DOE High Energy Physics Report to HEPAP

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Outline

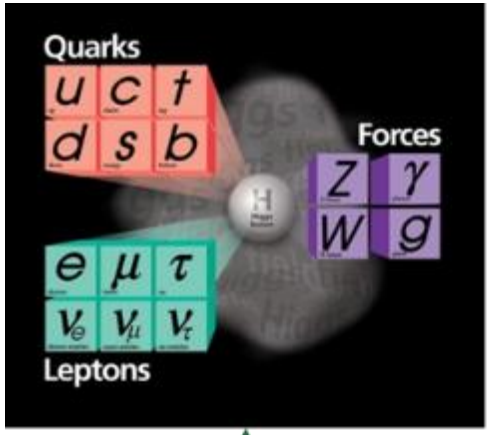
- HEP Mission
- Frontiers and Science Drivers
- Research, Projects and Operations Balance
- Status and Highlights across the frontiers and research initiatives
- Status of Projects from perspective of the 2014 P5 timeline
- Introduction to the 2023 P5 process (later dedicated report by H.M.)
- A few words about future colliders for HEP the international nature of HEP
- The U.S. Budget cycle and process
- Our Office of High Energy Physics organization (to be followed by details from G.C.)

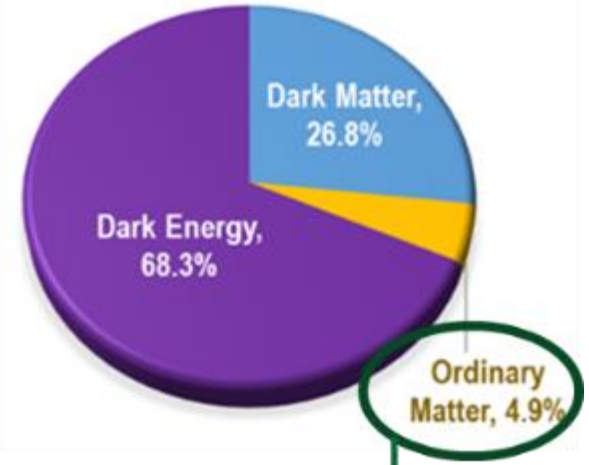
Office of High Energy Physics (HEP) Mission

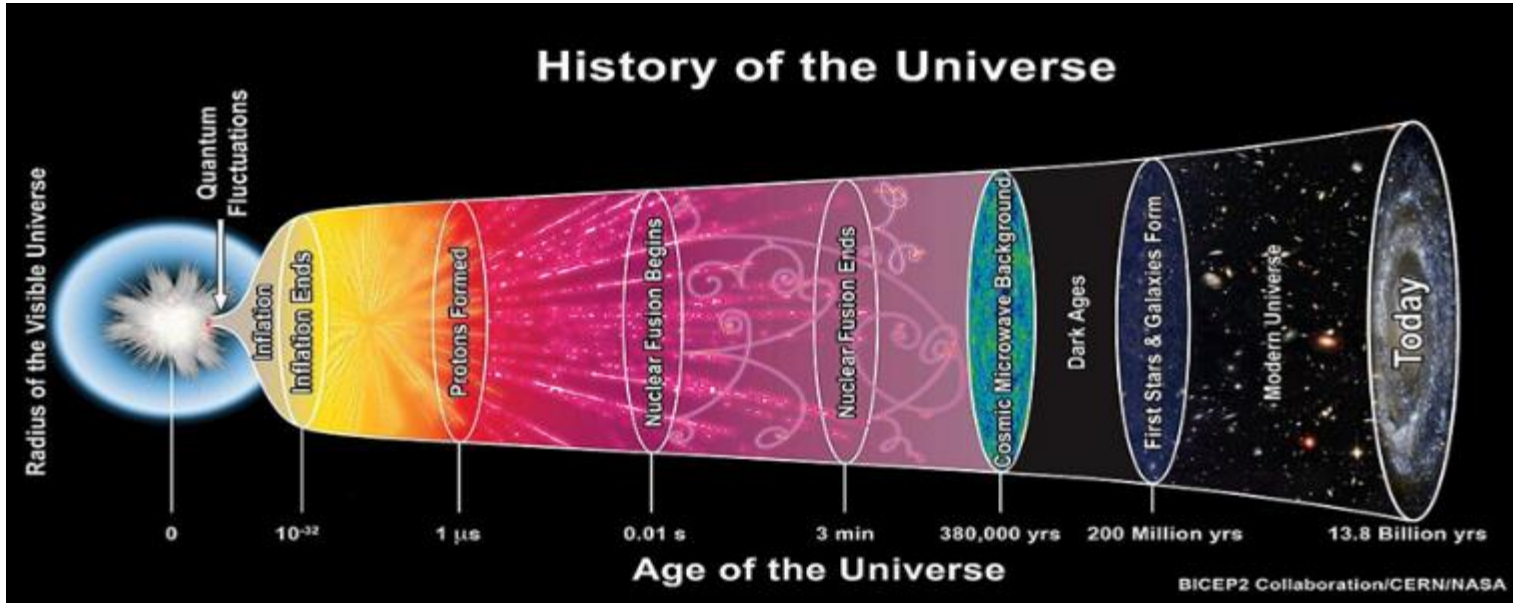
Understanding the how the universe works at its most fundamental level

- Discover the elementary constituents of matter and energy
- Probe the interactions between them
- Explore the basic nature of space and time

HEP carries out the DOE mission and objectives through a balanced portfolio to work at the cutting edge of science







How the Universe evolves

In the beginning… Hot/dense primordial mass-energy

Expansion… Passing through mass-energy phases

Universe as we observe it now… Large scale structure evident

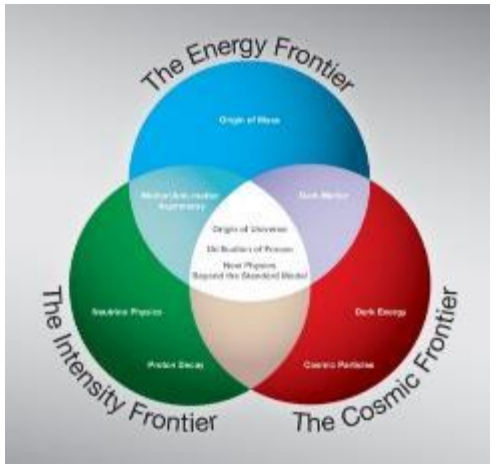
- Structure is a strong function of mass-energy constituents & dynamics as the Universe evolves

HEP Research and Technology

Colliders to the Cosmos

Spans the breadth of three "frontiers":

- Energy Frontier
- Intensity Frontier
- Cosmic Frontier

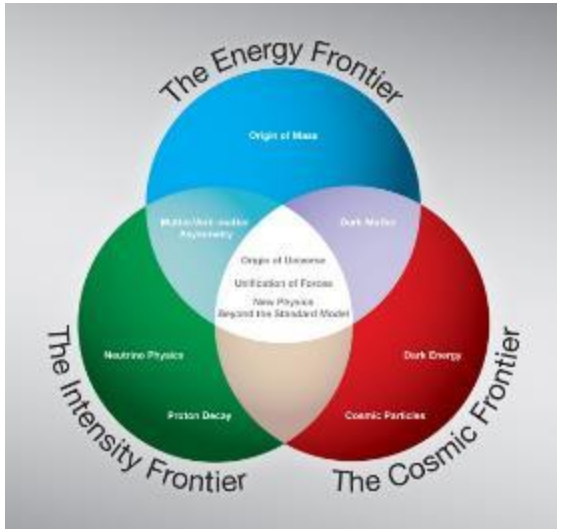


2008 P5

Plus cross-cutting themes

- Theoretical physics
- General Accelerator and Detector R&D
- Computational HEP and AI/ML
- QIS Research and Microelectronics

2008 P5 defined three experimental frontiers for the field



<u>HEP is carried out along 3 Frontiers</u>: Advancements at all 3 frontiers are needed to achieve the long-term goals of the field.

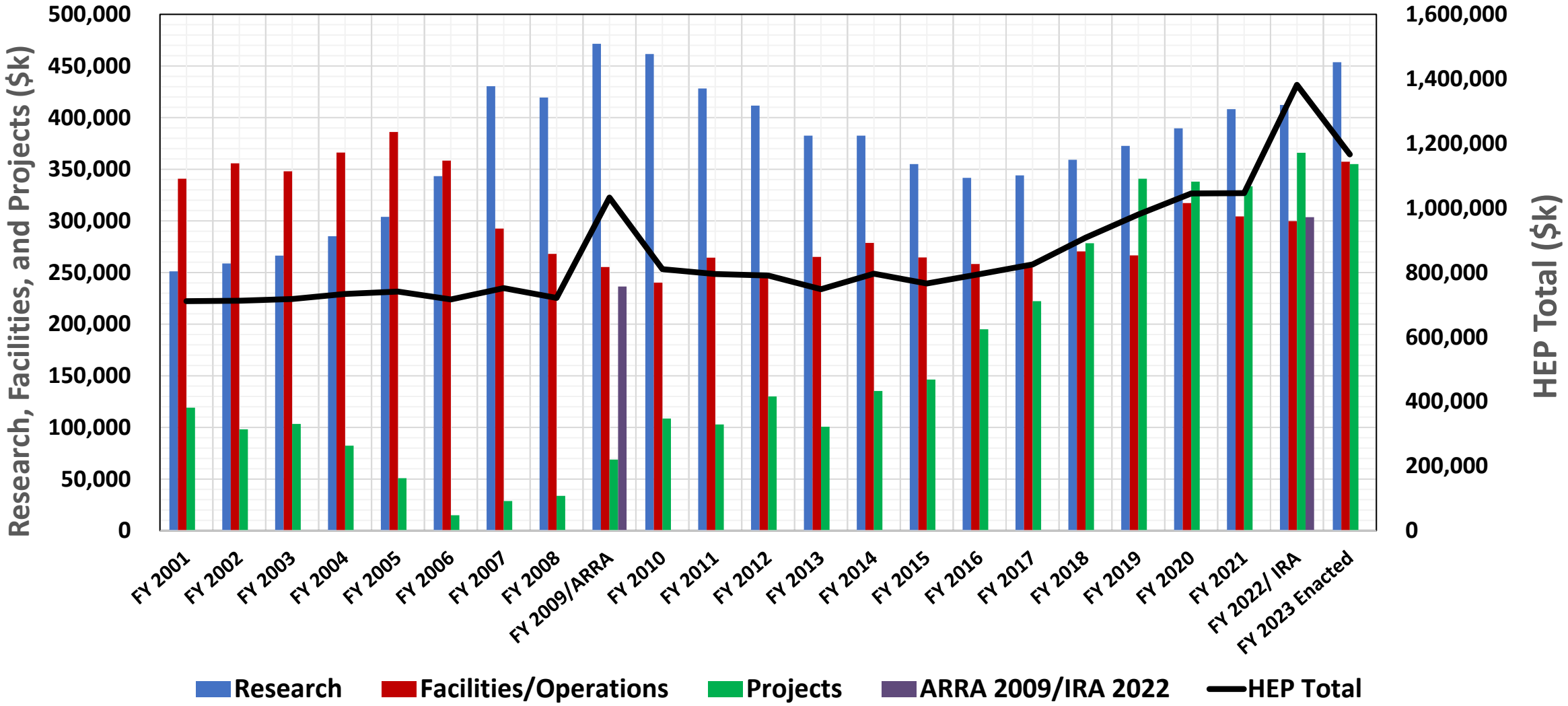
→HEP has historically been primarily a **Particle Accelerator based program**: Energy & Intensity Frontiers

→Cosmic Frontier uses **naturally occurring particles and the cosmos itself** to study the fundamental nature of matter, energy, space and time in areas complementary to accelerator experiments.

- Increasingly important area for discovery
- In the last decade, Cosmic Frontier has grown into an integral and priority part of the HEP program.

2014 : Frontiers to Science Drivers

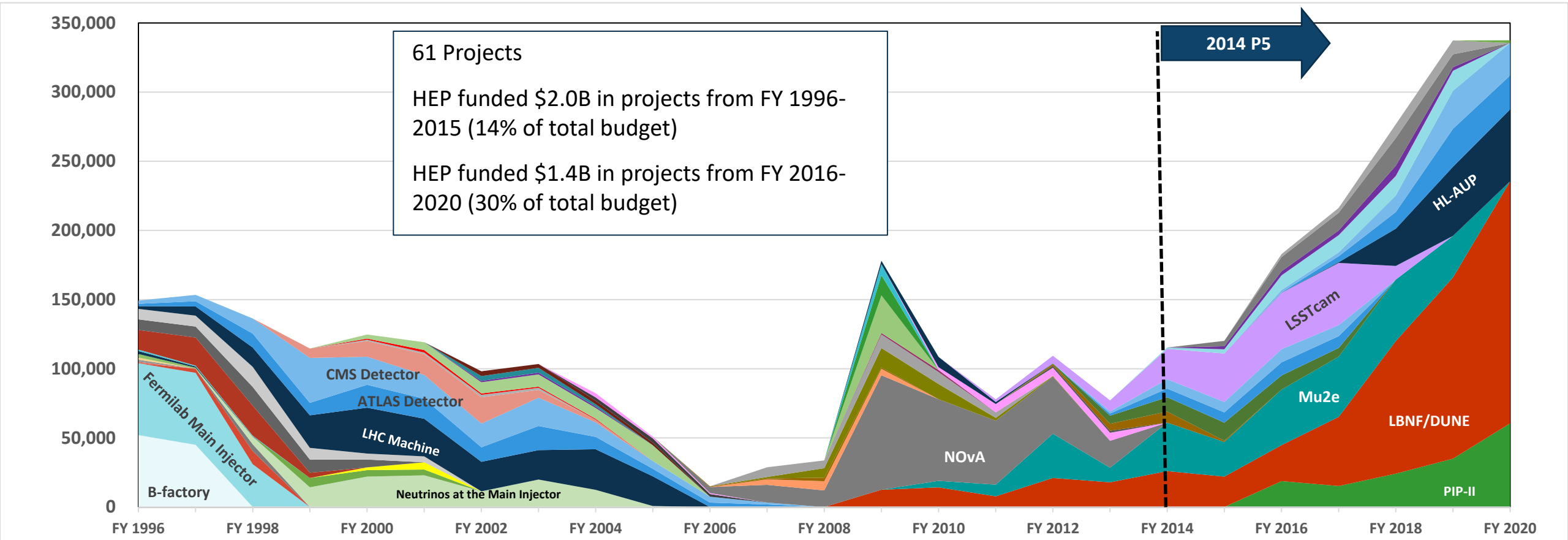
	Energy Frontier	Intensity Frontier	Cosmic Frontier
Higgs Boson	●		
Neutrino Mass		●	●
Dark Matter	●	●	●
Cosmic Acceleration			●
Explore the Unknown	●	●	●



ARRA 2009 funds supported Research, Facilities, and Projects
IRA 2022 funds supported Projects only

Historical Chart of HEP Projects

FY 1996 – FY 2020



B-factory | Fermilab Main Injector | SLAC Master Substation Upgrade | C-Zero Area Experimental Hall | Neutrinos at the Main Injector | Willson Hall Reno | SLAC Research Office

