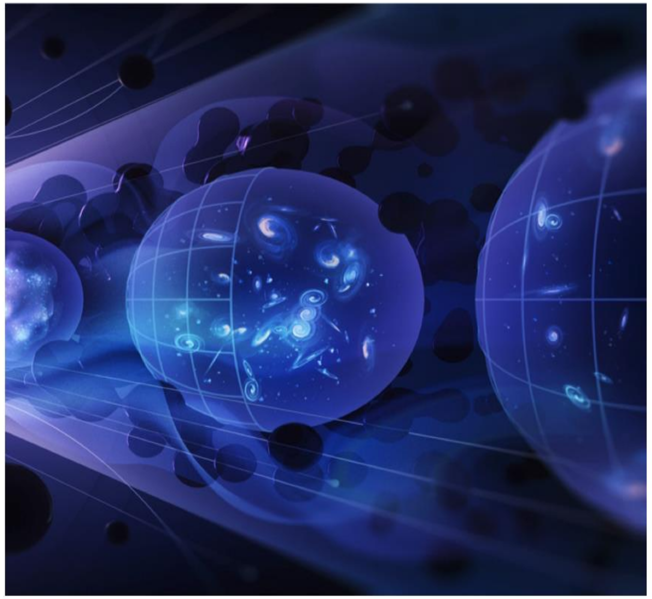
Reveal the Secrets of the Higgs Boson



Explore New Paradigms in Physics

Search for Direct Evidence of New Particles

Pursue Quantum Imprints of New Phenomena



Illuminate the Hidden Universe

Determine the Nature of Dark Matter

Understand What Drives Cosmic Evolution

https://science.osti.gov/-/media/hep/hepap/pdf/Reports/2024/2023_P5_Report_Single_Pages.pdf

HEP Research and Technology

Colliders to the Cosmos

HEP Research is organized along three "Frontiers"

- **Energy Frontier**: experiments utilizing high-energy accelerators
- **Intensity Frontier**: experiments utilizing high-intensity accelerators (and sometimes reactors)
- **Cosmic Frontier**: experiments using naturally occurring cosmic particles and phenomena

Supported by cross-cutting research efforts:

- Theoretical physics
- General Accelerator R&D (GARD)
- **Detector R&D and Microelectronics (ME)**
- Computational HEP and **Artificial Intelligence/Machine Learning (AI/ML)**
- **Quantum Information Science (QIS)**

Office of High Energy Physics

Regina Rameika, Director
Eric Colby, Sr. Technical Advisor
Carol Atherly, Administrative Support (*CONTR*)
Janice Hannan, Administrative Support

HEP Budget and Planning
Michelle Bandy
Erin Cruz
Alan Stone

International Cooperation
Abid Patwa

HEP Support
Christie Ashton
David Bogley
Kathy Yarmas

Broadening Engagement
Alan Stone
Jacqueline Smith (AAAS Fellow)

Accelerator and Technology Division

Regina Rameika, Acting Director

Accelerator Programs
Camille Ginsburg
Derun Li
Ken Marken
Craig Burkhart (Detailee)
Christine Clarke (Detailee)
Roark Marsh (Detailee)

Detector R&D and Microelectronics
Helmut Marsiske
Ray Bunker (Detailee)

Computational HEP, AI/ML, QIS
Jeremy Love
Vacant PM (Acting: *Glen Crawford & Abid Patwa)*
Eric Church (Detailee)

Research Division

Glen Crawford, Director

Energy Frontier
Abid Patwa
Charles Young (Detailee)

Intensity Frontier
Brian Beckford
Jessica Esquivel (Detailee)
Laurence Littenberg (Detailee)

Cosmic Frontier
Manuel Bautista
Bryan Field
Kathy Turner
Chris Jackson (Detailee)

Theory
William Kilgore

AGILE
Glen Crawford

Facilities and Projects Division

Michael Procario, Director

Facility Lab Operations
Eric Feng (FACET-II, DUNE, NERSC)
Clayton Hallowell (SURF)
John Kogut (FNAL, BNL, SLAC, LBNL)
Abid Patwa (LHC, ANL)
Kathy Turner (Cosmic Experiments)

Projects
Joseph Diehl (LBNF/DUNE)
Athans Hatzikoutelis (HL LHC)
John Kogut (ACORN)
Ted Lavine (mu2e, CMB-S4)
Simona Rolli (LBNF/DUNE)
Kathy Turner (LuSEE night, DMNI)

HEP and SC Technology Research Efforts

- (Generic) Detector R&D is a HEP core research subprogram
  - Develop potentially transformative, broadly applicable technologies; not in the business of optimizing the technology of any particular (single) experiment
- The corresponding program for accelerators – General Accelerator R&D (GARD) – will be covered in a future Office Hour

- Three government-/SC-wide Technology Initiatives with close ties to HEP
  - Microelectronics (ME)
  - Artificial Intelligence/Machine Learning (AI/ML)
  - Quantum Information Science (QIS)

- For associated funding opportunities and FAQs see https://science.osti.gov/hep/Funding-Opportunities

HEP Detector R&D Goals

- Support research leading to fundamental advances in the science of particle detection, and develop the technologies for the next generation of instrumentation for HEP
- Provide (under)graduate and post-doctoral research training in instrumentation to foster the next generation of detector experts
- Support "infrastructure"–technical personnel, equipment, "facilities", and test beams–required for experimental detector R&D and fabrication

