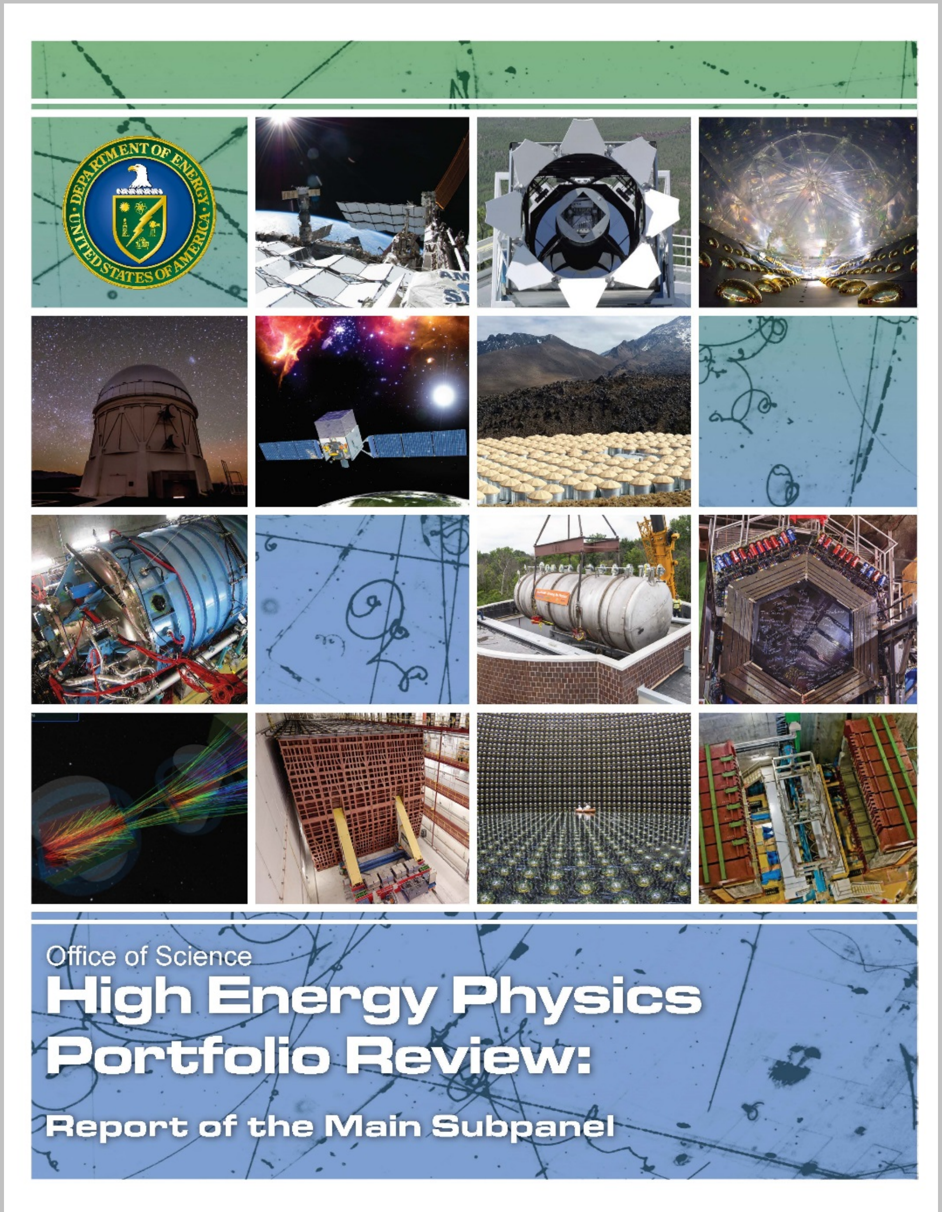

Portfolio Review
Main Subpanel Report

HEPAP May 14, 2018
P. Grannis

Charge†

Review and evaluate experiments that have been operating for at least 2 years and are expected to receive DOE support during FY2019–2022.