PIP-II | LBNF/DUNE | Mu2e | PIP-III | LBNF Hi-Flux | Mu2e Upgrade | Future Collider

Rare k-decay Experiment | KTeV Experiment | Next Linear Collider Test Facility | g-2 | Antimatter in Space | Super-K | BaBar

CDF Upgrade | D-Zero Upgrade | LHC Machine | ATLAS Detector | CMS Detector | MINOS | AMS Upgrade

CDMS | GLAST/LAT | Auger | Run IIb CDF Detector | Run IIb D-Zero Detector Project | VERITAS | BaBar Upgrade

NOvA | MINERvA | T2K | Daya Bay | DES | SuperCDMS at Soudan | BELLA

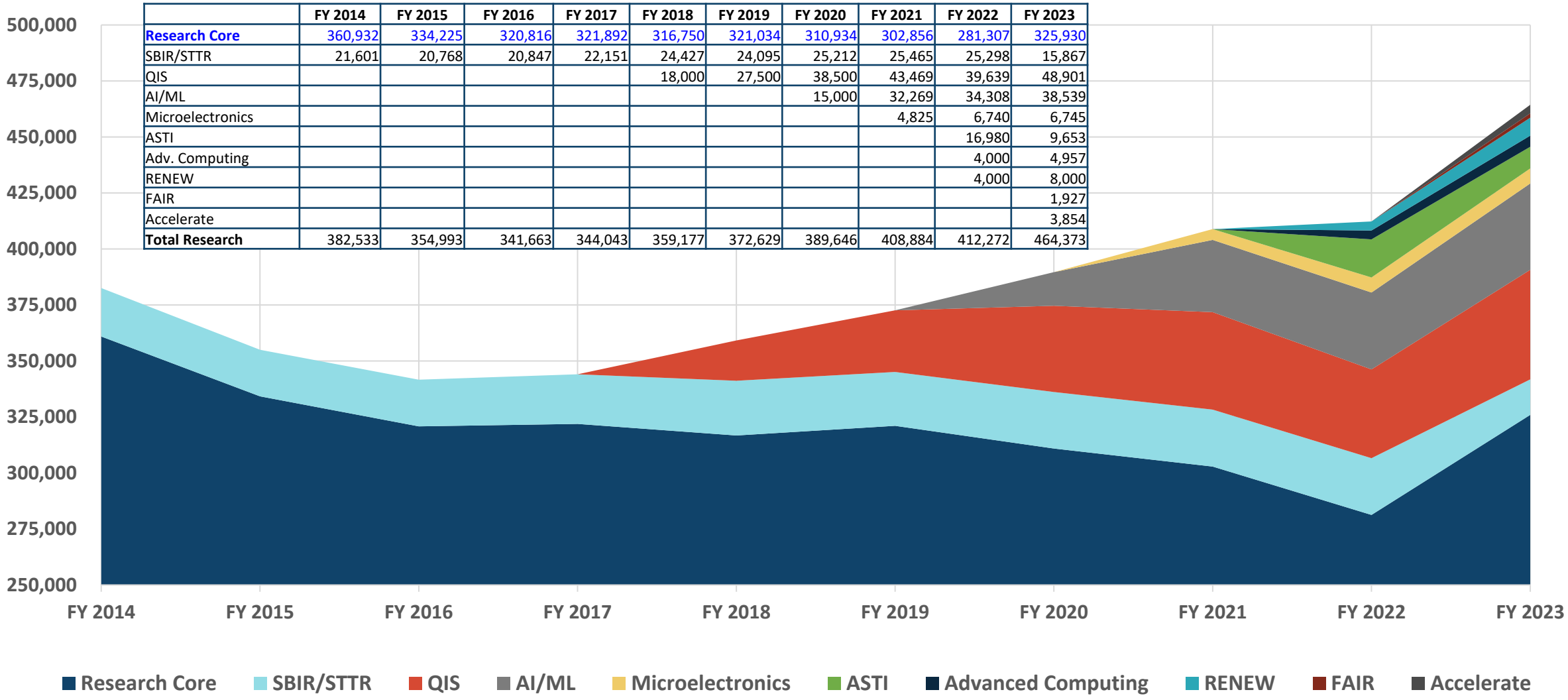
FACET | Cryogenic Refrigerator | MicroBooNE | HAWC | Belle II | Muon g-2 | LHC Accelerator Upgrade

LHC ATLAS | LHC CMS | LSSTcam | HL-AUP | HL-LHC-ATLAS | HL-LHC-CMS | LZ

SuperCDMS | DESI | FACET-II | CMB-S4 | FACET-II Upgrade

HEP Research Breakdown ($k) FY 2014-2023

	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Research Core	360,932	334,225	320,816	321,892	316,750	321,034	310,934	302,856	281,307	325,930
SBIR/STTR	21,601	20,768	20,847	22,151	24,427	24,095	25,212	25,465	25,298	15,867
QIS					18,000	27,500	38,500	43,469	39,639	48,901
AI/ML							15,000	32,269	34,308	38,539
Microelectronics								4,825	6,740	6,745
ASTI									16,980	9,653
Adv. Computing									4,000	4,957
RENEW									4,000	8,000
FAIR										1,927
Accelerate										3,854
Total Research	382,533	354,993	341,663	344,043	359,177	372,629	389,646	408,884	412,272	464,373



HEP Budget ($K): Research, Facilities/Ops, Projects

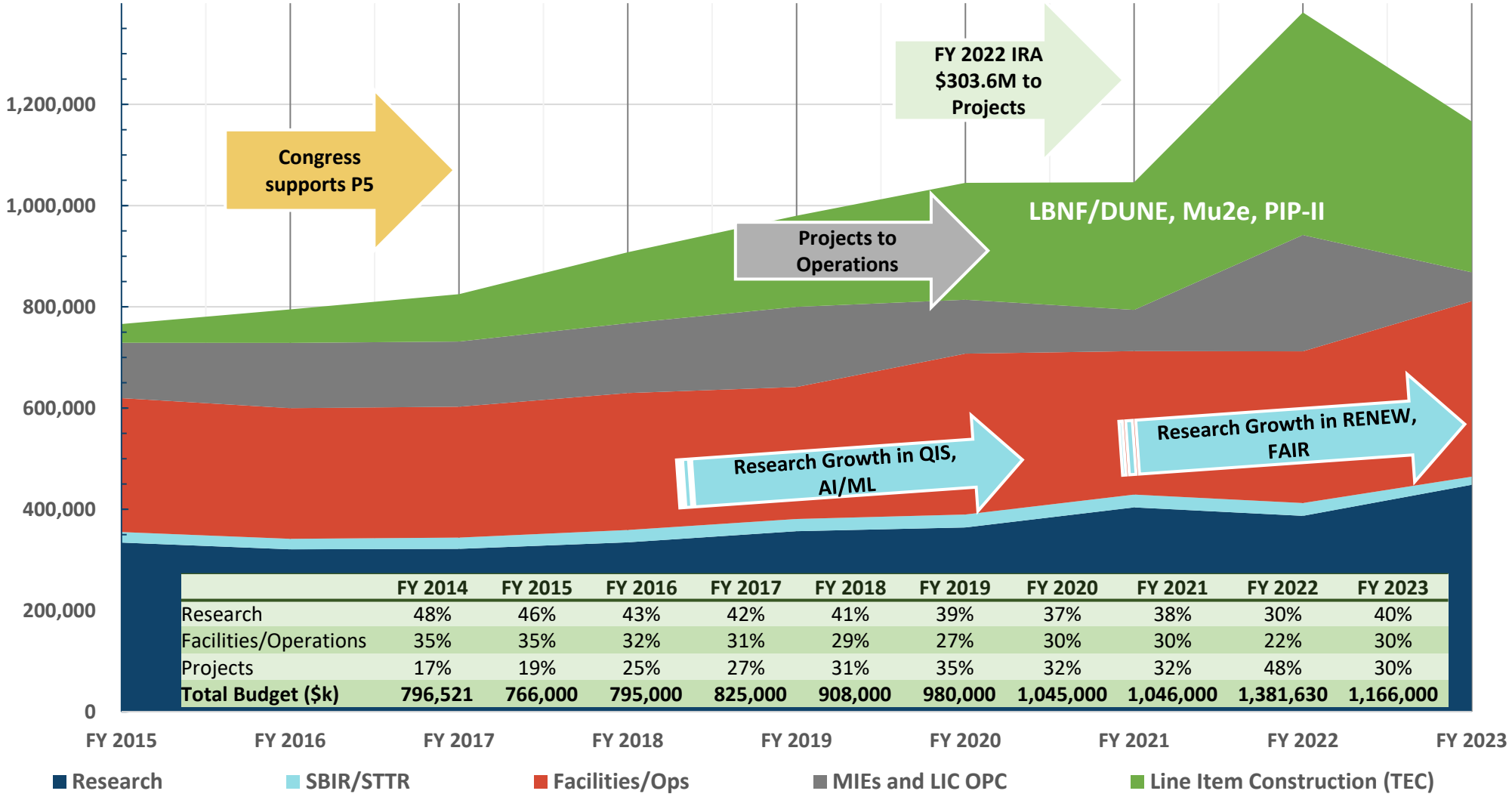
FY 2014 – FY 2023

Strategic Plan for U.S. Particle Physics next 10 years

Particle physics is global

Community made difficult choices

Increase investment in construction

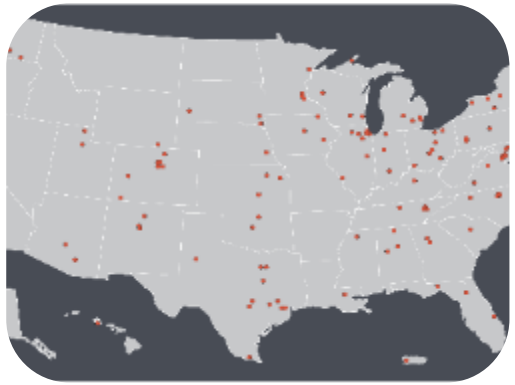


	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Research	48%	46%	43%	42%	41%	39%	37%	38%	30%	40%
Facilities/Operations	35%	35%	32%	31%	29%	27%	30%	30%	22%	30%
Projects	17%	19%	25%	27%	31%	35%	32%	32%	48%	30%
Total Budget ($k)	**796,521**	**766,000**	**795,000**	**825,000**	**908,000**	**980,000**	**1,045,000**	**1,046,000**	**1,381,630**	**1,166,000**

Office of High Energy Physics at a Glance

FY 2023 Enacted: $1.166B

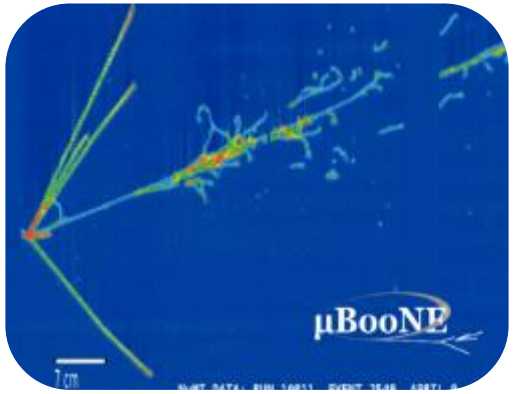
Largest Supporter (**~85%**) of Particle Physics in the U.S.



Funding at **>160** Institutions, including **12** DOE Labs

Over **1,175** Ph.D. Scientists and **525** Grad Students Supported

Over **2,325** Users at **2** SC Scientific Facilities



Research:

39.8%, $464.4M

~30% of Research to Universities

Projects:

30.4%, $355M

Facility Operations:

29.7%, $346.6M

HEP Mission and Support at DOE National Laboratories

Fermi National Accelerator Laboratory
$843.5M Total ($257.834 IRA)
- Quantum Information Science
- Superconducting Quantum Materials and Systems Center
- Artificial Intelligence and Machine Learning
- Energy, Intensity, and Cosmic Frontier particle physics research
- Theoretical and Computational Physics
- Advanced Technology R&D and Microelectronics
- Fermilab Accelerator Complex *(SC User Facility)*
- LHC Operations
- Cosmic Frontier Experimental Operations
- Acc. and Det. Infrastructure and Test Facilities
- LBNF/DUNE, PIP-II, Mu2e Construction Projects
- HL-LHC Accelerator, CMS Detector Upgrade, and ACORN MIE

AMES	$1.61M
LANL	$2.43M
LLNL	$3.45M
ORNL	$2.42M
PNNL	$3.24M
SNL	$0.10M
TJNAF	$0.89M

Argonne National Laboratory
$17.5M Total
- Quantum Information Science
- Artificial Intelligence and Machine Learning
- Energy, Intensity, and Cosmic Frontier particle physics research
- Theoretical and Computational Physics
- Advanced Technology R&D
- LHC Operations
- Cosmic Frontier Experimental Operations

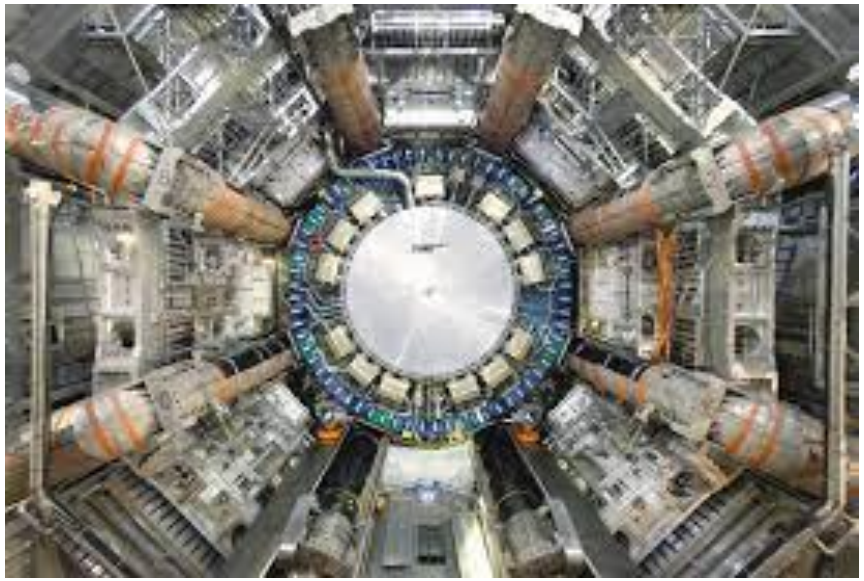
Lawrence Berkeley National Laboratory
$95.7M Total ($10M IRA)
- Quantum Information Science
- Artificial Intelligence and Machine Learning
- Energy, Intensity, and Cosmic Frontier particle physics research
- Theoretical and Computational Physics
- Advanced Technology R&D and Microelectronics
- LHC Operations
- Cosmic Frontier Experimental Operations, including DESI and LZ
- Accelerator and Detector Infrastructure and Test Facilities (BELLA)
- CMB-S4 MIE (lead lab)
- HL-LHC Accelerator and ATLAS Detector Upgrade MIEs