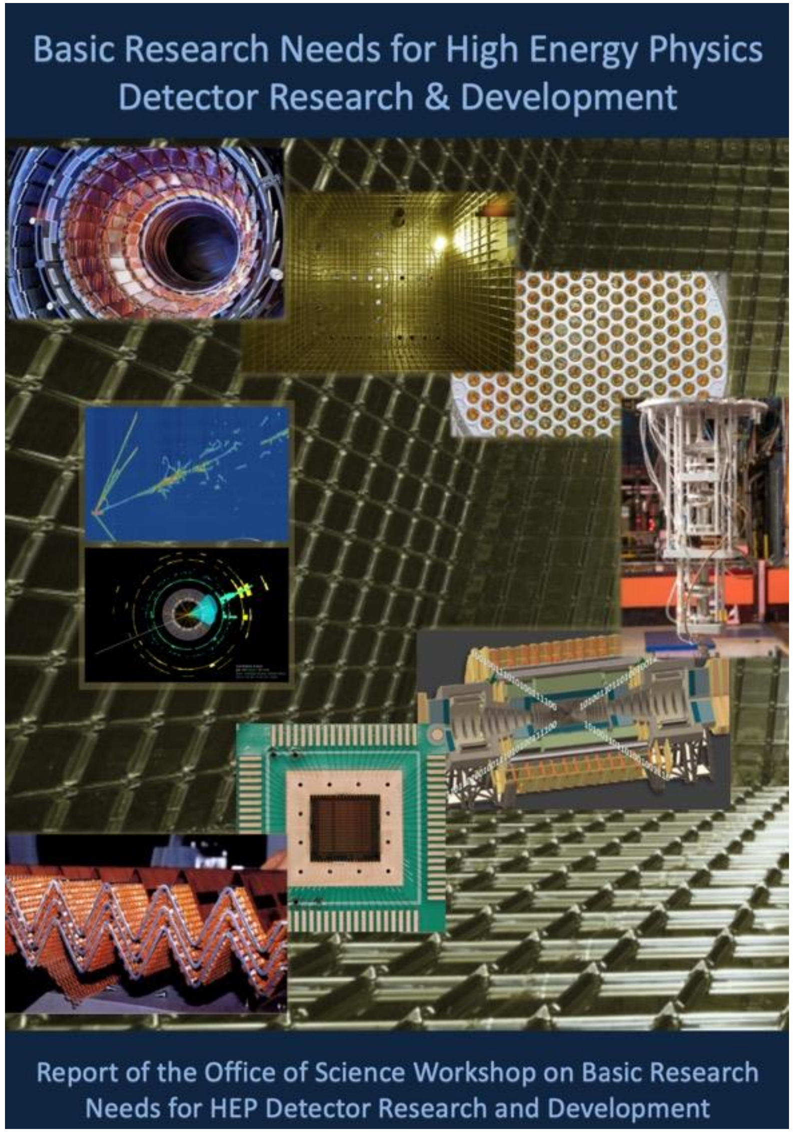
HEP Detector R&D Program

- Forward-looking, broad Detector R&D program in support of all research efforts in the Cosmic, Energy, and Intensity Frontiers
- Supports scientific and technical personnel and equipment at nine DOE national labs and more than 20 universities
  - University support focused on junior scientific personnel (students, post-docs, and junior faculty); some support for technical personnel and (small) equipment
- Operates and maintains large-scale facilities/test-beams and sizable hardware installations at multiple national labs
  - E.g., Fermilab silicon detector lab, liquid argon test stands, and test beam facility/irradiation test area; LBNL microsystems lab

HEP Detector R&D Program, cont.

- Project portfolio aims to improve existing technologies for the next round of HEP experiments; more importantly, aims to discover and mature new, transformative technologies for far-future HEP experiments – "Blue Sky" R&D
  - Priority research directions identified in Basic Research Needs Study

  https://science.osti.gov/-/media/hep/pdf/Reports/2020/DOE_Basic_Research_Needs_Study_on_High_Energy_Physics.pdf
- Synergistic with SC-wide initiatives in ME, AI/ML, and QIS



HEP Detector R&D in the University Comparative Review

DE-FOA-0003177

- **FY 2025 call for proposals issued as part of FY24 SC Open Call**
- Applications for support of HEP research activities in any of the six areas identified below may be submitted to this FOA. HEP expects to convene comparative merit review panels on a yearly basis, as described below, for both New and Renewal applications devoted to these research activities.
  - Experimental HEP: **Energy Frontier, Intensity Frontier, Cosmic Frontier**
  - Technology R&D: **General Accelerator R&D (GARD), Detector R&D**
  - Theoretical HEP: **Theory**

Pre-applications due: August 1
Full applications due: September 5

- HEP allows applications from single institutions that span multiple research areas described in this FOA, including applications that span multiple HEP subprograms (a.k.a “umbrellas”), as well as single research area applications from multi-institutional consortia
- The Detector R&D subprogram also participates in several other HEP FOAs/LABs
  - Early Career Research Program
  - U.S.-Japan Science and Technology Cooperation Program In High Energy Physics
  - HEP Traineeships

Microelectronics in SC/HEP

[SC Report: Basic Research Needs for Microelectronics]

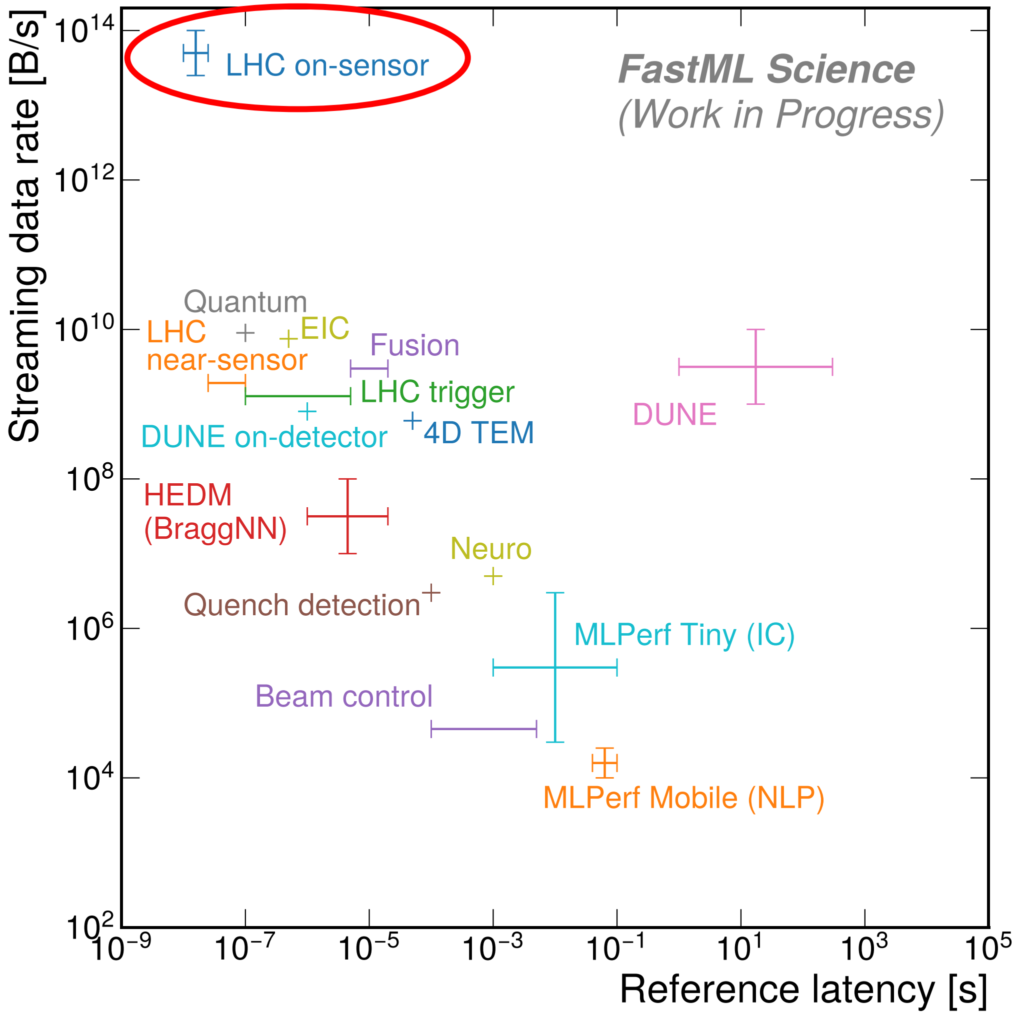
- Advanced microelectronics technologies underpin the DOE missions in Energy, Science/Innovation, and Security
- For decades DOE-SC has been at the leading edge of microelectronics, both as a consumer and as an engine of scientific understanding and technological innovation
- Multiple SC programs are contributing, from materials and surface chemistries/processing to devices to sensors to integrated circuits to (edge) micro processors to networks to high-performance computing architectures, algorithms, and software
- In FY 2021, Microelectronics Co-design LAB call with ASCR, BES, FES, HEP, and NP programs participating and co-funding awards
- In FY 2022, the CHIPS and Science Act appropriated (DOC, DOD, NSF)/authorized (DOE) significant funding for microelectronics activities across the government

