Cosmic Frontier Experimental Program

DOE/HEP report to the AAAC

January 18, 2024

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Short update since the December 2023 meeting

- Office news
- Project news
- HEPAP P5 subpanel report

HEP/Cosmic Frontier News

- Cosmic Frontier program managers:

Bryan Field – Cosmology Research

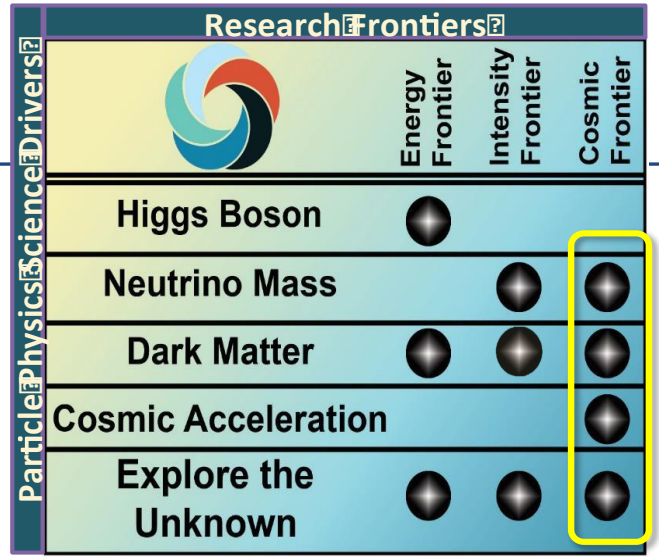
➔Manuel Bautista – Dark Matter Research * NEW – started January 2!

Kathy Turner – Cosmic Frontier operations/projects

Chris Jackson – detailee from PNNL; dark matter

* Significant effort from others in HEP, e.g. Helmut Marsiske for the LSST Camera project; overlaps with other subprograms, e.g. computing, detector R&D

Program Guidance



→HEPAP - reports to both DOE and NSF

HEPAP subpanel – P5 study (2014) – our current strategic plan

Recommended science & project priorities aligned with science drivers
- in Dark Energy, Dark Matter, CMB projects + small projects.

- **Cosmic Acceleration:**
  - **Dark Energy:** build **LSST (Rubin) & DESI**
  - **CMB:** support as part of the core program within multi-agency context; carry out multi-agency **CMB-S4** project later in the decade
- **Dark Matter:** suite of "generation 2" direct detection experiments to detect DM particles: **ADMX-G2, SuperCDMS SNOLAB, LZ**

HEPAP subpanels – Recent/Current

- HEPAP International Benchmarking study – completed Nov. 2023 – described at the Dec. 2023 meeting
- **HEPAP Particle Physics Project Prioritization Panel (P5) study – completed Dec. 2023 – will be used for future program planning**
  - Used as input: Astro2020, European physics strategy, Snowmass report etc
- Committee of Visitors (COV) for the HEP Facilities Division
- Office of Science wide Facilities Construction Project subpanel study – described at the Dec. 2023 meeting

→AAAC – reports to NASA, NSF, DOE

→National Academies study continuing: Elementary Particle Physics 2024 (EPP2024)
https://www.nationalacademies.org/our-work/elementary-particle-physics-progress-and-promise

DOE Office of Science, Office of High Energy Physics (HEP) -- Cosmic Frontier (CF) experimental research

HEP/CF is following the 2014 P5 strategic plan.

→ **Responding to Astro2020 and future program planning to aligned with the Dec. 2023 P5 strategic plan.**

See 12/7/23 P5's presentation to HEPAP at https://science.osti.gov/hep/hepap/Meetings/202312

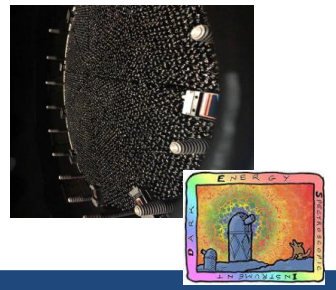
2014 P5 → Current primary Cosmic Frontier program aligned with 2014 Science Drivers:

Cosmic Acceleration – Phases of the Cosmos

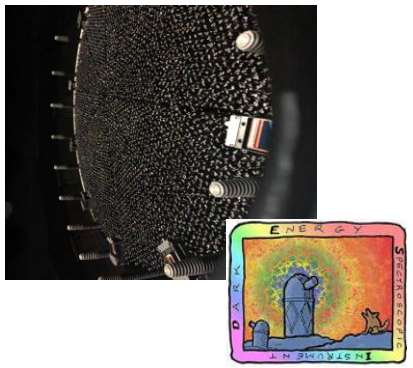
- Nature of **Dark Energy** using imaging & spectroscopic surveys (BOSS, eBOSS, DES, DESI, Rubin + future planning)
- Using the CMB to study the era of **Inflation** (SPT-3G, CMB-S4 design)
- First investigation of the **Dark Ages** (LuSEE-Night underway, going to the lunar farside)

Dark Matter:

- Direct Detection searches (WIMPs, Axions) using a variety of methods and technologies
- Generation 2 experiments: ADMX-G2, LZ, SuperCDMS-SNOLAB
- Concept designs for potential new initiatives – ADMX-EFR, DM-Radio, OSCURA, TESSERACT



Cosmic Frontier:
Current Program Based on 2014 P5 recommendations is Continuing



Cosmic Acceleration – Phases of the Cosmos

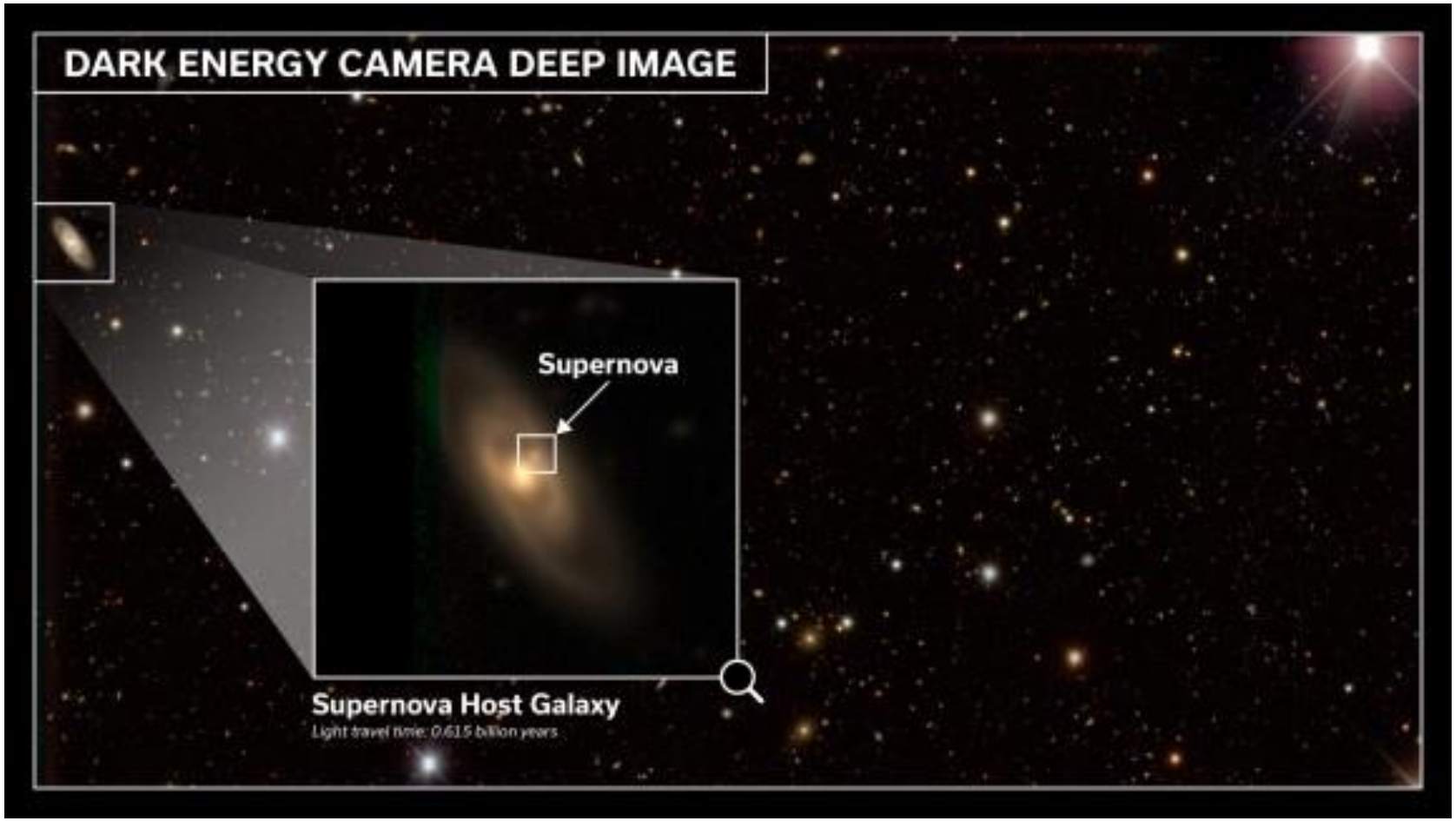
- Nature of **Dark Energy** using imaging & spectroscopic surveys
  - Stage 3 - ***eBOSS*** *(completed 2020)*, **DES** doing final data analyses
  - Stage 4
    - **DESI** (operating)
    - **LSST** Camera (project completed, now testing, commissioning) for Rubin Observatory
      - Operations planning ongoing, Dark Energy Science Collaboration (DESC)
- Peer into era of **Inflation** with **SPT-3G (operating), CMB-S4 (R&D, design, planning)**
- **Small Projects** - First investigation of the **Dark Ages** (**LuSEE-Night** underway, going to the lunar farside)