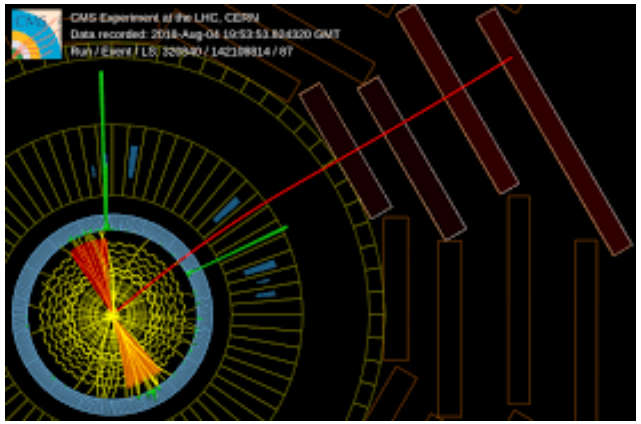
Brookhaven National Laboratory
$127.9M Total ($32.785 IRA)
- Quantum Information Science
- Artificial Intelligence and Machine Learning
- Energy, Intensity, and Cosmic Frontier particle physics research
- Theoretical and Computational Physics
- Advanced Technology R&D and Microelectronics
- LHC Operations
- Intensity Experimental Operations (Belle-II)
- Cosmic Frontier Experimental Operations, including Vera C. Rubin Observatory
- LBNF/DUNE Construction Project
- HL-LHC Accelerator and ATLAS Detector Upgrade MIEs
- Lunar Surface Electromagnetic Experiment (LuSEE)-Night MIE

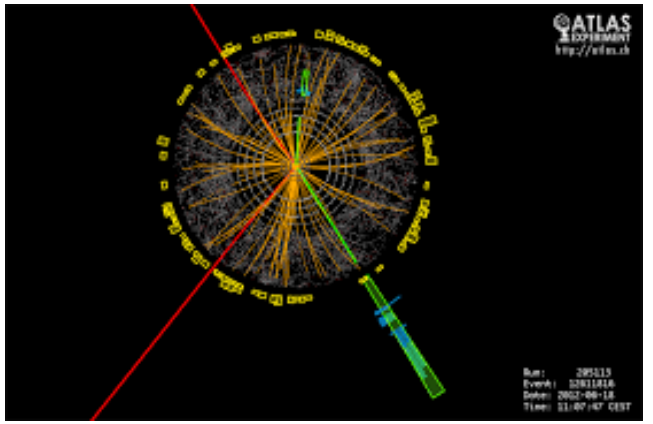
SLAC National Accelerator Laboratory
$83.8M Total
- Quantum Information Science
- Artificial Intelligence and Machine Learning
- Energy, Intensity, and Cosmic Frontier particle physics research
- Theoretical and Computational Physics
- Advanced Technology R&D and Microelectronics
- FACET Operations *(Scientific User Facility)*
- Cosmic Frontier Experimental Operations, including Vera C. Rubin Observatory, SuperCDMS-SNOLAB
- Accelerator Infrastructure and Test Facilities

Energy Frontier: Large Hadron Collider Experiments

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

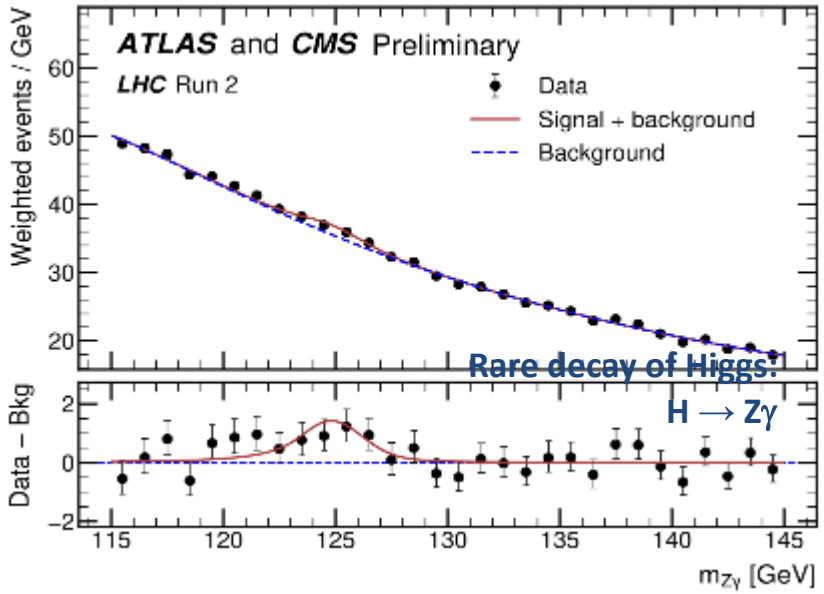


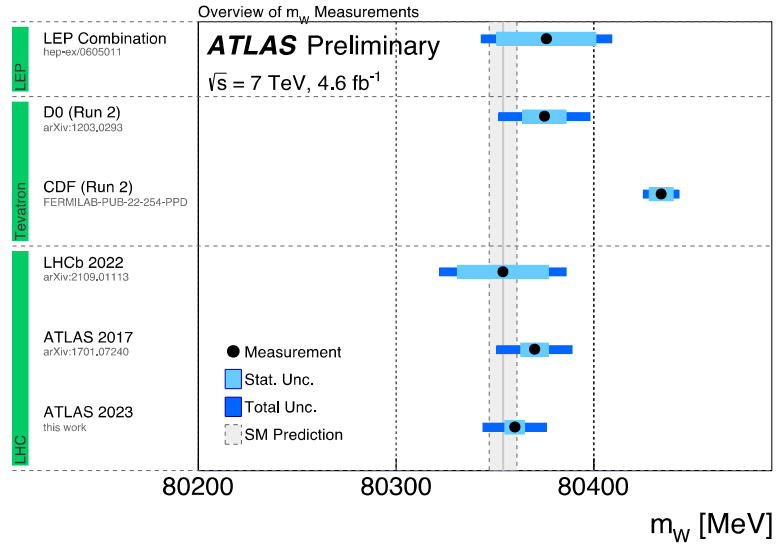




Energy Frontier Program – LHC

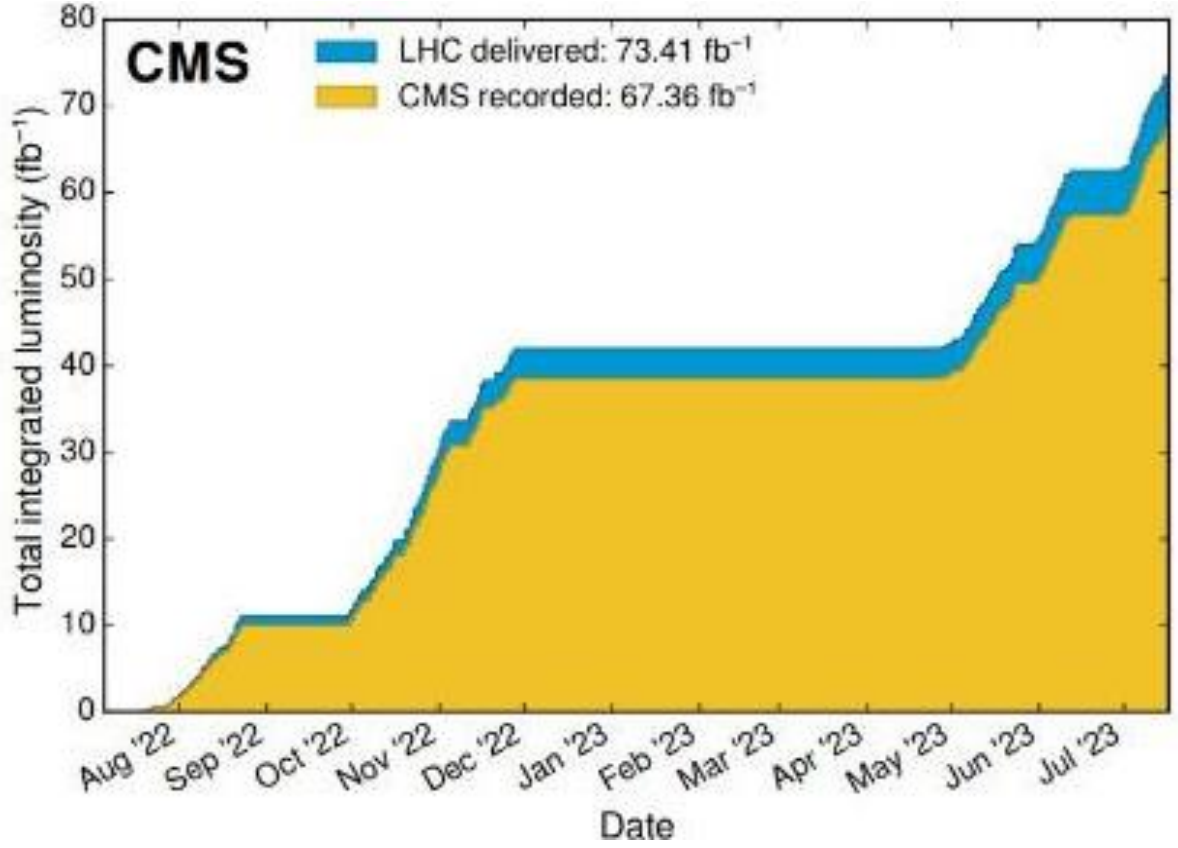
- **Over 2,240 publications in peer-reviewed journals by the ATLAS and CMS collaborations since data taking began at the LHC in 2009**
  - Excellent showing at the 2023 summer conferences and workshops
- **Representative highlights include 1st evidence of rare Higgs decay to Zγ**
  - Decay probability in SM for H ⟶ Zγ is predicted to be 0.15%
  - Independent searches by ATLAS and CMS for this decay process, including application of AI/ML techniques to distinguish signal from backgrounds
  - Combined result with Run 2 data reveals significance of 3.4σ
  - Look forward to results from Run 3 to study this rare decay in even more detail
- **Precision measurement of the W-mass by ATLAS**
  - Re-analysis of 7 TeV data with improved precision: **M_W = 80360 ± 16 MeV** (previous ATLAS result 80370 ± 19 MeV)
  - Result includes using more recent PDFs and constrained profile likelihood fit
  - Agreement with the SM





LHC Operations and HL-LHC Upgrade Projects

- **Run 3 resumed this calendar year in April at 13.6 TeV, nicely delivering data to the LHC experiments**
  - ATLAS and CMS performing well with ~30 fb^{-1} of data recorded this year by each
  - On July 17, 2023, LHC lost beam with several quenches occurring around the ring, including at the inner triplet magnets near the LHCb interaction point
  - A small 1.6 mm-long helium leak formed at the bellow interactions between two inner triplet cold masses
  - Repairs are underway over next few weeks; likely to impact the remaining LHC proton running for Run 3 during CY 2023



High Luminosity LHC Upgrade Projects

- **U.S. HL-LHC Accelerator Upgrade Project progressing well**
  - Project was re-baselined by DOE in March 2023 to account for impacts from COVID, inflation, and supply chain issues
  - Total project cost increased from $242M to $266M

- **U.S. HL-LHC [Phase-II] Detector Upgrade Projects baselined (CD-2) by DOE in Jan 2023 (ATLAS) and Mar 2023 (CMS)**
  - 5 DOE national labs and over 65 U.S. universities delivering major portions of the detectors, now moving into production
  - Total project cost for each ATLAS and CMS upgrade at $200M, takes into consideration impacts from COVID, inflation and supply chain, and the Ukraine-Russia conflict

All US HL-LHC Projects in Advance Fabrication

- All the cables that will be used for the superconducting magnet coils of the 10 quadrupole magnets have already been manufactured at LBNL.

- The first of the 10 quadrupole magnets is ready for shipment from FNAL to CERN.

Celebrations for Last Cable Completed @ LBNL

US HL-LHC Projects in Advance Fabrication (Cont.)

- The mechanical support system of the ATLAS detector is built and worked on at LBNL and Oxford. The sensors and electronics of the detector system will be mounted on these very thin big shells.

- The CMS sensor and DAQ-readout chips (ETROC and ECON-D) invented specifically for the upgraded CMS, are in advance prototyping, hosted at the new testing lab in the new IERC building at FNAL.

Outer Cylinder Shell, LBNL

Strip Barrel Shell, Oxford

New testing site of CMS, ETROC- ASIC, IERC, FNAL

DOE Publicly Commended by CERN:

- "For leading all funding agencies in helping with the work left out after banning the Russian institutions."

- The board on resources for the LHC experiments is meeting biannually when all the funding agencies meet the CERN directorate. At the beginning of the latest meeting, the Lab director and the Research director shared CERN's gratitude to the ATLAS and CMS projects, and by extension to DOE for supporting them. The projects were recognized for taking on extra work and accepting additional cost in support of the shortfall, due to the exclusion of the Russian and Belarus institutes from the LHC experiments. They were particularly praised for leading the way for all other international funding agencies which reflects the DOE's commitment to the LHC upgrade and the future of Energy Frontier research.