Microelectronics for HEP <-> HEP for Microelectronics

- Sensors and integrated front-end electronics (both analog and digital) have become extremely complex high-speed, high-performance components, often located in extreme radiation or temperature environments and with stringent power limitations
- Sophisticated on-detector, low-latency data denoising, compression, and categorization are increasingly critical as data volumes accelerate and exceed off-detector communication bandwidth → energy-efficient real-time edge computing using new architectures and paradigms; e.g., neuromorphic and AI/ML

- Extremely demanding HEP requirements often go far beyond what's available commercially and drive developments that are sure to find uses in other science fields, medicine, security, and industry

HEP Grand Challenges Driving Innovation



- **Driver for novel chip designs/ detectors:** driven by some of the most challenging constraints/requirements on power, area, latency, efficiency, performance
- **Impactful solutions:** lead to next generation of medical and industrial detectors
- **Benchmarks** to drive innovation in industry
- **Democratizing** innovation by creation of open source tools and hardware
- **Edge AI/ML** for solving data challenges for BES, NP, FES and Quantum applications
- Advanced AI/ML techniques and tools for efficient **hybrid architectures**

Selected Areas of HEP Microelectronics Expertise

- Application Specific Integrated Circuit (ASIC) design
  - Low Temperatures [Cryogenic (mK – to 100K)]
  - High radiation (beyond Grad)
  - Ultra-fast timing (better than 10 ps)
- System Co-design: Sensors + ASICs + Integration + Architectures + Algorithms
  - Principle of "codesign" is a primary theme of the 2018 DOE ME BRN report.
  - Focus on HW-SW co-design for AI/ML algorithms
  - Extreme data rates for HEP/QIS
- System integration
  - Heterogeneous structures: Sensing + edge Computing + Communication
  - High-density interconnects
  - Advanced packaging
- Characterization and testing of systems
  - Unique cryogenic and radiation facilities, high throughput testing capabilities
- Design tool development
  - Niche open-source tools and methodologies to complement existing CAD-EDA tools for custom applications

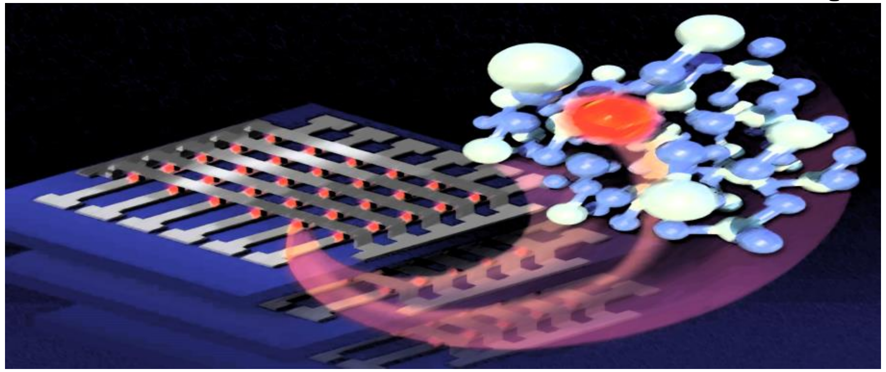
Microelectronics Science Research Center (MSRC) Projects

LAB call Issued : May 8

Pre-applications due: May 30

Pre-application response date: June 20

Full applications due: July 25



LAB 24-3320

HEP POC: Helmut Marsiske

- Each center will have a focus either on energy efficiency or on extreme environments **and is comprised of a *network of awards***
- Labs must be lead institution; teaming arrangements with other labs, universities, and industry strongly encouraged
- Proposals are requested for fundamental scientific research in the following four Research Areas:
  - 1. New or improved materials, surface processing and control, chemistry, synthesis, and fabrication
  - 2. Advanced computing paradigms and architectures
  - 3. Integrated sensing, edge computing, and communication
  - 4. Processing in extreme environments, radiation, radiation transport, and materials interaction
- Each Pre-Proposal and Proposal in response to this funding opportunity is encouraged to propose research that is integrated across at least two of these areas.