DES and DESI presented results and Rubin Observatory held a town hall at the January 2024 AAS.
Congratulations to Prof. John Carlstrom on the 2024 Heineman prize in astrophysics!

Black: HEP support ended
Green: support continues
Recommended by 2014 P5

Dark Energy Survey (DES) presented results at the Jan. 2024 AAS mtg

DES presented cosmology results with ~1500 new high-redshift type Ia supernovae using the full 5-year dataset. Results are consistent with a ΛCDM universe but don't rule out more complex model.



The image shows a DES supernova within the field covered by one of the individual detectors in the DECAm. The supernova exploded in a spiral galaxy with redshift = 0.04528. This is one of the nearest supernovae in the sample. Image: DES collaboration

DES is an international collaboration with > 400 members from > 25 US and international institutions, led by DOE's Fermilab. DES is supported by a DOE/NSF partnership, with US lab, university, and international contributors. DES mapped an area almost one-eighth the entire sky using the 570 Mpixel Dark Energy Camera (DECam) built by Fermilab and operated on the Blanco telescope at the NSF's CTIO. The DES survey was carried out over 758 nights across six years.

Text & images from https://www.interactions.org/press-release/final-supernova-results-dark-energy-survey-offer-unique

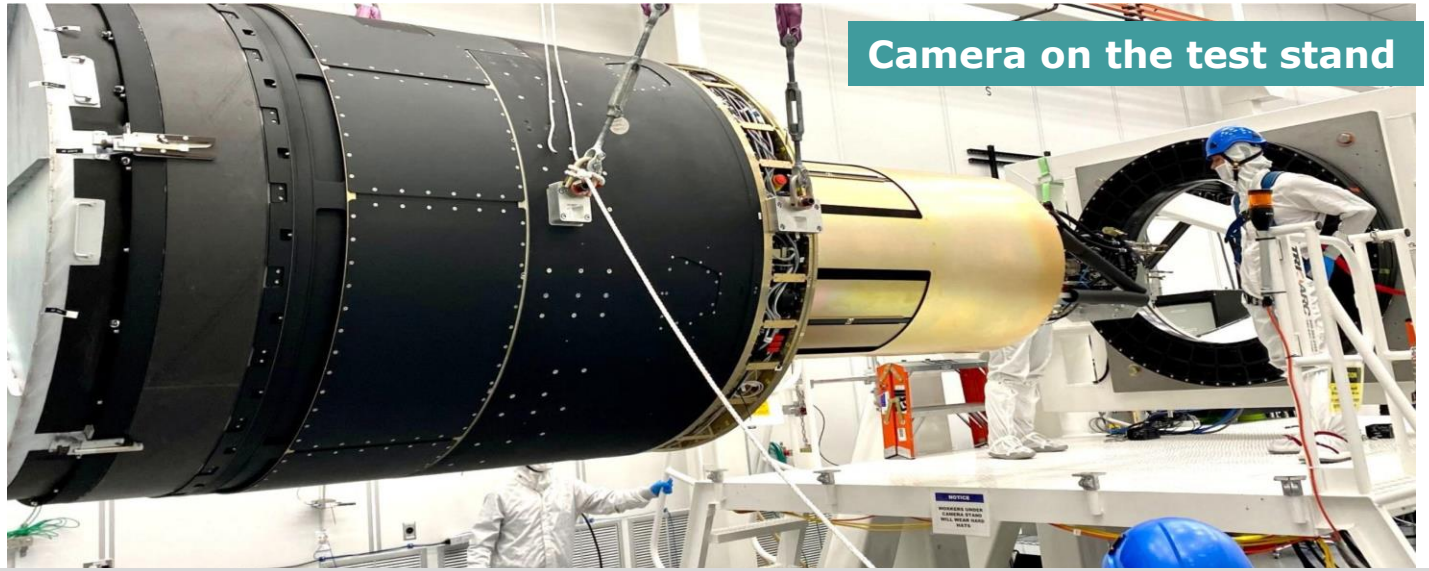
DOE Office of Science, Office of High Energy Physics (HEP) -- Cosmic Frontier (CF) experimental research