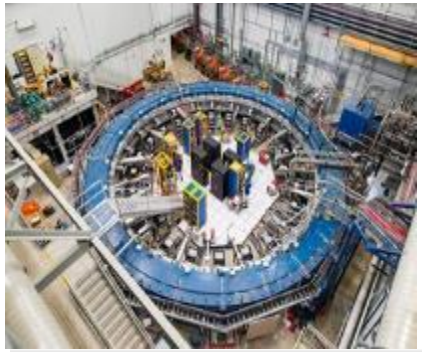
Intensity Frontier Experiments

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

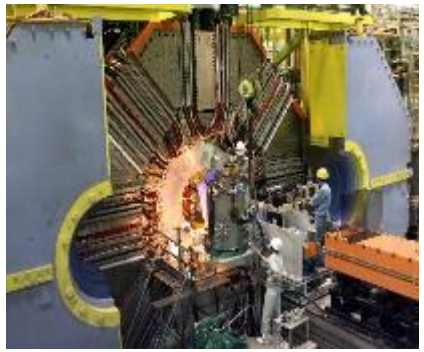
NOvA at Fermilab and Ash River

ICARUS at Fermilab

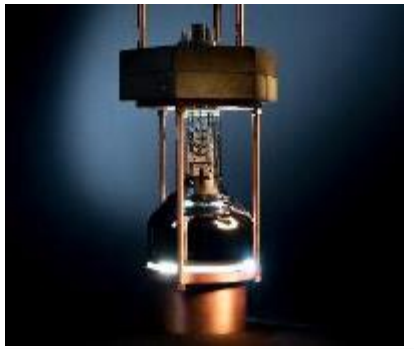
Mu2E at Fermilab



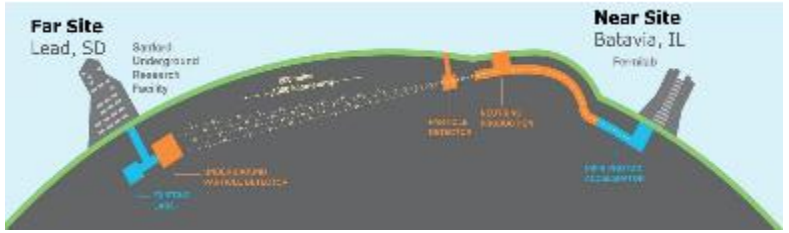
Muon g-2 at Fermilab



Belle II at KEK, Japan



COHERENT at ORNL

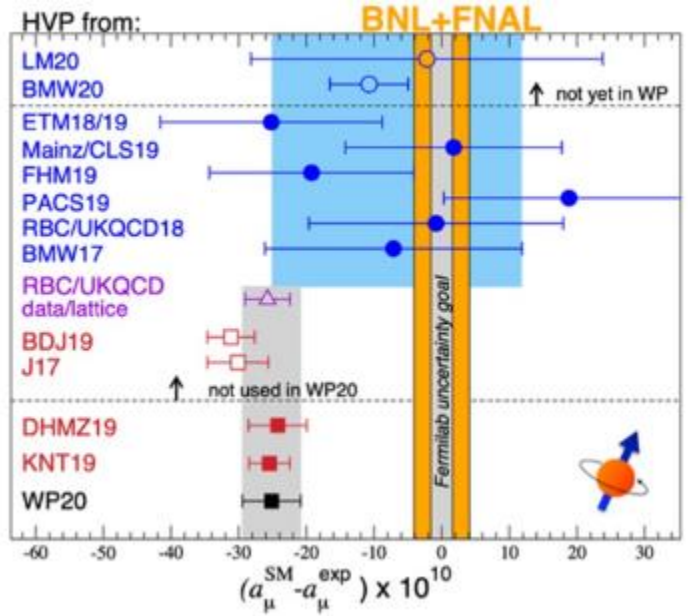


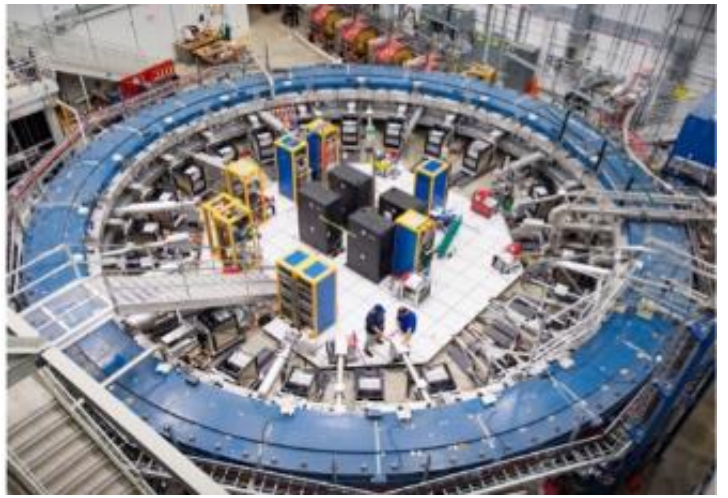
DUNE at Fermilab and Lead, SD

vA : Fermilab & Ash River, MN

FY 2023 HEP Intensity Frontier Highlights (Muon-g-2)

- FNAL's accelerator infrastructure is a key enabler of world- leading IF experiments such as Muon g-2 and Mu2e
- Muon g-2 completed TDR goal collecting 21x BNL stats
- Muon g-2 Run6 has been completed closing out their planned data taking and experimental runs.

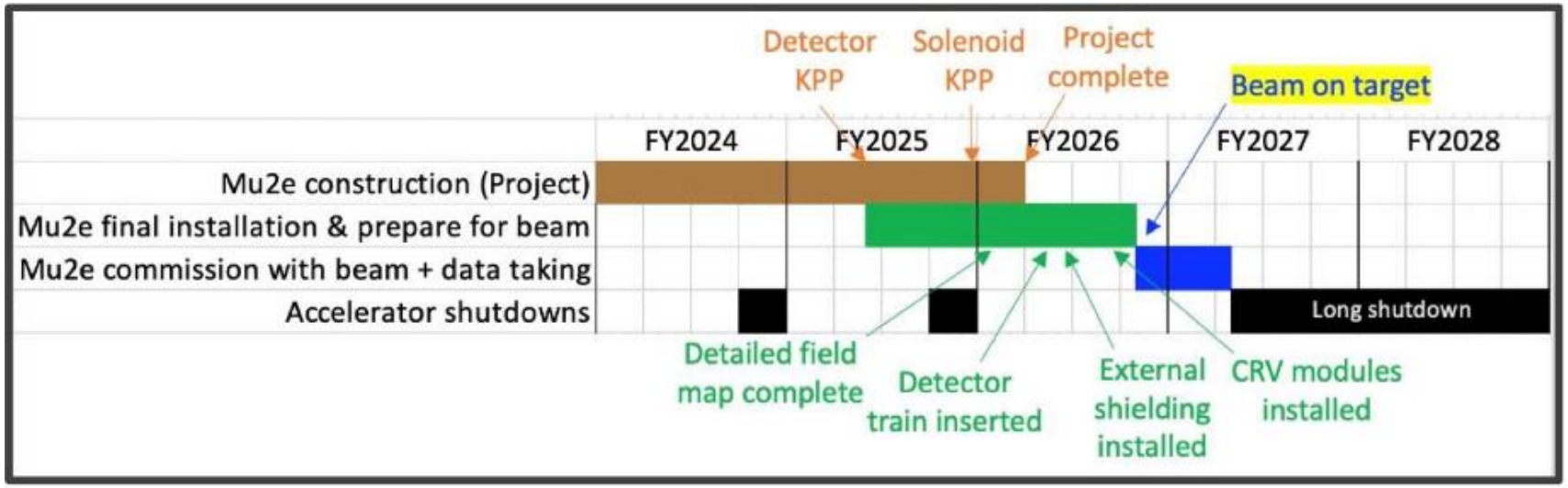




Intensity Frontier: New Muon g-2 Results

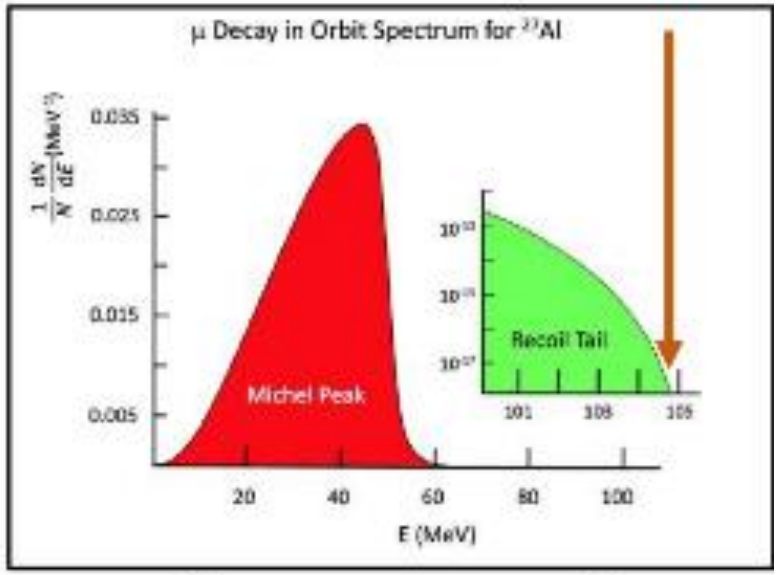
FY 2023 HEP Intensity Frontier Highlights (Mu2e)

- Mu2e Project is fully funded and 85% complete
- Aiming for Project early completion date Dec 2025.
- Begin Run 1 data taking mid-CY2026 - about 6 months of data
  - Goal: 10% of total data set and x1000 improvement in sensitivity over present experimental limit
- Resume after shutdown and take data for 4 more years.



105 MeV

$\mu N \rightarrow eN$

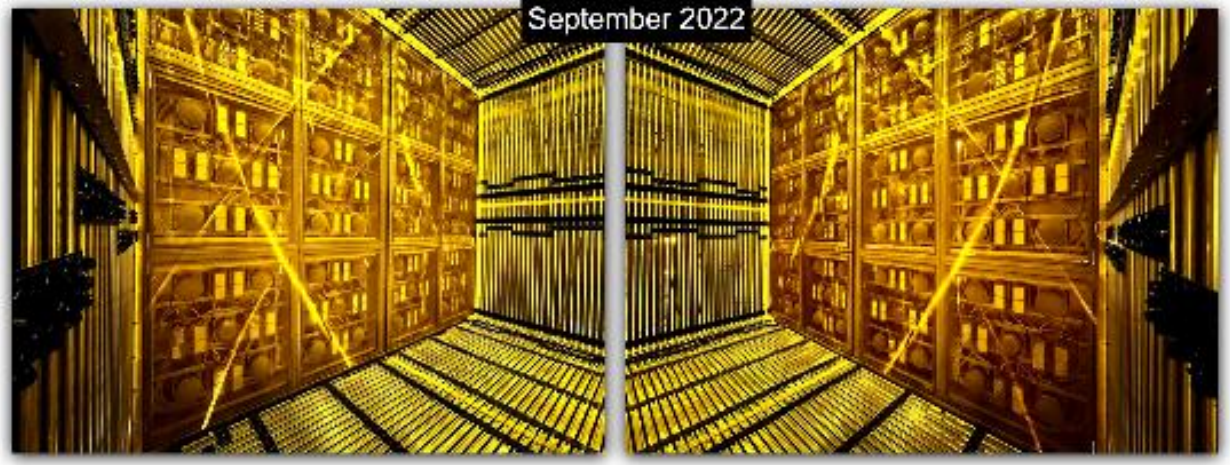


$$\mu^- + {}^{27}_{13}Al \rightarrow e^- + \bar{\nu}_e + \nu_\mu + {}^{27}_{13}Al$$

Short Baseline Neutrino Program~2023

Short Baseline Neutrino Program

The SBND Detector Assembly was moved from DAB to the final detector location in SBND.



SBND detector completed

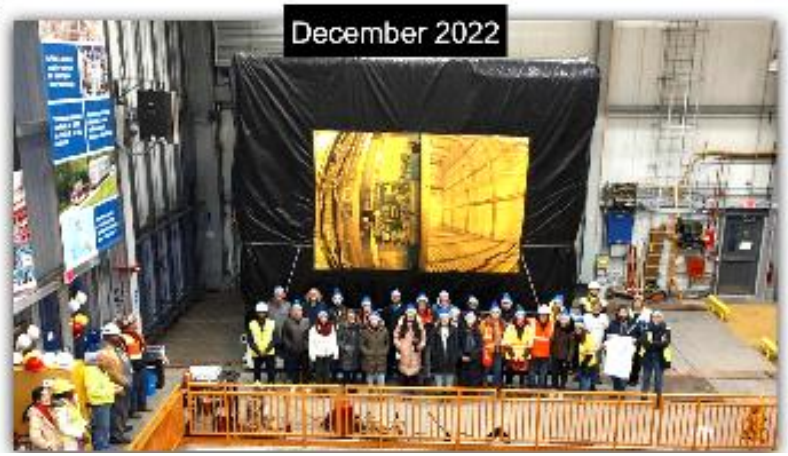
Membrane cryostat as in DUNE FD1 and FD2

SBND cryostat completed

On **December 1, 2022** the assembled SBND TPC + photon detector systems was successfully moved across the Fermilab site from DAB to the SBND Detector hall

A newsworthy day

SBND detector move

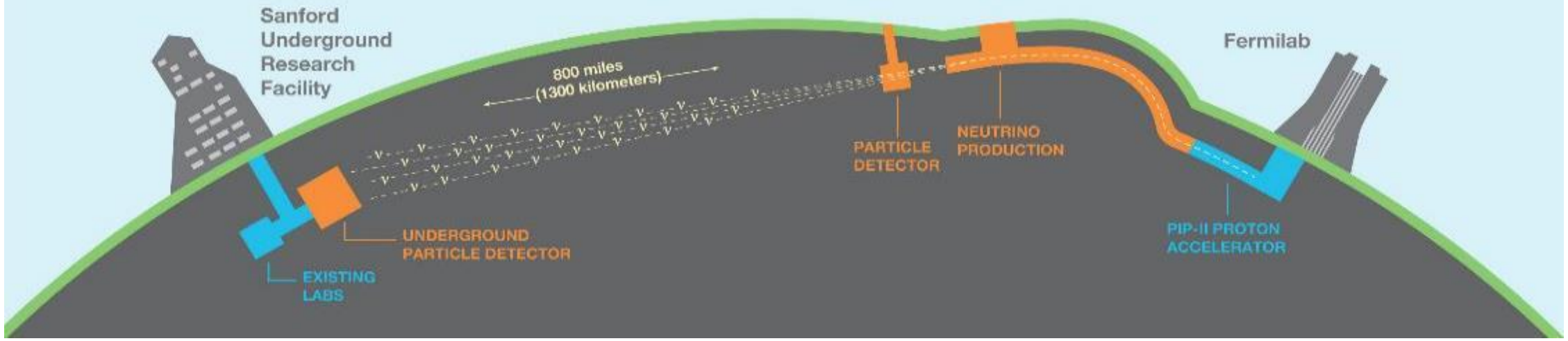


LBNF/DUNE: US Project Scope

Delivered at Two Sites through Five Subprojects

Far Site – SURF in Lead, SD
Facility/Infrastructure and Far Detectors

Near Site – FNAL in Batavia, IL
Facility/Infrastructure, Neutrino Beamline, and Near Detectors



Three subprojects

- **FSCF-EXC** – Far Site Excavation
- **FSCF-BSI** – Far Site Building & Site Infrastructure
- **FDC** – Far Detectors and Cryogenic Infrastructure

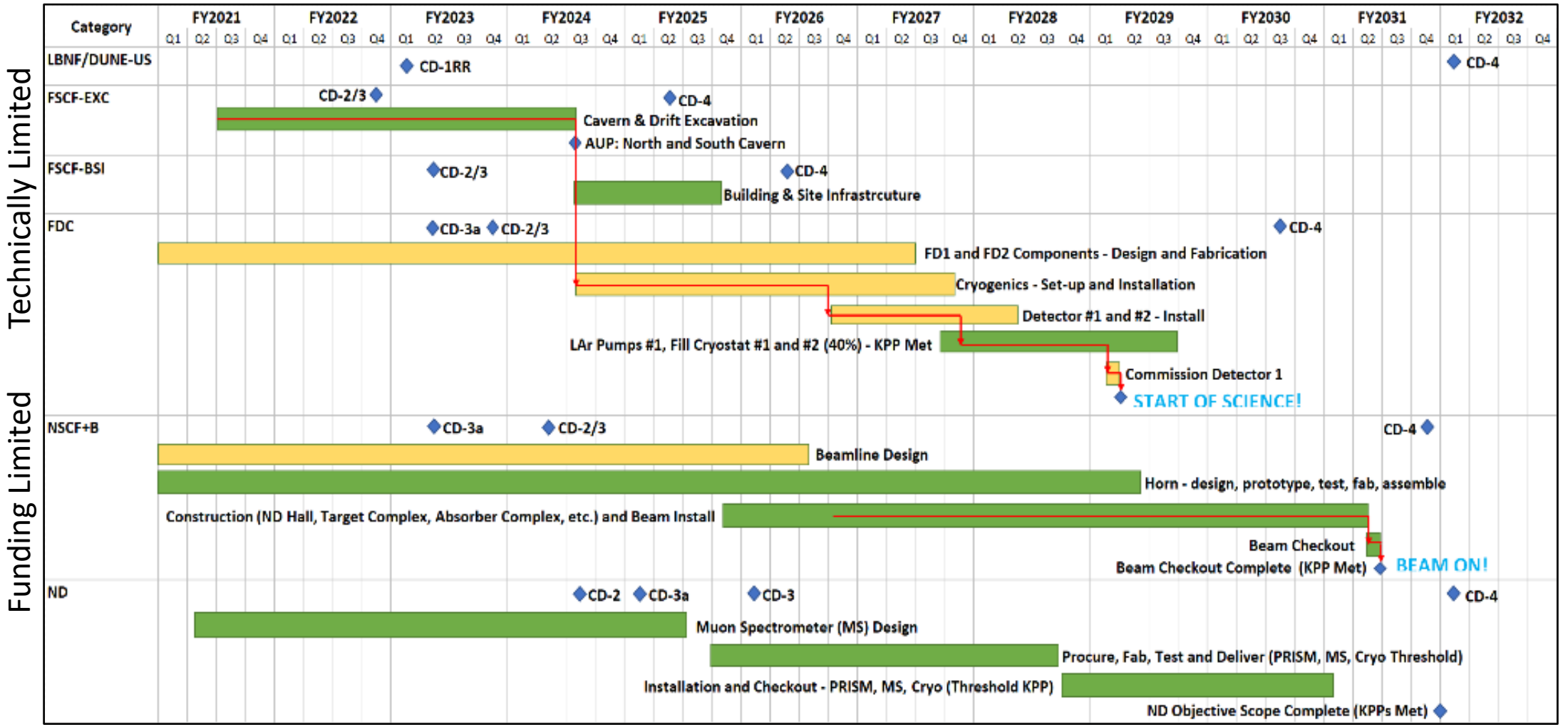
Technically limited schedule

Two subprojects

- **NSCF+B** – Near Site Conventional Facilities + Beamline
- **ND** – Near Detectors Funding limited schedule