LHC experiments were the highest priority in P5 plan, so were considered separately. The 'Main subpanel' examined the rest (all in Intensity or Cosmic Frontier).

Evaluations to be based on

- Science merit and productivity (including training and mentoring)
- Present and future impact on P5 Science Drivers
- Efficiency and impact of DOE-supported contributions

P5 Science Drivers

- Use the Higgs as discovery tool
- Pursue physics associated with neutrino mass
- Explain dark matter
- Understand dark energy and inflation
- Explore new particles, interactions, principles

† From Stephen Binkley, acting Director, DOE Office of Science and James Ulvestad, acting Assistant Director, NSF Mathematical and Physical Sciences

Panel Membership

Robert Cahn	Lawrence Berkeley National Laboratory
Robert Cousins	University of California, Los Angeles
Paul Grannis	Stony Brook University (chair)
Francis Halzen	University of Wisconsin
Daniel Marlow	Princeton University
James Matthews	Louisiana State University
Irina Mocioiu	Pennsylvania State University
Ritchie Patterson	Cornell University
Jack Ritchie	University of Texas, Austin
Abraham Seiden	University of California, Santa Cruz
David Sinclair	Carleton University
Christopher Stubbs	Harvard University
Karl van Bibber	University of California, Berkeley
James Wells	University of Michigan
Andrew Lankford	University of California, Irvine (ex officio)

13 Experiments in review

Intensity Frontier

- **Daya Bay** (reactor neutrinos, Guangdong Province, China)
- **KOTO** ($K_L \to \pi^0 \nu\nu$ at J-PARC, Japan)
- **MicroBooNE** (Booster beam, Fermilab)
- **MINERvA** (NUMI beam, Fermilab)
- **NA61/SHINE** (North area, CERN)
- **NOvA** (on Fermilab site and at Ash River, MN)
- **SuperK** (Kamioka mine, Japan)
- **T2K** (on J-PARC site and at SuperK)

Cosmic Frontier

- **AMS** (Alpha Magnetic Spectrometer, on International Space Station)
- **DES** (Dark Energy Survey, Cerro Tololo Observatory, Chile
- **eBOSS** (extended BAO Spectrographic Survey, Apache Point, NM)
- **Fermi/LAT** (Large Area Telescope, low earth orbit)
- **HAWC** (High Altitude Water Cherenkov observatory, Sierra Negra, Mexico

The 13 experiments varied widely:

- Scientific goals and scope
- Location
- Size of collaboration
- Leadership roles of DOE grantees
- DOE fraction of collaboration
- DOE/HEP funding
- Goals other than P5 Drivers
- Impact on future experiment technologies/methods
- Prospect for future experiments to improve on results

➡ Difficult to compare

The subpanel considered these in making evaluations as well.

<u>2017 funding levels (sum of Research and Operations)</u>

> $4M	AMS, DES, NOνA
$2M – $4M	Fermi/LAT, MicroBooNE
$1M – $2M	Daya Bay, eBOSS, HAWC, MINERνA, T2K
< $1M	KOTO, NA61/SHINE, SuperK

Max: $7M
Min: $0.3M
Avg: $2.5M

The Process

- Each experiment submitted a 30 page document outlining science goals, future plans and technical information, plus appendices on data management, demographics, and manpower associated with science goals.
- Each panelist was assigned primary responsibility for one experiment.

- In Meeting 1, each experiment presented a summary of their goals and plans, and answered questions from the subpanel.
- Formed 3 subcommittees to make initial evaluations, comparisons and numerical rankings of 4 – 5 experiments

  (subgroups: accelerator based, ν oscillations, cosmic frontier)
- Full subpanel then recommended an assignment of each experiment into one of 4 Groupings.

- Between Meetings 1 and 2, panelists drafted Findings and Comments; these were edited for consideration in Meeting 2 by the full subpanel.