Application Track	Award Floor (Annual)	Award Ceiling (Annual)	Award Duration
Lab Application	$750,000	$3,000,000	4 years

Artificial Intelligence/Machine Learning in SC/HEP

- 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.**"

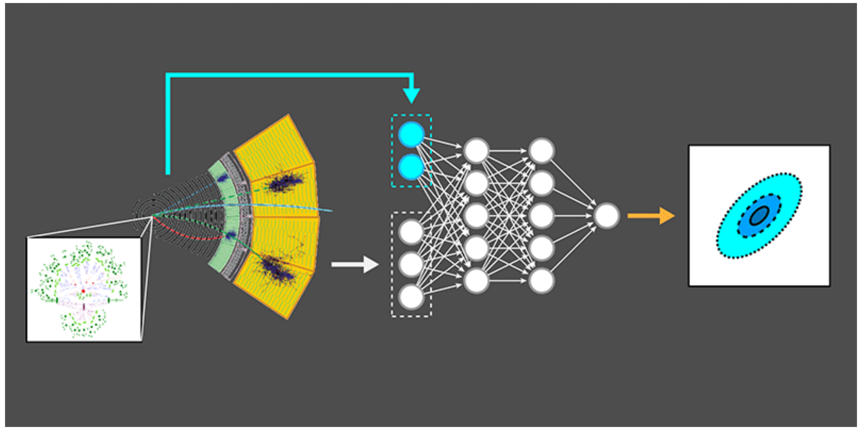
- Investment in AI research is an investment in HEP Science – not a zero-sum game
  - As an early adopter HEP benefits from AI research by other sciences
- Our community is recognized as users and developers of cutting-edge AI techniques, and a uniquely statistically rigorous and data driven field.
  - AI/ML techniques are embedded throughout all aspects of the HEP programs

AI/ML for HEP <-> HEP for AI/ML

- For decades physics analyses 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 subprogram’s pursuit of the P5 Science Drivers through integrated/embedded AI/ML use in the frontier programs.
    - Applications within a given frontier where primarily ML techniques are the best ones suited to improve physics results.
    - This is approximately 85% of our 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 the study of fundamental AI techniques and their limitations

Programmatic AI/ML Research

- Research making use of existing AI/ML techniques in HEP context
  - Research that furthers the goals of the HEP subprograms
    - Administered by Subprogram PMs; contact with any questions
  - Value of the work should be subprogram science regardless of method
    - Programmatic AI/ML research is when the best techniques to improve a result happen to be ML
- Programmatic AI/ML Research is supported as a part of general HEP FOAs: Early Career, Open Call (University Comparative Review), US-Japan, etc.
  - ML methods and techniques are expected to be described at an appropriate level just like any other technical work
    - Reviewers must be able to identify what work is being done, who is doing it, and what level of their time is needed to carryout the ML activities.



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
  - Exa.TrkX – using exascale computing to develop Graph Neural Nets for LArTPC and tracking detector reconstruction
  - 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

Hardware-Aware AI for HEP

LAB 24-3305

Lab Call Issued : May 1

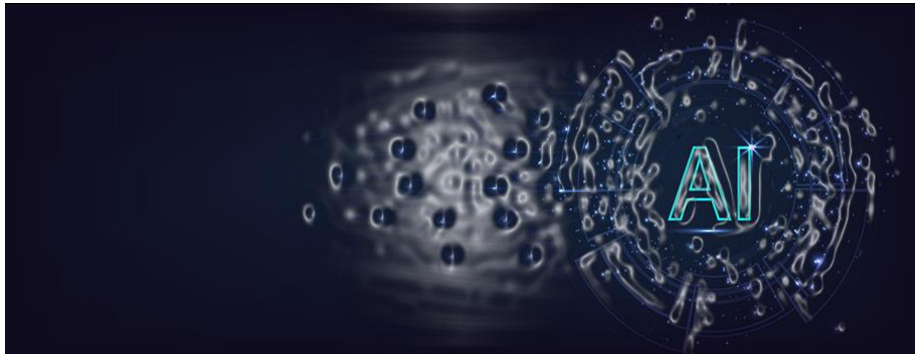
- University PIs may submit proposals in this area for a Research review through the SC Open Call FOA-3177

Pre-applications/LOIs due: June 26

Full applications due: July 24

Webinar date : May 29. Registration required.

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



HEP POC: Jeremy Love

- 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

Quantum Information Science in SC

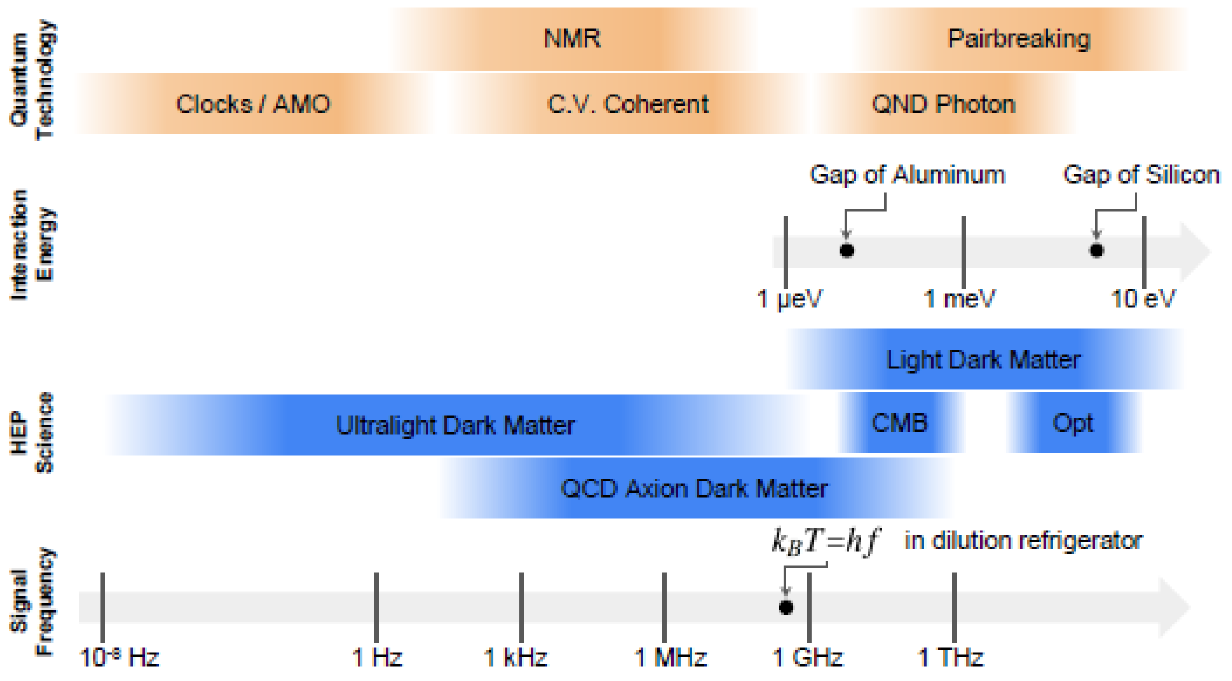
- The DOE Office of Science is an integral partner in the National Quantum Initiative (NQI) and has launched a range of research programs in QIS, leveraging SC's unique strengths and capabilities
- SC is targeting four major application areas for QIS:
  - Quantum computing for scientific simulations, optimization, and machine learning
  - Analog quantum simulation of physical quantum systems like materials and chemicals
  - Quantum communication for secure encryption and cybersecurity
  - Quantum sensing and microscopy for highly sensitive measurements
- In FY 2020 SC established five National Quantum Information Science Research Centers (NQISRCs) as part of the National Quantum Initiative (NQI); one is led by HEP researchers and hosted at Fermilab:
  - SQMS (Superconducting Quantum Materials and Systems Center)
    - 31 partner institutions; over 500 collaborators