Largest **DOMESTIC** project in Office of Science (TPC = $3.2B)

LBNF/DUNE Project Schedule FY 2021-2032



Project CD-4 is defined as Near Detector CD-4 date (last Subproject to finish Early CD4 12/2031 (Dec 2034 late finish at 90% CL)

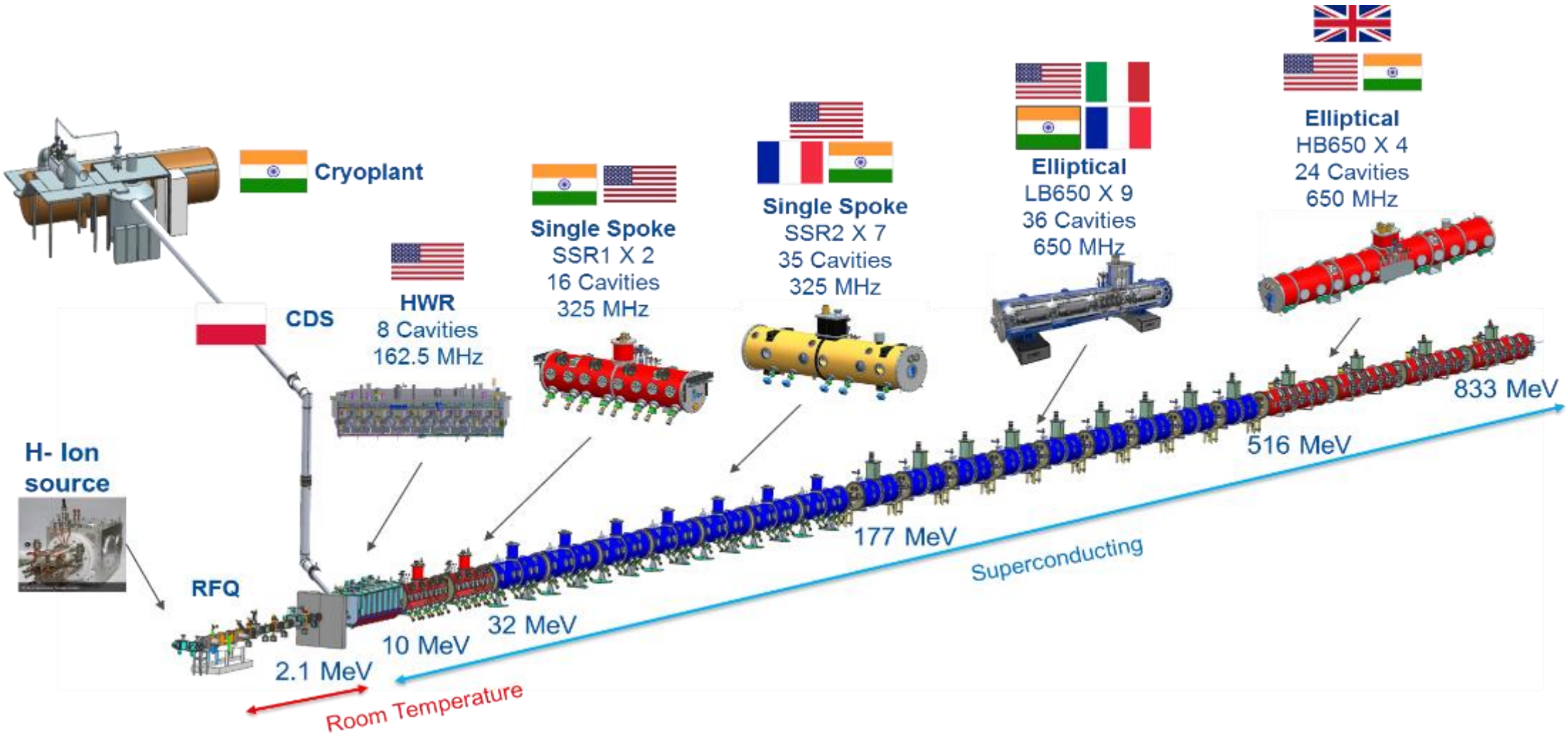
PIP-II Construction Project

- New SRF Linac will replace Fermilab's 50-year-old front-end infrastructure, increasing beam power, energy, reliability, flexibility and upgradability.
- Extends Fermilab's leadership with world's most intense neutrino beam for long baseline experiment and other scientific opportunities.
- DOE Total Project Cost = $978,000,000.
- Timeline

CD-3 a	3/16/2021	Approved Long-lead Procurement
CD-3	4/18/2022	Approved Start of Construction
CD-4	1Q FY 2033	Forecast for Project Completion

- International contributions : France, India, Italy, Poland, UK

PIP-II International Scope



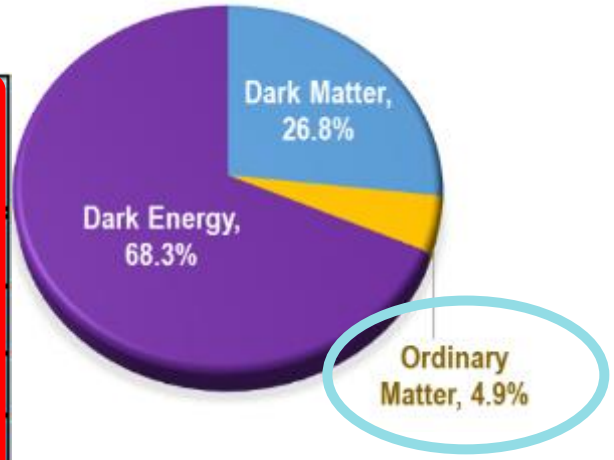
PIP-II Construction Status Highlights

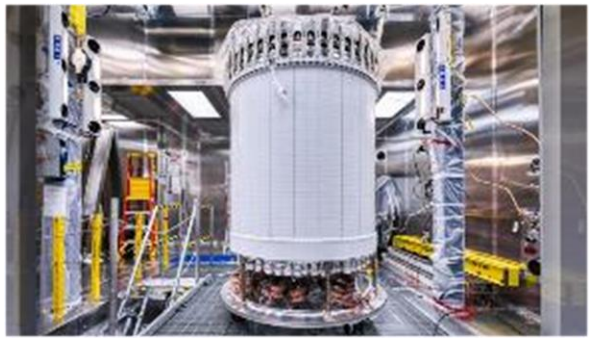
- Joint statement was published in June by India and the U.S. hailing the in-kind contribution from DAE to Fermilab toward collaborative development of the PIP-II accelerator for the Long Baseline Neutrino Facility.
- International agreements and project planning documents are being finalized with all of the international partners.
- The cryoplant building has Authorization for Use and Possession and will be ready to receive the cryoplant when it arrives from Air Liquide as an in-kind contribution by India.
- Civil Construction at the PIP-II site has been stopped since May 25 due to serious injury of an ironworker and is expected to restart by October following the conclusion of accident investigations and improved safety protocols.
- Schedule recovery plans are being implemented with improvements in several areas.
- The project contributed over 45 publications to the International Conference on RF Superconductivity last June.

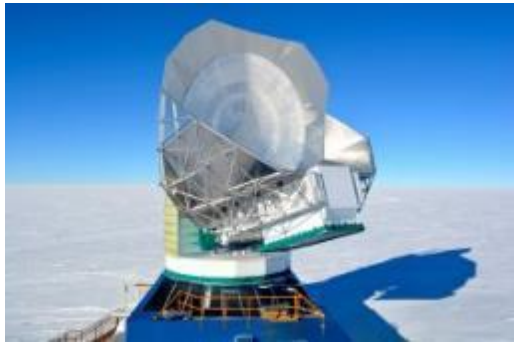
Cosmic Frontier Experiments

- **Cosmic Frontier experiments** address four of five science drivers
- They use naturally occurring sources to determine the fundamental nature of matter, energy, space and time.

	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

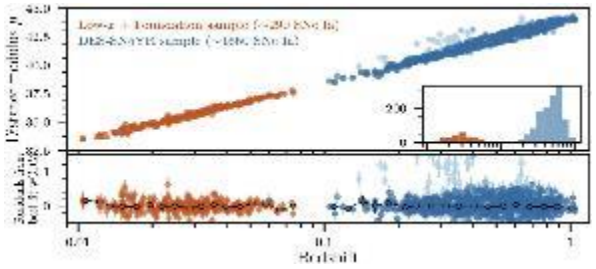
Direct Detection Dark Matter - DM-G2's & DMNI's

- Staged suite of complementary generation 2 direct detection experiments with multiple technologies to search for dark matter axions and WIMPs as recommended by P5
- ADMX-G2 axion search is currently operating at U. Washington
  - 2021 results are 5-orders of magnitude better than previous limits, ruling out axion DM hypothesis in this mass-coupling range
- LZ data-taking started end of 2021; now in Run 2. World-leading results published in PRL July 2023.
- SuperCDMS-SNOLAB MIE project in fabrication phase; CD-4 March 2023; Data-taking with one production tower in 2023; with all 4 towers in 2025.
- Dark Matter New Initiatives (DMNI) for <u>new</u> small projects to address the 2019 Basic Research Needs study; 4 Cosmic Frontier concepts in design and project execution <u>planning phase</u> (ADMX-EFR, DM-Radio, OSCURA, TESSERACT) + 1 Intensity Frontier (LDMX)

  - most could be ready to start fabrication in FY2025

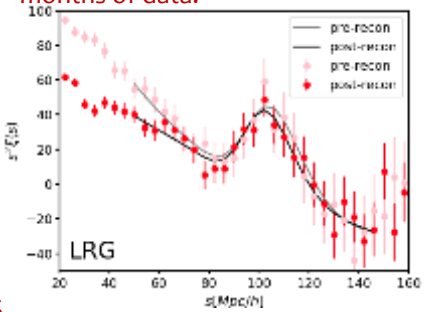
Cosmic Acceleration: Dark Energy & Dark Ages
→ DES, DESI, Rubin/LSST & LuSEE-Night

DES SNe1a sample



Stage III DES imaging survey in final data processing and analysis in progress. Cosmology with ~ 1700 type 1a supernovae to be published soon (largest and deepest sample from a single telescope). Public data release of SNe1a light curves end of 2023 & full cosmology catalogs by end of 2024.

DESI BAO signal at 5sigma from first 2 months of data!



Stage IV DESI – continues successful spectroscopic survey; down June to Sept. 2022 due to the Contreras Fire; primary mirror just completed re-aluminized due to reflectivity loss from fire-borne particulates. June 2023: Early Data Release was made publicly available and contains all the data from the Commissioning and Survey Validation phases. Collaboration released 2 "Key papers" describing the data, and 14 science and technical papers simultaneously.

Upgrade to DESI-II and then stage 5 project proposed to P5.

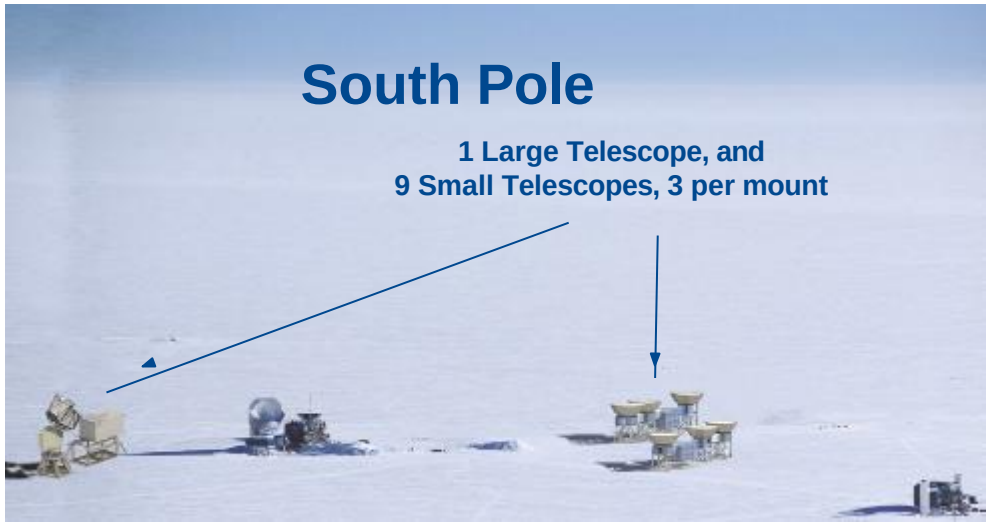
LSST Camera in test stand at SLAC.

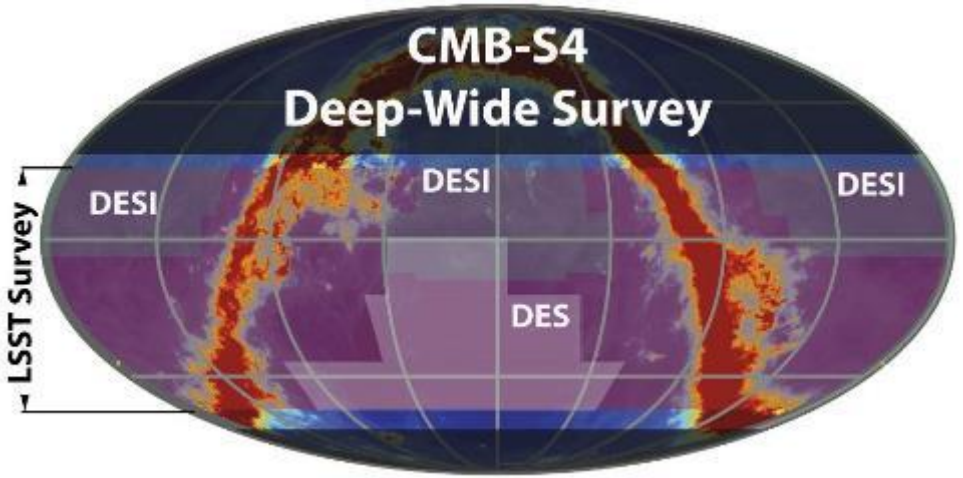
Stage IV Rubin Observatory in final construction, then integration & commissioning; starts operations early 2025. DOE has roles in overall Rubin Project and in commissioning.