- Meeting 2 was devoted to re-examination of the Grouping assignments, and refining Findings, Comments and general portions of the report.

The Groupings

- Group I: Experiments that should proceed with the highest priority.

- Group II: Experiments with outstanding promise and relevance to the P5 Science Drivers, but whose funding could be reduced somewhat in the event of severe budget shortfalls.

- Group III: Experiments that address the P5 Drivers in important ways but for which a reduction in funding would cause less harm to the DOE/HEP program than in the case of Groups I or II.

- Group IV: Experiments that require further demonstration of likely success, or whose future program is less effective in advancing the P5 Science Drivers.

The Process (caveats)

The subpanel had neither the time nor detailed documentation with which to undertake an in-depth evaluation of the prospect for achieving the goals, or to perform a full technical assessment of the experiments.

During Meeting 1, we came to an understanding that a fully numerical ranking of priority from 1 to 13 would be neither feasible nor desirable, owing to the diverse character of the experiments. There is necessarily a qualitative element in our Grouping assignments.

We looked only at experiments with DOE funding expected in FY19-22 and in operation for at least 2 years. Thus we have not considered the broader range of experiments just starting, those funded by other agencies, or those not requesting funding during FY19-20.

The focus was on the importance of support for FY19-20, not on past accomplishments. So an outstanding experiment nearing completion may not be ranked as high as one that has major data-taking still to come.

The subpanel was not asked to consider whether the supported experiments gave optimum coverage of the P5 Drivers.

General comments

The 13 experiments under review have all been subjected to extensive reviews by funding agencies and Laboratories. All address high priority physics goals and have shown a high degree of technical competence. The portfolio review had the more limited scope of offering a basis for triage in the case of funding shortfalls. The primary focus was on future operations, not past achievements.

The subpanel was asked to distribute the Groupings uniformly, even if a detailed numerical ranking was not feasible.

The subpanel believes that a first priority for all experiments is the analysis and dissemination of the data already collected.

These were the first portfolio reviews of DOE/HEP experiments, so HEPAP evaluation of the process gives useful guidance for future panels,

Acknowledgements

The subpanel thanks the members of the 13 experiments for their clear and useful documents and presentations. We understand that this new review added to their workload and to their anxiety level.

We thank the staff of the Research and Technology Division of the Office of High Energy Physics for their advice and help in guiding the review.

Although the review centered on DOE/HEP's portfolio of ongoing experiments, we benefited from the participation of NSF/AST during the review.

Subpanel evaluations of the 13 experiments follow with the format:

Experiment

- ❖ Findings (taken from the materials supplied to the subpanel by the collaboration)

- ➢ Comments (Summary of the subpanel's discussions that give the reasoning for the recommendation.)

Recommendation: (assignment of experiment to one of the four Groups)

Arrange reports alphabetically for Intensity and Cosmic Frontiers respectively

Daya Bay (at Daya Bay reactor site in China)

- Liquid scintillator tanks at three locations near six reactors.
- Most precise $\sin^2(2\theta_{13})$ (Now 4%, expect 3% uncertainty by end 2020).
- Important data for resolving anomaly in reactor flux and spectrum; remaining running will halve uncertainty.
- Combined with other experiments, can probe sterile ν explanation of LSND/MiniBooNE anomalies.

- Has made a dramatic impact on ν physics & prospects for future experiments.
- ν_1-ν_3 mixing measurement is well aligned with P5 Science Drivers.
- Understanding reactor flux anomaly is useful, but not a P5 Driver.
- Will finish run in 2020, so mostly data analysis effort is requested.
- U.S. has had critical roles in experiment and analyses.
- Precision on $\sin^2(2\theta_{13})$ will not improve greatly with remaining data and further impact on neutrino properties (e.g. δ_{CP}) is small.