QIS for HEP <-> HEP for QIS

- The HEP-QIS research program has been developed via a series of community round tables, pilot studies, and workshops since 2014; see https://science.osti.gov/hep/Community-Resources/Reports and https://arxiv.org/abs/2311.01930
- HEP issued Funding Opportunity Announcements "Quantum Information Science Enabled Discovery (QuantISED)" in FY 2018 and FY 2019; awards Abstracts can be found here
- HEP-QIS supports
  - Foundational quantum theory and quantum simulations
  - QIS-enabled quantum sensors enabling novel experiments to explore new HEP physics
  - HEP-developed theoretical and experimental techniques/technologies for QIS

QIS for HEP: Quantum Sensing

- QIS exploits quantum properties such as coherence, superposition, entanglement and squeezing and combines them with elements of information science to acquire, communicate and process information beyond what classical approaches can achieve
- Going beyond the Standard Quantum Limit (SQL): precisely controlled quantum systems can overcome the noise that quantum fluctuations produce and can achieve sensitivity and resolution that is superior compared to conventional (classical) measurement approaches ➔ precision measurements of the magnitude, direction and phase shifts of fields
- Prime example: searching for (ultra) low-mass dark matter particles over a huge mass range employing a multitude of technologies
- Clocks / AMO (clocks, ion traps, neutral atom interferometers); nuclear magnetic resonance (NMR) with spin ensembles; Continuous Variable (C.V.) Coherent (including parametric amplifiers, radio-frequency quantum upconverters); Quantum Non-Demolition (QND) Photon sensors (including qubits, Rydberg atoms); and Superconducting Pairbreaking detectors (including superconducting transition-edge sensors (TES), microwave kinetic inductance detectors (MKIDs), superconducting nanowire single photon detectors (SNSPDs)).



HEP-QIS : QuantISED 2.0

DE-FOA-0003354

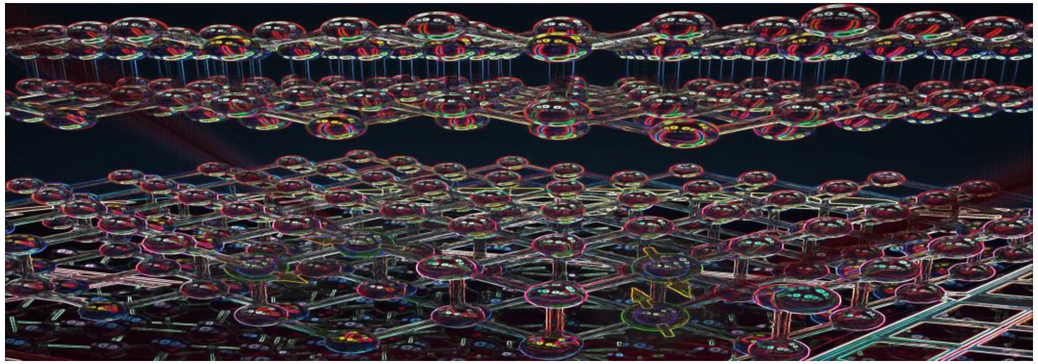
FOA Issued : May 7

Optional LOIs due: June 18

LOI response date: July 2

Full applications due: July 30

Webinar date : TBA



HEP POCs: Glen Crawford, Bill Kilgore, Helmut Marsiske

- QuantISED 2.0: further development of the theory and practice of understanding and deploying real-world quantum systems, building on the achievements of the first cycle of QuantISED awards (FY 2018 and FY 2019).
- Interviewed QIS PIs and consulted Snowmass QIS and Detector BRN/Sensor Workshop reports. This informs three main topical areas : HEP-QIS Theory; Quantum Sensing; and Pathfinder/Demonstrator Experiments.
- There are two application tracks that are differentiated by the award size, number of applicants and duration. See FOA for further guidance and restrictions.

Application Track	# of PIs	Award Floor (Total)	Award Ceiling (Total)	Award Duration
Seed Application	1	$140,000	$1,000,000	2-3 years
Team Application	>1	$1,200,000	$5,000,000	3-5 years

Thank You

Questions?

OFFICE OF SCIENCE **BY THE NUMBERS**

Delivering scientific discoveries and major scientific tools to transform our understanding of nature and advance the energy, economic, and national security of the United States

FY23

6 CORE SCIENCE PROGRAMS

- Advanced Scientific Computing Research
- Basic Energy Sciences
- Biological and Environmental Research
- Fusion Energy Sciences
- High Energy Physics
- Nuclear Physics

3 ENGINEERING AND TECHNOLOGY OFFICES

- Accelerator Research and Development and Production
- Isotope Research and Development and Production
- Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR)

5 NATIONAL QUANTUM INFORMATION SCIENCE RESEARCH CENTERS

ACROSS ITS 10 NATIONAL LABS, OFFICE OF SCIENCE MAINTAINS APPROXIMATELY

24 MILLION SQUARE FEET OF SPACE

1,600 BUILDINGS

38,000 ACRES OF LAND OWNED

SUPPORTS RESEARCH SPANNING

16 DOE NATIONAL LABS

50 STATES, GUAM, PUERTO RICO, AND WASHINGTON, D.C.

>310 UNIVERSITIES AND HIGHER-LEARNING INSTITUTIONS

4 BIOENERGY RESEARCH CENTERS

2 ENERGY INNOVATION HUB PROGRAMS

51 ENERGY FRONTIER RESEARCH CENTERS

STEWARDS **10** DOE NATIONAL LABORATORIES

3 World-Leading Supercomputers

ESTIMATED RESEARCHERS SUPPORTED

- **11,100** Permanent PhDs
- **3,400** Postdoctoral Associates
- **5,200** Graduate Students
- **9,700** Other Scientific Personnel