- DOE's LSST camera is in testing and will ship to Chile Nov. 2023.
- Operations planning: DOE's ~ 50% share supports management, Camera M&O and the full US Data Facility.
- DOE's research efforts are organized through the DESC, which is collaborating with Rubin in commissioning and providing simulated data.

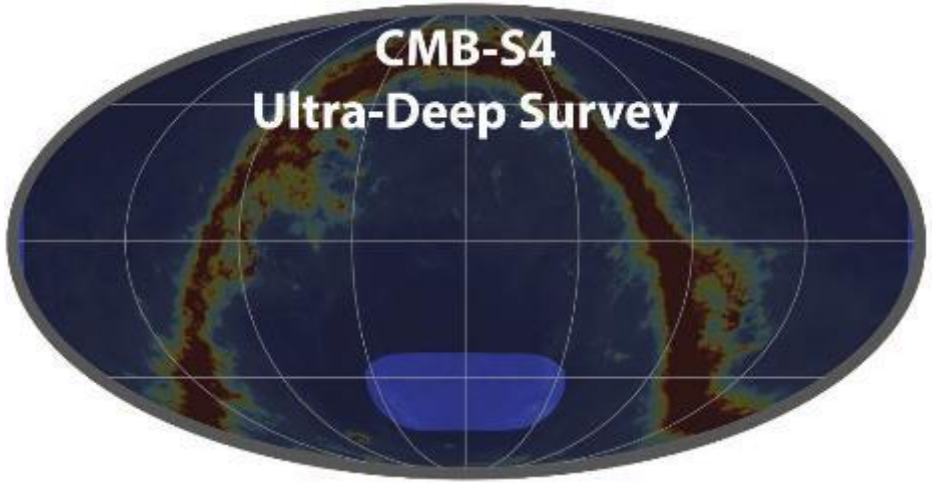
The **NASA/DOE LuSEE-Night pathfinder** mission to the lunar farside will observe the long-wavelength radio signal through the lunar night. It will place most sensitive constraints and potentially discover the Dark Ages signal (between CMB and star/galaxy formation). PD-3 review in August; DOE deliverables in mid 2024 & will launch ~ late 2025.

CMB-S4: Four Science Goals, Two Sites





Observed from Chile



Observed from South Pole

Large area survey motivated by N_{eff}, matter mapping, and time domain science and enabled by the mid-latitude site

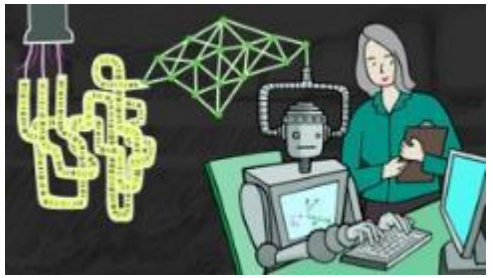
Small area survey primarily targeting inflationary gravitational waves, enabled by the sky coverage, low horizon blockage, and ultra stable atmosphere at polar site.

Summary : HEP Current Major Projects Portfolio

- Fermilab
  - LBNF/DUNE - CD-1RR; 5 subprojects
  - PIP-II – CD-3
  - Mu2E – CD-3
  - HL-LHC-AUP – CD-2
  - HL-LHC-CMS – CD-2
  - ACORN – CD-0
- HL-LHC-ATLAS (Brookhaven) – CD-2
- LSST camera for Vera Rubin Observatory (SLAC) – CD-4, commissioning
- CMB-S4 (Lawrence Berkeley Lab) – CD-0

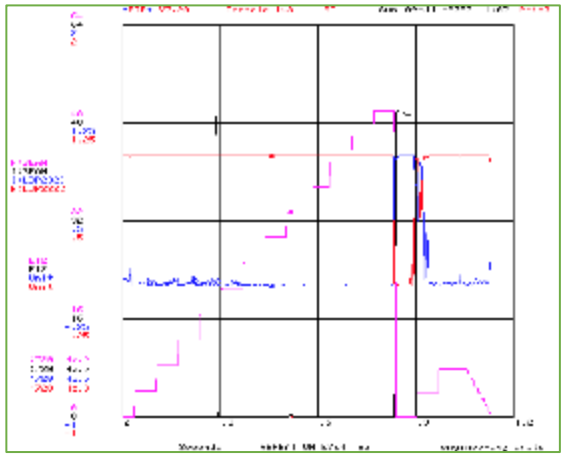
HEP Research Initiatives (from SC initiatives)

- QIS, AI/ML, Microelectronics, Advanced Computing, Accelerator Science and Technology, and ACCELERATE
- Quantum Information Science co-develops quantum information, theory, and technology with core research activities.
  - to more strongly focus and integrate efforts that align with HEP strengths in quantum sensors and theory
- AI/ML effort is highly embedded in core HEP research and accelerator technology, with a new thrust in proposal-driven, cross-cutting R&D. The balance between leveraging AI/ML tools for HEP science and using HEP data to drive AI/ML development will be reassessed.

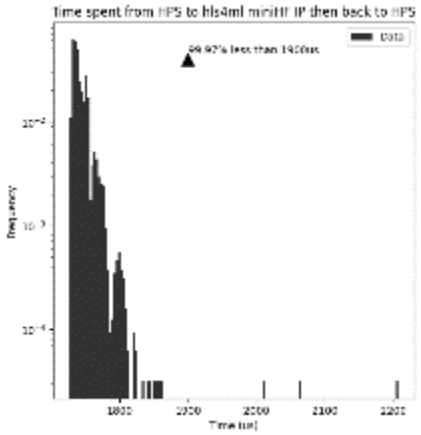


Real-time Edge AI for Distributed Systems (READS)

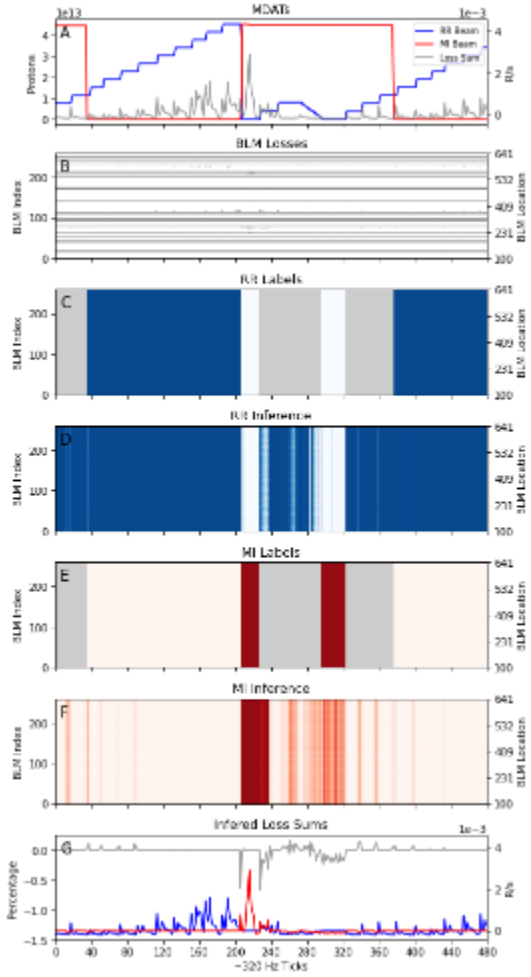
- Main Injector/Recycler Ring beam loss deblending:
  - MI/RR share a tunnel and disentangling beam loss requires expertise and often to bring down both beams when either one is causing losses.
  - **Develop a system to attribute beam loss in real-time (<3mS)**
- Many novel techniques/technologies implemented
  - Developed custom electronics to sample beam loss monitors, perform inference on FPGA, and provide results via a new network to Control Room
  - Synthesized ML U-net model on an FPGA and studied impact of layer precision
- **First real-time edge AI demonstrated on the Fermi accelerator controls system**
  - Inferences are accessible to Main Control Room operators and experts using existing tools used to tune and diagnose the accelerators
- **READS should improve the pulse inefficiency by 25% and machine downtime by 20%.**



Realtime ACNET Inferences!



Inference Latency



Offline Inferences

SQMS Research Center

Superconducting Quantum Materials and Systems Center at Fermilab

- **SQMS – the National QIS Research Center – hosted at Fermilab making excellent progress**
  - To-date: 155 publications of which 76 in peer-reviewed journals
  - Trained over 200 students with schools and internships in 2023
  - Today: 30 partner institutions with over 450 collaborators
  - Since last HEPAP meeting, four additional partner institutions joined the Center, including new collaborations with University of Michigan, U. Southern California, and UK institutions Royal Holloway and National Physical Laboratory

- **Mid-Term Progress Review of each of the five DOE Office of Science QIS Centers held during Feb-Mar 2023**
  - Evaluated each Center on five merit criteria: technical areas, S&T innovation chain, ecosystem stewardship, management structure, and instrumentation & facilities
  - SQMS reviewed strongly across all 5 criteria elements – some excerpts from the review committee include:
    - "SQMS leverages the expertise of Fermilab and a large number of collaborating institutions. … Well established goals and achievements in, and with first rate infrastructure for, quantum SRF cavity measurements and sensor development."
    - "Excellent summer internship program. Center has strong ties to industry partners to advance research & create talent pipeline."
    - "… Well-defined and strong management team is in-place with a "science first" approach to define ambitious goals."

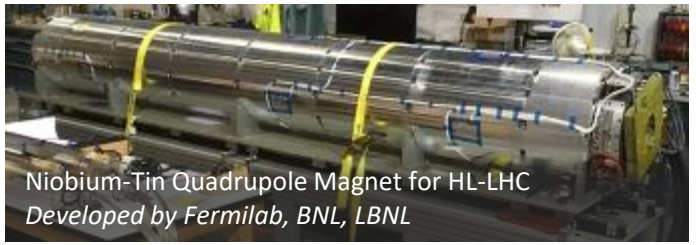
General Accelerator Research and Development

Advanced accelerator concepts

Superconducting radiofrequency (SRF) accelerators

High-field magnets to enable future colliders

Targets



Niobium-Tin Quadrupole Magnet for HL-LHC
Developed by Fermilab, BNL, LBNL

LCLS-II SRF Cavity Processing
Photo credit: Fermilab

Laser-driven Plasma Wakefield Channel *BELLA at LBNL*

GARD R&D Highlights: Advance Accelerator Concepts

- FACET-II: A National User Facility Based on High-Energy Beams and Their Interaction with Plasmas and lasers
  - New Experimental Area developed with strong engagement from User Community.
  - Hosted 8 DOE and NSF supported summer students.
  - Operation resumed late July 2023 and experimental plans developed.
  - Continuous operation until mid-November 2023.

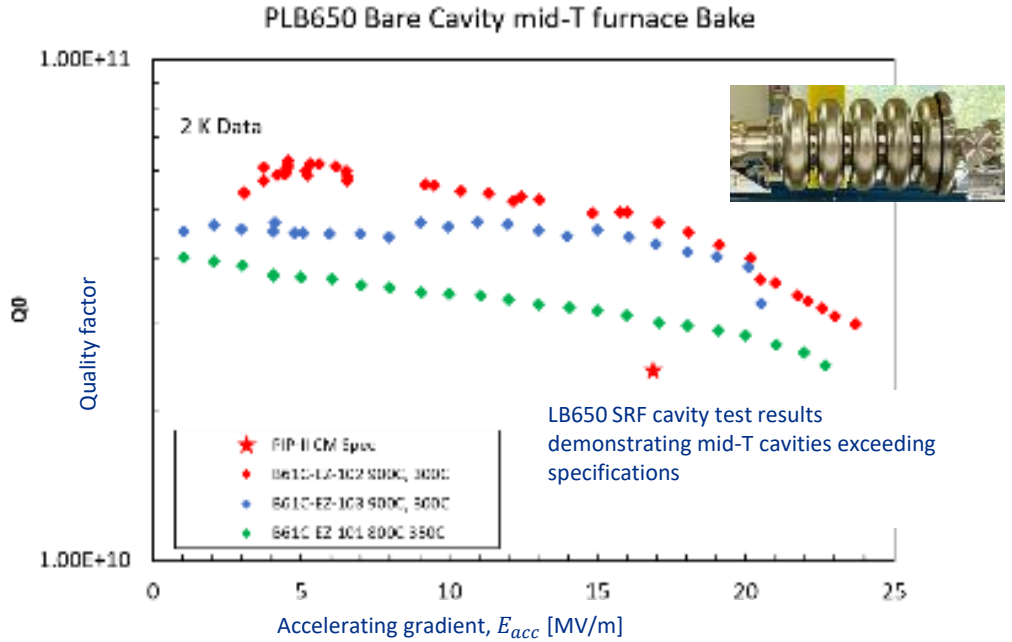
- Berkeley Lab's BELLA Second Beamline completed and started operations
  - New beamline diagnostic probe in operation shows plasma density too low.
  - Will power multi-GeV staging, advanced guiding, higher energies;
  - Extend plasma-based accelerators towards future e+e- colliders
  - First experiment: collaboration with U. Maryland, increased energy via guiding

- Berkeley Lab's AMP team awarded Leading Exascale Computing and SciDAC-5 Accelerator Projects

GARD R&D Highlights: SRF

Pushing the performance of SRF cavities and understanding performance limit

- Improving quality Q → lowering losses.
- Increasing accelerating gradients:
  - PIP-II has studied both nitrogen doping and mid-T baking for 650 MHz cavities.
  - Recent test results on a low-beta cavity show improved performance after mid-T baking, providing significant increase in Q.
  - Mid-T baking developed at Fermilab provides an easy operation technique to improve Q and has been widely adopted by SRF community.



Argonne Wakefield Accelerator (AWA) has achieved record-setting high RF power generation and high gradient

- Record power generation in MTM (0.565 GW) and metallic (0.5 GW) PETS (Power Extraction and Transfer Structure).
- Record gradients in dielectric (100 MV/m) and metallic (0.4 GV/m) structures.
- An AWA-SLAC team developed and demonstrated a novel analysis algorithm, based on differentiable physics simulations and machine learning, for rapid measurement of the 4D phase space of a beam distribution.
- AWA and NIU have designed a damping-ring-free electron injector capable of delivering flat electron beams with parameters compatible with the requirements for a linear collider.

GARD R&D Highlights: Superconducting Magnets

- Berkeley Lab's SC magnet R&D milestones advance future colliders
  - The first AUP cryomodule reached acceptance current and stable operation at 1.9K.
  - Record CORC cable performance, 12.9 kA in 5.7T background field, successful quench detection and protection at full current and field.
  - First Bi2212 high-temperature superconducting accelerator dipole magnet – leading the path to high fields 20+T.

- Recent Developments in Superconducting magnets at Fermilab
  - Nb3Sn wire R&D can help realize future hadron collider and muon collider.
  - New 2022 Nb3Sn wires with artificial pinning centers simultaneously achieve critical current Jc at the FCC-hh specification and have stability at low magnetic field – crucial for applications.
  - 2023 European Physical Society Accelerator Award: **Frank Sacherer Prize** for an individual in the early part of his or her career, having made a recent significant, original contribution to the accelerator field
    - Dr. Xingchen XU at Fermilab (DOE HEP ECA)

"for his contributions in demonstrating the effectiveness of the internal oxidation method in Nb_3Sn wires to strongly improve the performance of this superconductor by using artificial pinning centers, opening the way to the next generation of high field accelerator magnets."