Recommendation: Group III

KOTO (at J-PARC in Japan)

- Ultimate aim is 100 $K_L \to \pi^0 \nu\nu$ events at SM rate. Step 1 seeks a few events at SM level (3 orders of magnitude improvement over best previous limit).
- 2013 runs had large neutron halo background.
- 2015 run had 10x larger background than that expected from $K_L \to \pi^0\pi^0$, due to $K_L \to \pi^0\pi^+\pi^-$ and sequential neutron scatters.
- Did upgrades in 2016, 2017. Expect to have results in 2018.
- Will only reach Step 1 goal after 2022; Step 2 design is at preliminary conceptual level.

- An exceptionally challenging experiment. KOTO encountered unforeseen backgrounds requiring upgrades rather early in the program.
- Getting to Step 1 is not yet demonstrated. Wait for analysis of 2016-2017 data before a technical review to judge future plan. DOE decisions should be based on this review, done in concert with J-PARC PAC.
- U.S. groups are critical to KOTO success (both hardware and analysis).
- Put Step 2 planning on hold until progress made on Step 1.

Recommendation: Group IV

MicroBooNE (in Booster Neutrino and NUMI Beams at Fermilab)

- MicroBooNE is a 85 ton LAr detector that seeks to understand the MiniBooNE low energy e/γ excess seen in ν interactions.
- Will measure ν cross sections on Ar
- Also a major prototype of the LAr technology and algorithms for DUNE.
- MicroBoone has had several technical problems – HV breakdown at 60% of design, cross connection of ~10% of wires. But LAr purity is excellent.
- A cosmic ray tagger was installed to control large cosmic ray backgrounds after 45% of expected protons on target.

- 7 publications, 19 public notes, all on technical issues/methods so far.
- Four algorithms being developed for event reconstruction.
- Given reduced sensitivity before the CR veto, need the full 1.32×10^{21} POT data sample to check the MiniBooNE anomaly. Results expected in 2020.
- If anomaly is not verified, change focus to understanding technical issues.
- If anomaly is seen, will need re-examination of priority for more running.
- Excellent mentoring of students and postdocs.
- Technical problems contribute to subpanel’s recommendation.

Recommendation: Group III

MINERνA (in NuMI beam at Fermilab)

- MINERνA measures ν and $\bar{\nu}$ cross sections on He, C, Fe, Pb, CH, H_2O (but not Ar) targets simultaneously in beams centered on 3 and 6 GeV.
- NOνA and T2K have already benefited from MINERνA constraints.
- 21 publications so far, mostly at 3 GeV, with another similar set at 6 GeV to come.
- Data taking to be complete in FY2019 with analyses done by FY2022.

- MINERνA results are important for DUNE.
- MINERνA data will be of great importance for refining ν cross section models; the MINERνA collaboration should be a key part of model building.
- Dedicated effort is needed to preserve data of this important resource.
- Training and mentoring efforts are excellent.
- While results do not directly address Science Drivers, they strongly support them.

Recommendation: Group II

NA61/SHINE (in SPS North Area beamline at CERN)

- NA61 has a broad program for hadron, heavy ion and ν physics experiments. In ν program it makes differential XS measurements for beams of π, K, p from 30 – 350 GeV on targets relevant for ν production.
- DOE supported groups focus on ν program and provided small angle TPCs, TOF upgrades, code modernization and GEANT4 implementation.
- One non-DOE U.S. group works on measurements for cosmic ray physics.

- NA61/SHINE results improve knowledge of hadron production for ν beams; such constraints have helped reduce uncertainties for T2K.
- To retain utility for DUNE, correlations and systematics in hadron production need be measured and archived.
- Some past analyses have been slow in being completed.
- DOE groups are leading the ν related studies. The studies related to cosmic ray physics are less essential.
- While results do not directly address Science Drivers, they strongly support them.