OVER **39,500** USERS AT **28** OFFICE OF SCIENCE FACILITIES

10 SITE OFFICES

1 CONSOLIDATED SERVICE CENTER

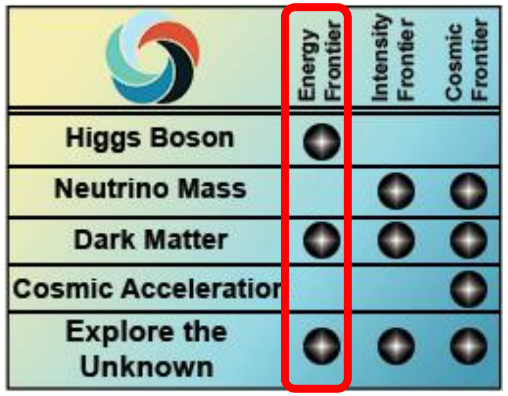
OVER **100** NOBEL PRIZES

$8.1 BILLION OVERALL OFFICE OF SCIENCE BUDGET

$918 MILLION USER FACILITY CONSTRUCTION

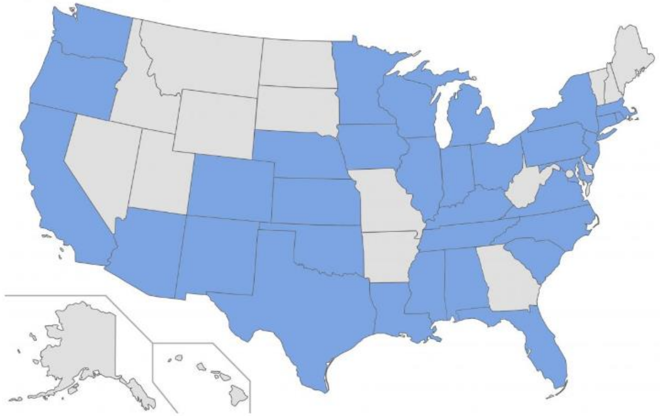
$281 MILLION SCIENCE LABORATORIES INFRASTRUCTURE

Energy Frontier Program

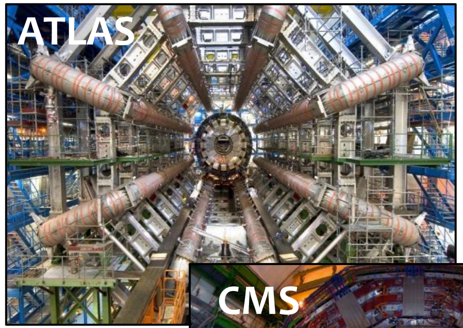


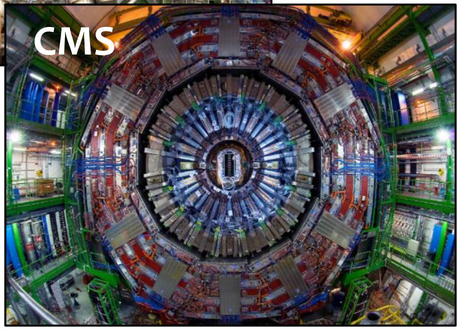
- **Two main focuses:**
  - U.S. participation at the **Large Hadron Collider (LHC) program at CERN**
  - Studies of an off-shore future collider in the intermediate term — i.e., linear or circular configurations

States hosting members of the U.S. LHC experimental program



- LHC: U.S. is the single largest collaborating nation in both the ATLAS and CMS experiments at the LHC
- CMS Collaboration: ~3,250 scientists from 255 institutions in 57 countries
  - U.S. CMS: ~29% of CMS collaboration = ~22% DOE/HEP + ~2.2% DOE/NP + ~5.7% NSF
  - 33 DOE-supported universities; 1 DOE lab: Fermilab (host lab for U.S.)
- ATLAS Collaboration: ~2,900 scientists from 183 institutions in 42 countries
  - U.S. ATLAS: ~19.5% of ATLAS collaboration = ~15.3% DOE/HEP + 0.6% DOE/NP + ~3.6% NSF
  - 30 DOE-supported universities; 4 DOE labs: ANL, LBNL, SLAC, and BNL (host lab for U.S.)





- **Seeding the future: R&D and conceptual physics studies towards next-generation largescale future colliders such as FCC-ee or ILC (Higgs factory); or FCC-hh or Muon Collider (multi-TeV collider)**

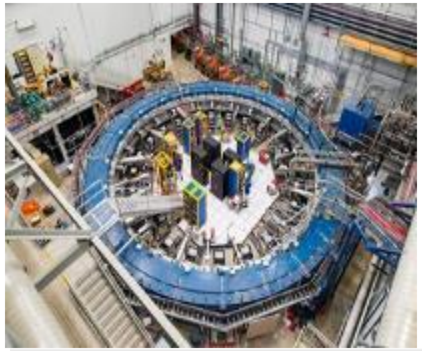
Intensity Frontier Experiments

	Energy Frontier	Intensity Frontier	Cosmic Frontier
Higgs Boson	●		
Neutrino Mass		●	●
Dark Matter	●	●	●
Cosmic Acceleration			●
Explore the Unknown	●	●	●