GARD R&D Highlights: Targets

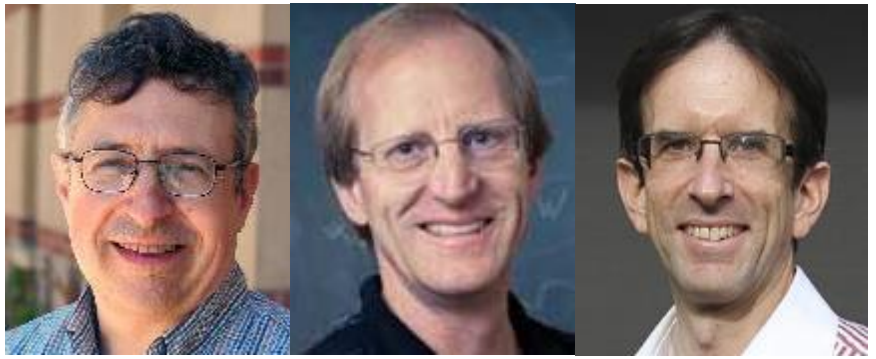
- High power targets (HPT)
  - Fermilab completed a thermal shock test at HiRadMat Facility (CERN). Nearly 120 samples were tested under single beam pulse at 4 different beam intensities;
  - Tested materials include materials for targets (graphite, Beryllium, nanofiber, tungsten alloys, SiC-SiC), and other beam intercepting devices, like windows (Ti-alloy, High Entropy Alloys, graphite)
  - The 2023 RaDIATE (Radiation Damage In Accelerator Target Environments) Collaboration Meeting held at Brookhaven National Laboratory from June 26 to 30, 2023.
  - High power targets and sources workshop was held (hybrid mode) at Fermilab and ANL from April 11-12, 2023
    - Development of High Power Target and Sources roadmap report in progress.

Theory Highlights

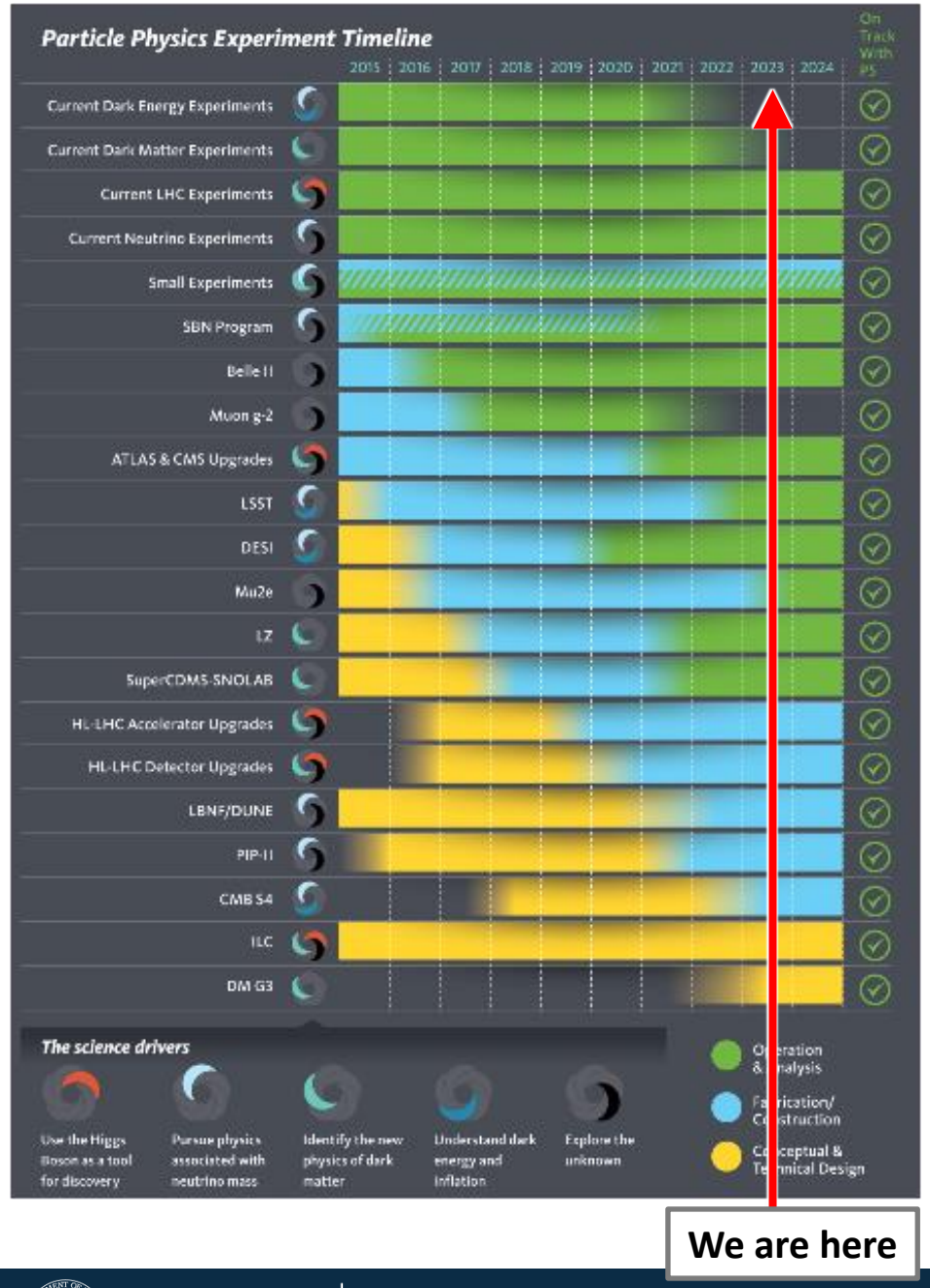
- HEP Theory supports over 200 university theorists on ~100 grants and ~ 50 theorists at National Laboratories
  - Hot topics include:
    - Dark Matter (Light DM, Wimp DM, Wave DM, Cosmic DM, …)
    - Inflation, Cosmic Acceleration, the h_0 controversy, …
    - Custom EFTs for SM, BSM, Gravity Waves, Inflation, …
    - Quantum information and QFT, Quantum Gravity, AdS/CFT, …
    - Higher Symmetries in Quantum Field Theory
    - Lattice for g-2, flavor, BSM, …
    - High-order Amplitudes for precision calculations in QCD, Electroweak, Gravity, …
  - HEP theorists are making outstanding advances in all these areas.

Awards for HEP Theorists 2023

- **Awards for HEP theorists in 2023 include:**
  - **2023 Galileo Galilei Medal,** Zvi Bern (UCLA), Lance Dixon (SLAC), and David Kosower (Saclay): For the development of powerful theoretical computational methods for collision processes at large particle accelerators.
  - **2023 New Horizons in Physics Prize,** David Simmons-Duffin (Caltech): For the development of analytical and numerical techniques to study conformal field theories, including the ones describing the liquid vapor critical point and the superfluid phase transition.
  - **2023 APS Henry Primakoff Award for Early-Career Particle Physics,** Bernhard Mistlberger (SLAC): For groundbreaking contributions to high-precision quantum field theory, including the next-to-next-to-next-to-leading order QCD corrections to the production of Higgs and electroweak vector bosons at hadron colliders.



2014 P5 Implementation Status



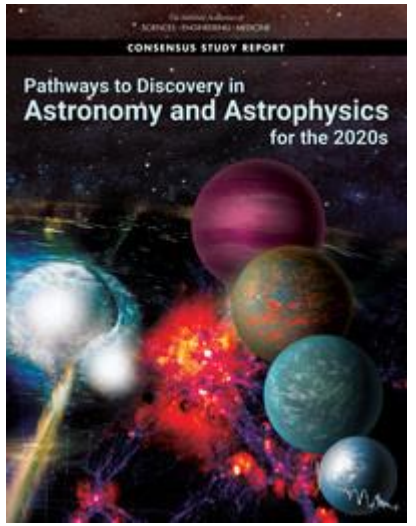
Implementation of the 2014 P5 strategy continues

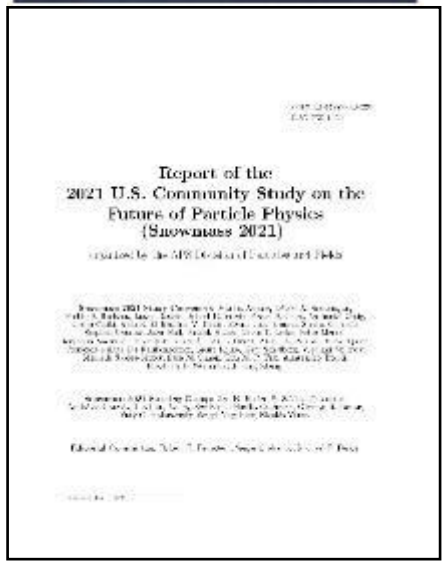
Continuous physics analyses and output throughout the "P5 envisioned" 10-year plan

- HL-LHC accelerator and detector upgrade projects underway
- LBNF/DUNE & PIP-II schedules advanced due to strong support by the U.S. Administration & Congress
- DESI, LZ and LSSTCam (for Rubin Observatory) projects completed
- Broad portfolio of small projects running
- General assessment – good progress, in spite of Covid delays
- LSST and Mu2e not yet operating
- CMB-S4 not yet in construction
- Direction for Future Colliders (beyond High Lumi-LHC) undetermined
- **Time to update and refresh the plan…**

U.S. Particle Physics Strategic Planning Process

- Each of these processes provides important input to the next P5 strategic process
  - Updated 2020 European Strategy for Particle Physics
  - NAS Astronomy and Astrophysics Decadal Survey (2021)
  - 2021-2022 Community Snowmass Process
  - New NAS Decadal Survey in Elementary Particle Physics
  - Upcoming HEPAP Report on International Benchmarking
- The 2023 P5 process is currently in progress
  - A P5 report by late 2023 will inform the FY 2025 U.S. budget formulation process



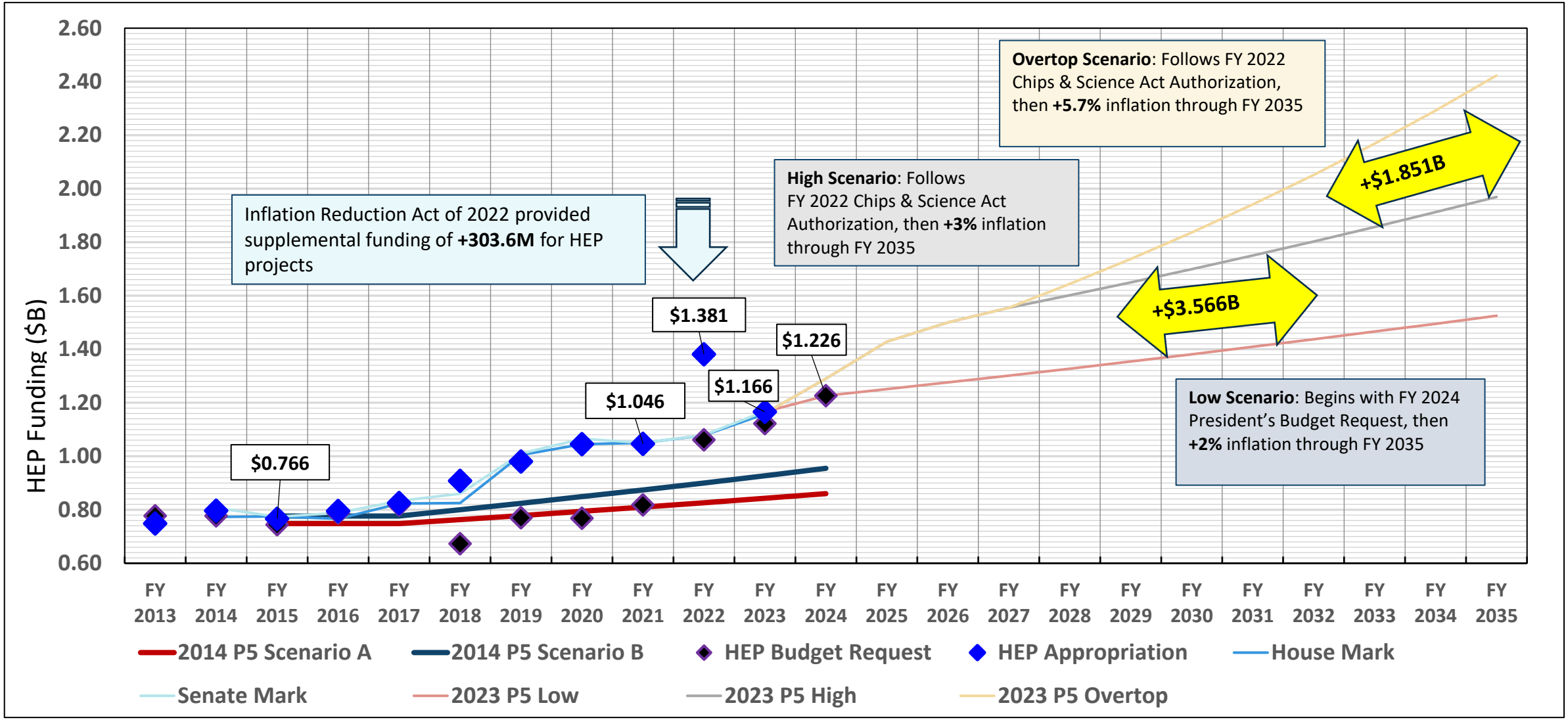

Report of the
2021 U.S. Community Study on the
Future of Particle Physics
(Snowmass 2021)