Recommendation: Group II

NOvA (in the NuMI beam at Fermilab and northern Minnesota)

- NOvA studies ν oscillation parameters in the ~2 GeV ν_μ, $\bar{\nu}_\mu$ beam.
- Measurements of $\sin^2\theta_{23}$, $(\Delta m_{23})^2$, and 2σ indication of normal hierarchy are among world's best.
- Expect 2.5x (6x) current samples of ν ($\bar{\nu}$) by end 2022.

- Combination of NOvA and T2K results will give important improvements on neutrino parameters. NOvA is better for mass hierarchy.
- NOvA is only U.S. long baseline ν experiment; it can be expected to have a major scientific impact.
- NOvA plays an important role in training young physicists for DUNE.
- DOE supported scientists play central roles in NOvA.
- Good alignment with P5 Science Drivers.

Recommendation: Group I

SuperK (in Kamioka mine in western Japan)

- 50T H_2O Cherenkov detector for studies of atmospheric & solar ν's, nucleon decay, supernova ν's.
- SuperK plans to add Gd salts in 2018 to allow n detection (e.g. $\bar{\nu}_e p \rightarrow n e^+$).
- SuperK goals also include supernova ν detection to study SN core collapse, improvement of ν oscillation parameters and nucleon decay limits.

- Do not consider SuperK's use as T2K far detector here.
- Largest supernova ν detector operating now; Gd neutron tagging will improve sensitivity.
- If a nearby supernova goes off, SuperK would provide important new knowledge on core collapse SNe and νν interactions in dense matter, but new information on neutrino properties would be limited.
- SuperK has operated since 1996; most studies of neutrino properties are now systematics dominated, so only moderate gain from additional running.

Recommendation: Group III

(T2K, with SuperK as far detector, is in Group I)

T2K (at J-PARC in eastern Japan and in Kamioka mine)

- Long baseline ν oscillation experiment in off-axis beam ~0.6 GeV.
- Current accumulations: 1.5 (0.8)x10^{21} POT for $\nu(\bar{\nu})$; aim for 5.3x10^{21} each.
- Measurements of $\sin^2\theta_{23}$, $(\Delta m_{23})^2$ are among world's best.
- T2K has sensitivity to CP violation, now favors $\delta_{CP}\sim 3\pi/2$; aim for 3σ exclusion for 50% of δ range.

- Combination of T2K and NOνA results will give important improvements on neutrino parameters. T2K better for CP-violation.
- Excellent mentoring of young physicists.
- Current T2K results are statistically limited; will improve with more POT.
- Will provide useful cross sections at low E_ν for DUNE.
- T2K should be watchful that Gd does not harm far detector performance.
- Good alignment with P5 Science Drivers.

Recommendation: Group I

AMS (on International Space Shuttle)

- High precision mass spectrometer since 2011; good particle ID $e^{\pm}$, $(Z,A)^{\pm}$
- NASA is lead for ISS ops; DOE supports only MIT research + AMS ops.
- High statistics observation of anomalous e^{+} excess out to 1 TeV, compatible in shape with 1.2 TeV DM particle annihilation.
- See 6 $\overline{He}^3$, 2 $\overline{He}^4$ candidates. $\overline{He}$ absent in cosmological models; estimates of production via cosmic ray interactions much smaller than seen.
- Antiproton fluxes are above existing astrophysical models.
- High statistics samples of p, d, He, C, O, etc. with excesses at high E seen.

- If e^{+} excess is DM, its size is hard to reconcile with other observations.
- Confirmation of cosmic $\overline{He}$ would be a transformative discovery; so need detailed studies of instrumental backgrounds.
- Data management plan did not describe means to provide broad access for independent analyzers; encourage agencies to help facilitate this.
- Data sample precision (e^{+}, $\bar{p}$, He, etc.) far exceeds the precision of models.
- Continued analysis of existing data is high priority but acquiring new data is less important.