NOvA : Fermilab & Ash River, MN

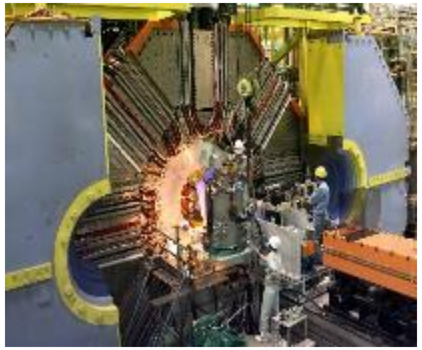
NOvA at Fermilab and Ash River

ICARUS at Fermilab

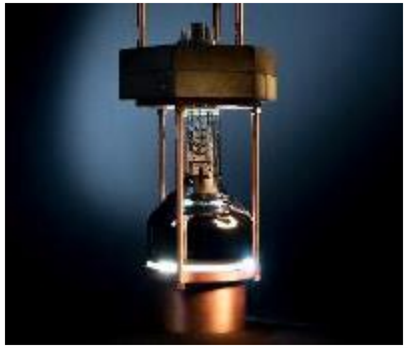


Muon g-2 at Fermilab

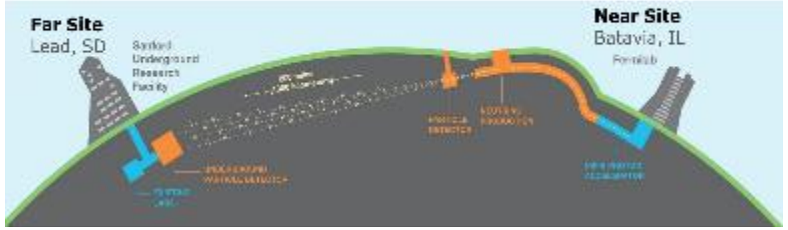
Mu2E at Fermilab



Belle II at KEK, Japan



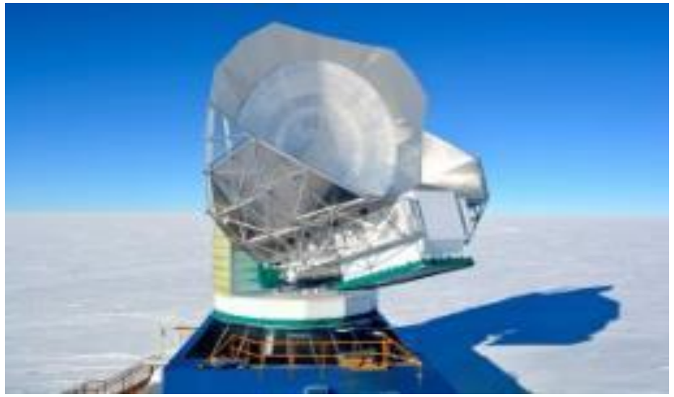
COHERENT at ORNL

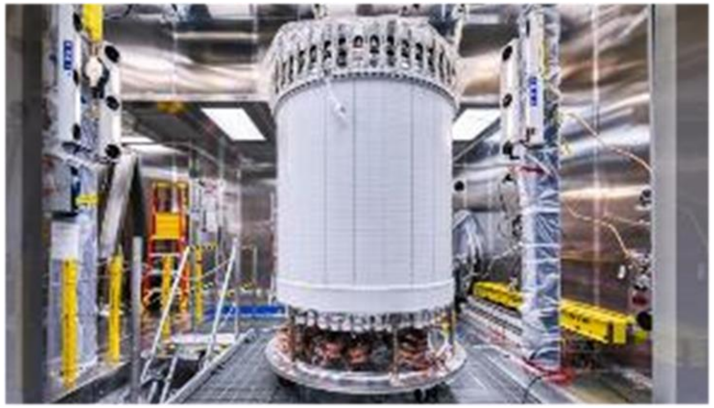


DUNE at Fermilab and Lead, SD

Cosmic Frontier Experiments

	Energy Frontier	Intensity Frontier	Cosmic Frontier
Higgs Boson	●		
Neutrino Mass		●	●
Dark Matter	●	●	●
Cosmic Acceleration			●
Explore the Unknown	●	●	●

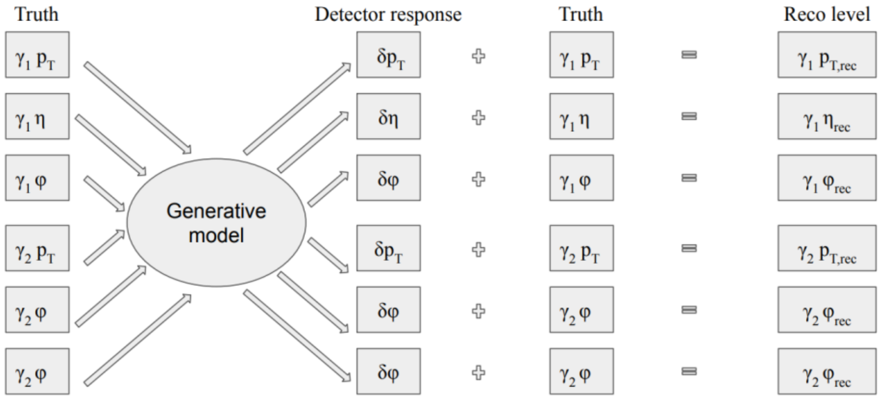




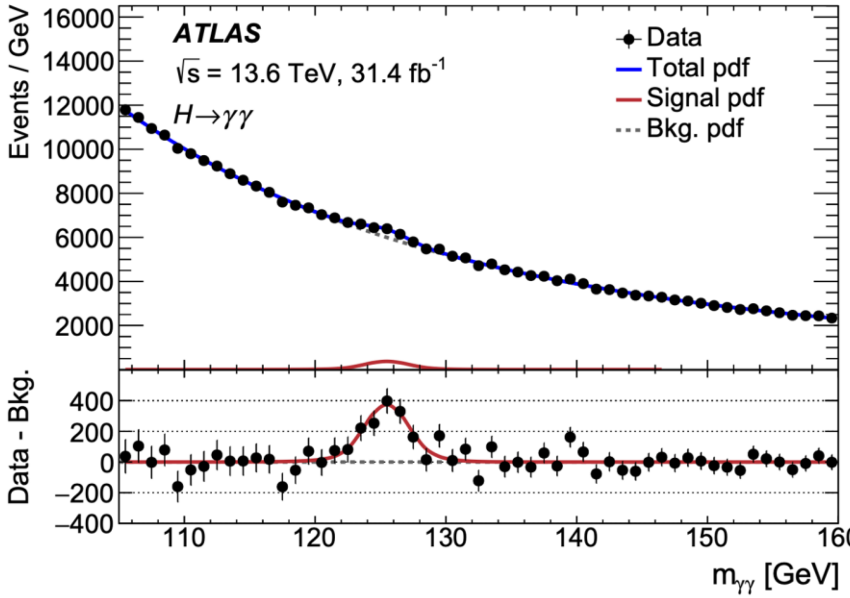
- Partnerships w/NSF (PHY, AST, OPP) NASA (AST, ISS, CLPS) are essential