The Rubin Observatory is the flagship project in HEP/CF
→ NSF (AURA) & DOE (SLAC) partnership, with private, international contributions

DOE's Primary roles & responsibilities

Construction/Commissioning: 3 billion pixel CCD camera plus efforts on the 9-CCD Commissioning Camera (ComCam)
Facility operations (50/50 NSF/DOE) - Camera maintenance, operations, US Data Facility
All phases – also roles in the overall management team, data quality and data verification studies
Scientific research – HEP's interests are carried out by the Dark Energy Science Collaboration (1 of 8 collaborations)

Camera testing is underway at SLAC; shipment to Chile planned spring 2024.



2024: Camera to Chile, ComCam on sky, Camera on telescope. Early 2025 – System First Light; Late 2025 – LSST starts

Cosmic Frontier:
Current Program Based on 2014 P5 recommendations is Continuing

Dark Matter:

- Direct Detection searches (WIMPs, Axions) using a variety of methods and technologies
  ADMX-G2 (operating), LZ (operating), SuperCDMS SNOLAB (installation, testing)
- Indirect searches: ***VERITAS, HAWC,*** **Fermi-LAT** (HEP now supporting ops only), **AMS** on ISS (ops)
- **Small Projects:** Dark Matter New Initiative (**DMNI**) concept designs for potential new direct detection searches in priority research directions, opening up new areas of phase space – **ADMX-EFR, DM-Radio, OSCURA, TESSERACT, LDMX** (accelerator-based)

Neutrino properties constrained using dark energy & CMB measurements

Exploring the Unknown - Always interested in New Physics!

Black: HEP support ended
Green: support continues
Recommended by 2014 P5

HEPAP 2023 December P5 report

DOE/HEP thanks the panel for the tremendous job they did over the last year leading to this excellent report.

- It will take a while for DOE to read the report and develop plans based on the recommendations.
- New program directions will likely take a few years to be implemented.

➔**See Hitoshi Murayama's P5 report talk at the Dec. 2024 AAAC meeting**

Charge
https://science.osti.gov/-/media/hep/hepap/pdf/202212/2022-601_Charge_Letter_P5-2022_AAB_and_SJ_Signed.pdf - 2 funding scenarios provided by HEP

12/7/23 P5's presentation to HEPAP
https://science.osti.gov/hep/hepap/Meetings/202312

12/8/23 draft report (draft approved by HEPAP but there may be some wording updates)
https://science.osti.gov/-/media/hep/hepap/pdf/Reports/P5Report2023_120123-DRAFT-to-HEPAP.pdf

HEPAP Dec. 2023 P5 report

- **Charge:** developing a 10-year strategic plan for US particle physics, in the context of a 20-year global strategy and two constrained budget scenarios.
- An essential source of input was the 2021 Snowmass Community Planning Exercise organized by the Division of Particles and Fields of the APS. Astro2020, the European strategic plan etc – also used as input.

The P5 identified three science themes and two focus areas within each theme :

- Decipher the Quantum Realm → Elucidate the mysteries of Neutrinos & Reveal the secrets of the Higgs Boson
- Explore News Paradigms in Physics → Search for direct evidence of new physics & Pursue quantum imprints of new phenomena
- Illuminate the Hidden Universe → Determine the nature of Dark Matter & Understand what drives cosmic evolution

The DOE provided the panel with two budget scenarios for High Energy Physics (HEP):

- The *baseline* scenario assumes budget levels for fiscal years 2023 through 2027 that are specified in the CHIPS and Science Act of 2022, and increases by 3% per year from fiscal year 2028 through 2033.
- The less favorable scenario assumes increases of 2% per year from fiscal year 2024 to 2033.