Recommendation: Group IV

DES (at Blanco 4m telescope, Cerro Tololo in Chile)

- 6 year imaging survey (photometric red shifts) of 5000 deg^2 of Southern sky, ending in 2018.
- Weak lensing & cluster counting to map large scale structure. Type 1a SNe & BAO for history of cosmic expansion.
- Anticipate measurement of equation of state parameter ($w=p/\rho$) to 3%, in combination with Planck CMB.

- Only first year results are now published, with 35% of final coverage.
- Besides $\sqrt{(time)}$ gain, improved contiguity of coverage and refined analyses will add sensitivity.
- Will be the leading DE imaging survey until LSST.
- Developing analysis tools & young scientists that are essential for LSST.
- Strong DOE-supported science leadership.
- Excellent mentorship of young scientists.
- Good alignment with P5 Science Drivers.

Recommendation: Group I

eBOSS (at Sloan Telescope in New Mexico)

- Spectroscopic survey of BAO characteristic length for luminous red galaxies, emission line galaxies, tracer quasars and Lyα forest.
- Map cosmic expansion history and rate of structure growth in region $1<z<2$ where cosmic expansion begins.
- Redshift distortions (RSD) allow tests of general relativity.
- Short distance RSD power spectrum measurement could limit ΣM_ν to 70 meV, thus helping fix ν hierarchy.

- eBoss is making substantial improvement of cosmological parameters.
- Will end observations by end 2019, earlier than expected.
- Fill in gap in z left by BOSS; aim on x2.5 improvement on $w=p/\rho$ over BOSS.
- Developing needed tools and scientists for DESI.
- Excellent mentorship of young scientists.
- Good alignment with P5 Science Drivers.

Recommendation: Group I

Fermi/LAT (in orbit on Fermi Gamma-ray Space Telescope)

- 20 MeV-300 GeV γ pair spectrometer on Fermi satellite; seek DM annihilation signals from galactic center, satellite galaxies, dwarf spheroidal galaxies (DSGs). DSGs believed to be rich in DM.
- Have set exclusions for WIMPs in 10-1000 GeV range.
- Exclusions on axion-like particles in 0.5-20 neV range.
- Many important astrophysical results (not P5 drivers).
- Most results from 1st 6 years; 10 years data in can; asking another 5 years.
- Most ops support now moved to NASA, but LAT ops is still at SLAC.
- Complementary to Fermi/GBM for compact binary merger sighting – better angular resolution, smaller field of view, higher energy threshold.

- γ energy range well matched to common WIMP models.
- Can substantially improve DM sensitivity by re-analyzing existing data as surveys identify new DSGs.
- Analyzing data from years 7-10 is high priority.
- Limited increase in sensitivity from acquiring another 5 years of data.

Recommendation: Group III

HAWC (on Sierra Negra plateau in Mexico)

- 300 H_2O Cherenkov tanks on Mexican mountain; detect air showers from 1-200 TeV γ's; recently installed outrigger tank array improves energy & angle resolution.
- See large swath of northern sky, operates 24 hrs/day.
- Ruled out γ's from 2 nearby pulsars as source of AMS e^+ anomaly.
- Seeks to extend operation by 1 year to end of 2019 to capitalize on outriggers.

- Poorly understood astrophysical backgrounds limit DM sensitivity.
- Sensitive to higher mass DM than popular models, but there are some candidate models in HAWC range.
- Large acceptance, continuous operation, good angular resolution aid multi-messenger studies with LIGO, IceCube etc.
- Good ability to find new dwarf spheroidal galaxies.
- HAWC operations are led by DOE scientists.
- Much of program is astrophysical studies; DM is mainly done by DOE groups.

Recommendation: Group II

Summary

Group assignment and FY17 funding for 13 reviewed experiments

	Funding I >$4M	Funding II $2-4M	Funding III $1-2M	Funding IV <$1M
Group I	DES NOvA		eBOSS T2K	
Group II			HAWC MINERvA	NA61/SHINE
Group III		Fermi/LAT MicroBooNE	Daya Bay	SuperK
Group IV	AMS			KOTO