Generative Machine Learning for Detector Effect Modeling

- Normalizing flows as a generative ML model developed as surrogate for full detector simulation
  - Capture detector response specific to object kinematics and event conditions, model non-Gaussian effects, reproduce correlations between measurements of different objects
    - [JINST 19 (2024) 02, P02003]()

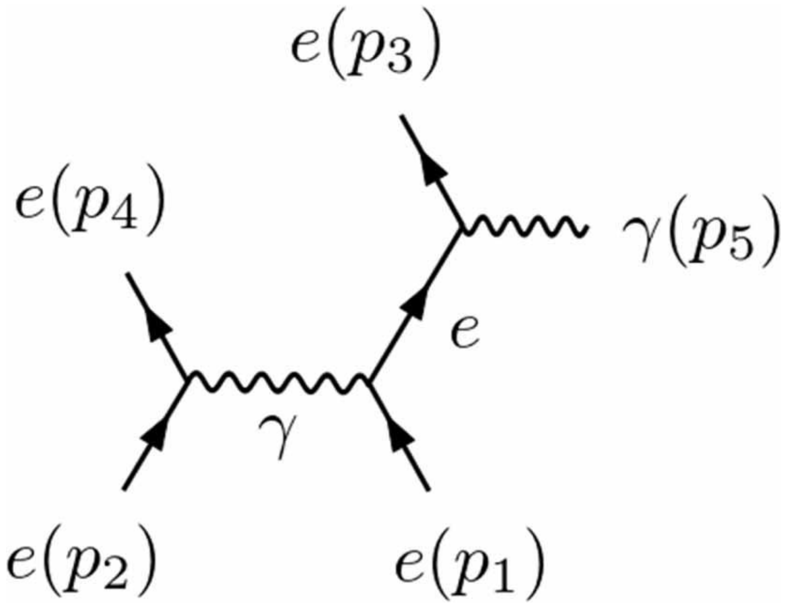


- This tool was used in the ATLAS Run-3 Higgs to diphoton measurement
  - Trained with ATLAS simulation samples to learn simulated detector response
  - Applied to *O(*100M*)* generator diphoton background events to obtain expected detector response
  - Used to determine the background PDF in the ATLAS paper
    - [Eur. Phys. J. C 84 (2024) 78]()



SYMBA: Symbolic calculation of squared amplitudes in high energy physics with machine learning

- Develop natural language processing models to calculate matrix elements from Feynman Diagrams
  - Automate calculation of scattering processes with higher order corrections in collider experiments that can not be done by hand
- For QED processes the model accurately predicts 99% of terms from the diagram
  - QCD 73% accuracy



A. Alnuqaydan et al 2023 Mach. Learn.: Sci. Technol. 4 015007

- ***The amplitude*** $(e\ e \to e\ e\ \gamma)$:

$$i\mathcal{M} = \frac{\frac{1}{2}\, ie^3\big(p_{3\rho}\,\gamma^{\rho}_{\epsilon}\,\gamma_{\rho\eta}\,A^{\rho *}_{j}(p_5)\,\mathbf{e}^{*}_{i\eta}(p_4)\,\mathbf{e}^{*}_{l\epsilon}(p_3)\,\mathbf{e}_{k\delta}(p_2)\,\mathbf{e}_{i\delta}(p_1) \,-\, \frac{1}{2}\,p_{5\sigma}\,\gamma_{\rho\epsilon}\,\gamma^{\rho}_{\epsilon}\,\gamma_{\rho\eta}\,\gamma^{\sigma}_{\epsilon}\,A^{\rho *}_{j}(p_5)\mathbf{e}^{*}_{i\eta}(p_4)\,\mathbf{e}^{*}_{l\epsilon}(p_3)\,\mathbf{e}_{k\delta}(p_2)\,\mathbf{e}_{i\delta}(p_1)\big)}{((m_e^2 - \vec{p_2}\,.\vec{p_4})\, *\, \vec{p_3}.\vec{p_5})}$$

- ***The squared amplitude*** $(e\ e \to e\ e\ \gamma)$:

$$|\mathcal{M}|^2 = -\frac{e^6}{((\vec{p_3}.\vec{p_5})^2 * (m_e^2 - \vec{p_2}.\vec{p_4})^2)}(2m_e^6 + m_e^4 * (-\vec{p_1}.\vec{p_3} - \vec{p_1}.\vec{p_5} - \vec{p_2}.\vec{p_4} + 2\vec{p_3}.\vec{p_5}) + m_e^2 * (\vec{p_1}.\vec{p_2} * \vec{p_3}.\vec{p_4} + \vec{p_1}.\vec{p_2} * \vec{p_4}.\vec{p_5} + \vec{p_1}.\vec{p_4} * \vec{p_2}.\vec{p_3} + \vec{p_1}.\vec{p_4} * \vec{p_2}.\vec{p_5} + \vec{p_1}.\vec{p_5} * \vec{p_3}.\vec{p_4} - \vec{p_2}.\vec{p_4} * \vec{p_3}.\vec{p_5}) - \vec{p_1}.\vec{p_2} * \vec{p_3}.\vec{p_5} * \vec{p_4}.\vec{p_5} - \vec{p_1}.\vec{p_4} * \vec{p_2}.\vec{p_5} * \vec{p_3}.\vec{p_5})$$

QuantISED 2.0 FAQs (see also FOA for specifics)

- **Eligibility**: Open to all institutions/individuals except certain non-profits.
  - Institutions and individuals underrepresented in the HEP research portfolio are particularly encouraged to apply.
- **Limitations:** No more than 2 LOIs and 2 full applications per PI. This includes being a co-I on a Team application from your institution or another institution.
  - No limitation on # of applications/LOIs per institution.
- **Lab/Univ restrictions:**
  - Universities may be lead or partner institutions on any proposal
  - DOE Labs may be lead on Team proposals, and subwardees on Seed proposals
  - Other non-DOE FFRDCs may be subawardees only
- **New/Renewal Proposals:** Renewals accepted only for Team proposals
  - For technical reasons, DOE Labs can only submit New proposals to this FOA
  - In practice, a New lab proposal can continue activities started under a previous award (eg QuantISED 1.0). See FOA for additional reporting requirements.