2023 P5 recommendations

The panel categorized projects as small (<$50M), medium ($50M–250M), and large (>$250M) based on the US contribution to their construction cost.

- In the large and medium categories, initiatives were first prioritized based on individual scientific merit, then assessed on project maturity, technical risk, and balance of project timescales.
- For the small category, the panel generally did not consider individual projects but did note areas where these could be particularly effective.

The highest priority was assigned to:

- Execution of project begun in the last decade,
- Three major facilities currently under construction: HL-LHC, DUNE, and Rubin

The panel made six recommendations.

P5 recommendations

1) As the highest priority independent of the budget scenarios, complete construction projects and support operations of ongoing experiments and research to enable maximum science. This includes support for

- HL-LHC (including ATLAS and CMS detectors, as well as Accelerator Upgrade Project) to start addressing why the Higgs boson condensed in the universe (*reveal the secrets of the Higgs boson*), to *search for direct evidence for new particles*, to *pursue quantum imprints of new phenomena,* and to *determine the nature of dark matter*.
- The first phase of DUNE and PIP-II to determine the mass ordering among neutrinos, a fundamental property and a crucial input to cosmology and nuclear science (*elucidate the mysteries of neutrinos*).
- **The Vera C. Rubin Observatory to carry out the LSST, and the LSST Dark Energy Science Collaboration, to *understand what drives cosmic evolution*.**
- NOvA, SBN, and T2K (*elucidate the mysteries of neutrinos*).
- DarkSide-20k, **LZ, SuperCDMS**, and XENONnT (determine the nature of dark matter).
- **DESI** (*understand what drives cosmic evolution*).
- Belle II, LHCb, and Mu2e

P5 recommendations

2) Construct a portfolio of major projects that collectively study nearly all fundamental constituents of our universe and their interactions, as well as how those interactions determine both the cosmic past and future. Plan and start the following major initiatives in order of priority from highest to lowest:

- **CMB-S4, which looks back at the earliest moments of the universe to probe physics at the highest energy scales. It is critical to install telescopes at and observe from both the South Pole and Chile sites to achieve the science goals.**
- Re-envisioned second phase of DUNE with an early implementation of an enhanced 2.1 MW beam—ACE-MIRT—a third far detector, and an upgraded near-detector complex as the definitive long-baseline neutrino oscillation experiment of its kind.
- An off-shore Higgs factory to reveal the secrets of the Higgs boson. The current designs of FCC-ee and ILC meet our scientific requirements. The US should aim for a contribution at funding levels commensurate to that of the US involvement in the LHC and HL-LHC.
- **An ultimate Generation 3 (G3) dark matter direct detection experiment reaching the neutrino fog, in coordination with international partners and preferably sited in the US.**
- IceCube-Gen2 for study of neutrino properties using non-beam neutrinos complementary to DUNE and for indirect detection of dark matter covering higher mass ranges using neutrinos as a tool

P5 recommendations

3) Create an improved balance between small-, medium-, and large-scale projects to open new scientific opportunities, enhance workforce development, promote creativity, and compete on the world stage. To achieve this balance the recommendation is to:

- Implement a new small-project portfolio at DOE, Advancing Science and Technology through Agile Experiments (ASTAE), across science themes in particle physics with a competitive program and recurring funding opportunity announcements. This program should start with the construction of experiments from the **Dark Matter New Initiatives (DMNI)** by DOE-HEP.
- Continue Mid-Scale Research Infrastructure (MSRI) and Major Research Instrumentation (MRI) programs.
- Support **DESI-II** for cosmic evolution, LHCb upgrade II and Belle II upgrade for quantum imprints, and US contributions to the global CTA Observatory for dark matter

P5 recommendations

Figure 2 – Construction in Various Budget Scenarios

Index: N: No Y: Yes R&D: Recommend R&D but no funding for project C: Conditional yes based on review P: Primary S: Secondary
Delayed: Recommend construction but delayed to the next decade
Can be considered as part of ASTAE with reduced scope