Snowmass 2021

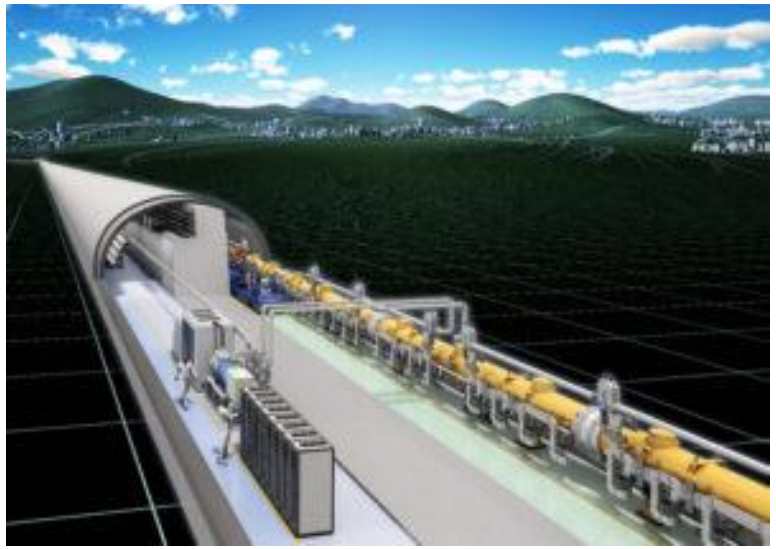
Charge to the 2023 P5 Subcommittee

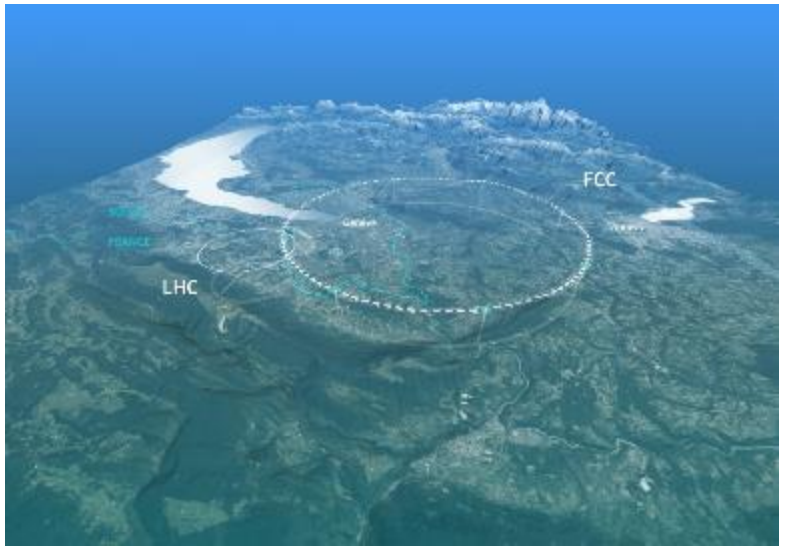
Consider : HEP is a global field	Support decisions to retain US leadership as a global partner	Preserve essential roles of Universities and National Labs	EDIA throughout the field results in improved science
Balanced core research budget is paramount to producing science	Remember costs of R&D, commissioning, and operations for future projects	Address synergies with broad national initiatives	Assess science case for on-going projects

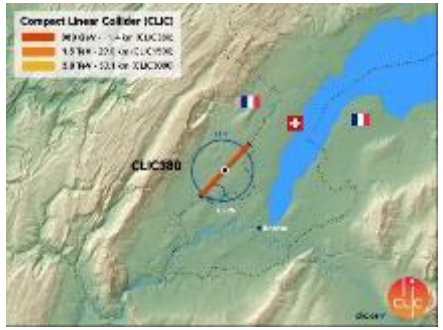
2023 P5 Budget Scenarios



Future Colliders – Many Options & Timelines to Consider







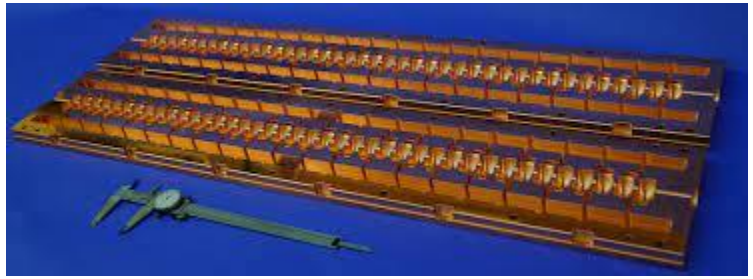
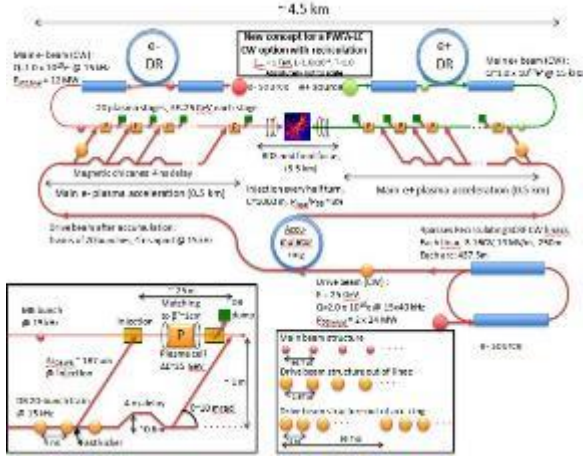
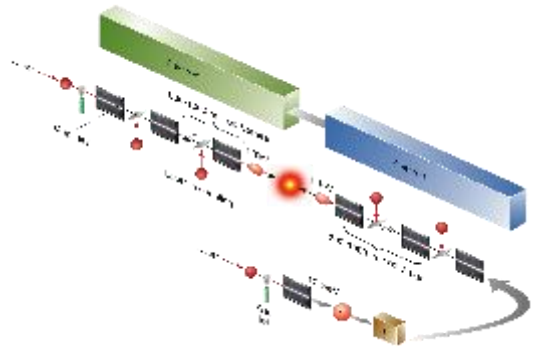


Figure 1: Layout of a 1 TeV PWFA Linear Collider





HEP International Cooperation Program

- **Advancing PIP-II cooperation with India during the State Visit by India's Prime Minister Modi in June 2023**

JUNE 22, 2023

Joint Statement from the United States and India

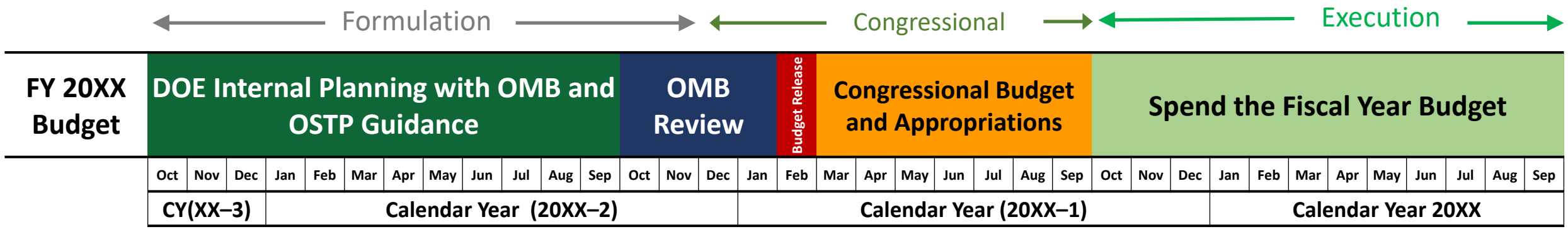
BRIEFING ROOM › STATEMENTS AND RELEASES

1. President Joseph R. Biden, Jr. and Prime Minister Narendra Modi today affirmed a vision of the United States and India as among the closest partners in the world – a partnership of democracies looking into the 21st century with hope, ambition, and confidence. The U.S.-India

10. President Biden and Prime Minister Modi hailed our deepening bilateral cooperation on cutting-edge scientific infrastructure, including a $140 million in-kind contribution from the Indian Department of Atomic Energy (DAE) to the U.S. Department of Energy's (DOE's) Fermi National Laboratory toward collaborative development of the Proton Improvement Plan-II Accelerator, for the Long Baseline Neutrino Facility — the first and largest international research facility on U.S. soil. They also welcomed the commencement of construction of a Laser Interferometer Gravitational-Wave Observatory (LIGO) in India. The leaders called on their administrations to extend these partnerships to advanced biotechnology and biomanufacturing, and enhance biosafety and biosecurity innovation, practices, and norms.

Three Phases of Budget Process

- **Formulation**: Executive branch prepares the President's Budget Request
  - White House Office of Management and Budget (OMB) controls this process, providing guidance to Executive branch agencies
- **Congressional**: Enacts laws that control spending and receipts
  - Congress considers the President's Budget proposals, passes a budget resolution, and enacts the regular appropriations acts and other laws that control spending and receipts
- **Execution**: Executive branch agencies carry out program
  - OMB apportions funds to Executive Branch agencies, which obligate and disperse funding to carry out their programs, projects, and activities



Overview of Budget Formulation Process

Spring

Spring & Summer

June

Sept.

Fall

Late Nov.

Dec.

Jan.

→**OMB provides policy guidance for Executive branch agency budget requests**
- Absent more specific guidance, agencies start with outyear estimates from previous budget

→**OMB works with agencies**
- Identify major issues, develop plans for fall review, plan analysis of issues that will require decisions

→**OMB provides detailed instructions for submitting budget material**

→**Agencies submit budgets to OMB** [before Labor Day]

→**OMB reviews budget proposals**
- Considers Presidential priorities, program performance, budget constraints

→**OMB provides recommended budget proposal to President and provides pass back to agencies** [after Thanksgiving]

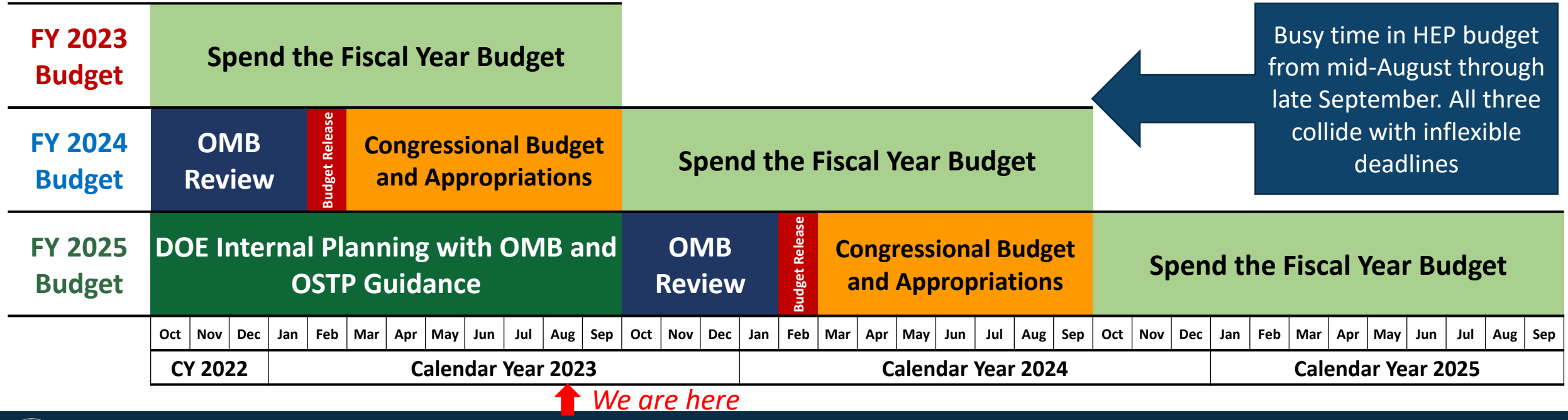
→**Agencies may appeal to OMB and the President**

→**Agencies prepare and OMB reviews final congressional budget justification materials** [early January]

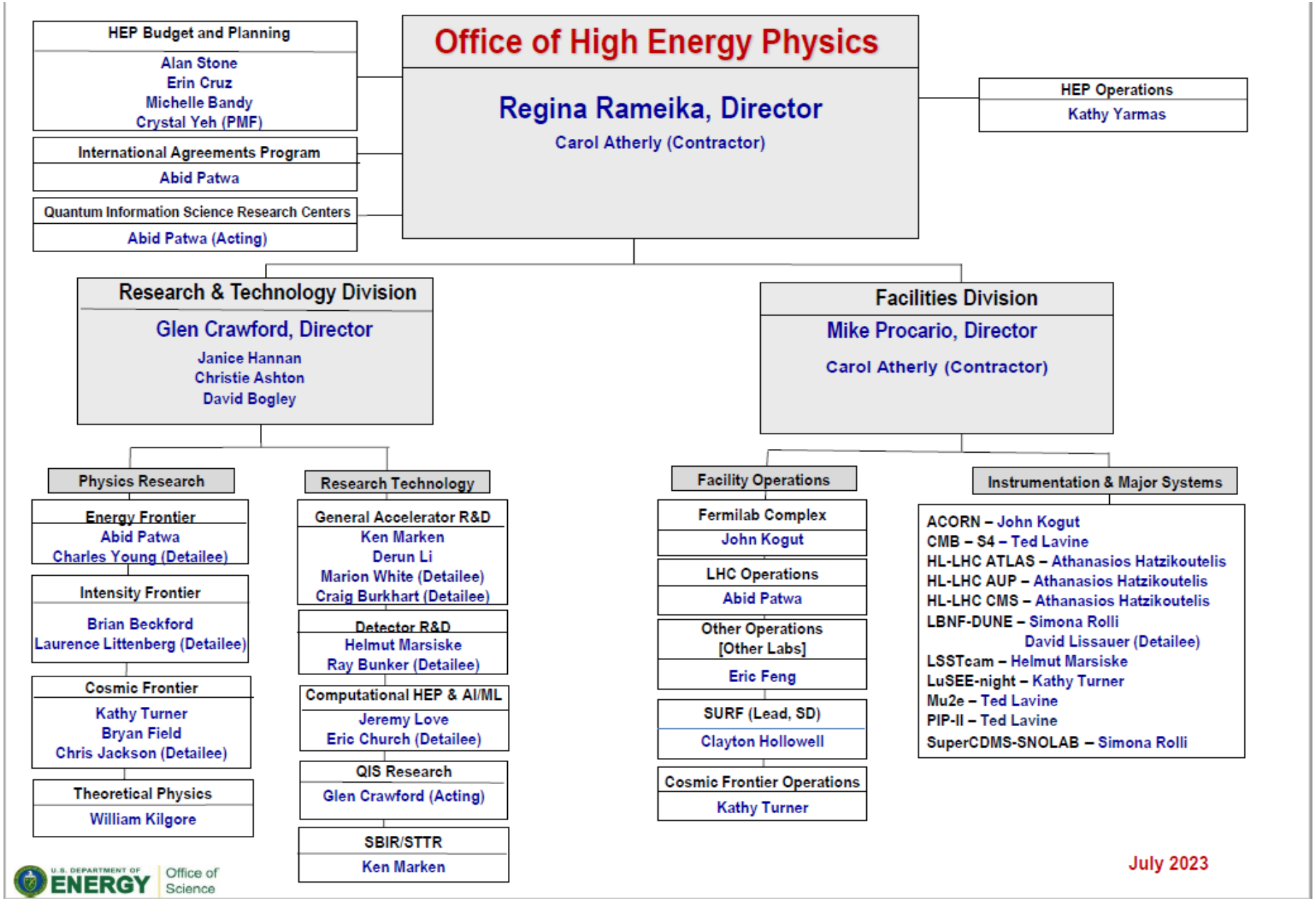
→**<u>February</u>: President transmits budget to Congress**

The U.S. Federal Budget Cycle

- Typically, three budgets are being worked on at any given time
  - Executing current Fiscal Year (FY; October 1 – September 30).
    - Aggregating final FY 2023 End of Year requests to determine final distributions of reserves
  - OMB review and Congressional Appropriation for upcoming FY.
    - Preparing FY 2024 Initial Funding Plan for DOE Labs and Program Managers annual budgets assuming a 3-month CR
  - Agency internal planning for the second FY from now
    - Submitting the FY 2025 HEP narrative draft to SC budget and DOE CFO for review before it goes to OMB for review



OHEP Organization



Summary and Outlook

- It is an exciting time for US-HEP
- Accelerator Experiments running at the LHC, Fermilab, KEK
- Cosmic data being collected by DESI, AMS
- We have a portfolio of projects across the frontiers in varying stages of completion
- We have made major investment and commitments to the new research initiatives in Quantum and AI/ML
- We have a strong portfolio of activities in accelerator R&D
- We have a P5 planning process underway that will lay out a compelling program for the next decade with a vision to a very bright future for HEP