US Construction Cost >$3B				Science Drivers						
Scenarios	Less	Baseline	More	Neutrinos	Higgs Boson	Dark Matter	Cosmic Evolution	Direct Evidence	Quantum Imprints	Astronomy & Astrophysics
on-shore Higgs factory	N	N	N		P	S		P	P	
$1–3B										
off-shore Higgs factory	Delayed	Y	Y		P	S		P	P	
ACE-BR	R&D	R&D	C	P				P	P	
$400–1000M										
CMB-S4	Y	Y	Y	S		S	P			P
Spec-S5	R&D	R&D	Y	S		S	P			P
$100–400M										
IceCube-Gen2	Y	Y	Y	P		S				P
G3 Dark Matter 1	Y	Y	Y	S		P				
DUNE FD3	Y	Y	Y	P				S	S	S
test facilities & demonstrator	C	C	C		P	P		P	P	
ACE-MIRT	R&D	Y	Y	P						
DUNE FD4	R&D	R&D	Y	P				S	S	S
G3 Dark Matter 2	N	N	Y	S		P				
Mu2e-II	R&D	R&D	R&D						P	
srEDM	N	N	N						P	
$60–100M										
SURF Expansion	N	Y	Y	P		P				
DUNE MCND	N	Y	Y	P				S	S	
MATHUSLA #	N	N	N			P		P		
FPF #	N	N	N	P		P		P		

HEP Cosmic Frontier
Summary & Future Planning

- HEP continues to carry out the 2014 P5 strategic plan

- **FY 2024 – we are in a continuing resolution**
  - FY 2025 – the President's Request budget has been developed
    - FY 2026 – work will start on this in the spring

- Future – Guidance provided by 2023 International Benchmarking, P5

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P5 recommendations

4: Support a comprehensive effort to develop the resources—theoretical, computational, and technological—essential to our 20-year vision for the field. This includes an aggressive R&D program that could yield revolutionary accelerator designs that chart a realistic path to a 10 TeV pCM collider. This requires the following:

- Support R&D toward a cost-effective 10 TeV pCM collider based on proton, muon, or possible wakefield technologies, including an evaluation of options for US siting of such a machine, with a goal of being ready to build major test facilities and demonstrator facilities within the next 10 years.
- Enhance research in theory to propel innovation, maximize scientific impact of investments in experiments, and expand our understanding of the universe.
- Expand the General Accelerator R&D (GARD) program within HEP, including stewardship.
- Invest **in R&D in instrumentation** to develop innovative scientific tools.
- Conduct R&D efforts to define and enable new projects in the next decade, including detectors for an *e*+*e*– Higgs factory and 10 TeV pCM collider, **Spec-S5**, DUNE FD4, Mu2e-II, Advanced Muon Facility, and line intensity mapping.
- **Support key cyberinfrastructure components** such as shared software tools and a sustained R&D effort in computing to fully exploit emerging technologies for projects.
- Prioritize computing and novel data analysis techniques for maximizing science across the entire field.
- Develop plans for improving the Fermilab accelerator complex that are consistent with the long-term vision of this report, including neutrinos, flavor, and a 10 TeV pCM Collider.

P5 recommendations

5) Invest in initiatives aimed at developing the workforce, broadening engagement, and supporting ethical conduct in the field. This includes:

- All projects, workshops, conferences, and collaborations must incorporate ethics agreements that detail expectations for professional conduct and establish mechanisms for transparent reporting, response, and training. These mechanisms should be supported by laboratory and funding agency infrastructure. The efficacy and coverage of this infrastructure should be reviewed by a HEPAP subpanel.
- Funding agencies should continue to support programs that broaden engagement in particle physics, including strategic academic partnership programs, traineeship programs, and programs in support of dependent care and accessibility. A systematic review of these programs should be used to identify and remove barriers.
- Comprehensive work-climate studies should be conducted with the support of funding agencies. Large collaborations and national laboratories should consistently undertake such studies. Professional associations should spearhead field-wide work-climate investigations.
- Funding agencies should strategically increase support for research scientists, research hardware and software engineers, technicians, and other professionals at universities.
- A plan for dissemination of scientific results to the public should be included in the proposed operations and research budgets of experiments. The funding agencies should include funding for the dissemination of results to the public in operation and research budgets.

P5 recommendations

6) Convene a panel across particle physics that makes decisions on the US accelerator-based program at the time when major decisions concerning an off-shore Higgs factory are expected, and/or significant adjustments within the accelerator-based R&D portfolio are likely to be needed. A plan for the Fermilab accelerator complex consistent with the long-term vision in this report should also be reviewed. The panel would consider:

- The level and nature of US contribution in a specific Higgs factory including an evaluation of the associated schedule, budget, and risks once crucial information becomes available.
- Mid- and large-scale test and demonstrator facilities in the accelerator and collider R&D portfolios.
- A plan for the evolution of the Fermilab accelerator complex, which may commence construction in the event of a more favorable budget situation.