Fermilab

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Cosmic Science at Fermilab: looking ahead

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Fermilab PAC I June, 2015

Cosmic Science at Fermilab

Fermilab vision addresses the fundamental nature of matter, energy, space and time

- Cosmic studies probe physics beyond the Standard Model: dark matter, cosmic acceleration, neutrino sector, gravity

Challenging experiments benefit greatly from unique capabilities of national laboratories

- Technology, development, engineering, scale, management
- Lab contributions should be unique and critical

Fermilab's future program plan aims to maximize our contributions to the science goals in the HEPAP/P5 report

PAC request: a more detailed plan

In summary, the PAC is pleased to see the evolution of elements of an exciting strategic plan that has the flexibility to adapt to future scientific discoveries and expanded funding opportunities. It also notes, however, that a successful program at a National Laboratory must be based upon experimental leadership in major projects and this will likely require that hard choices will have to be made to strengthen fewer efforts at the expense of broad support of many programs. The PAC looks forward to a more detailed activity plan for particle astrophysics at Fermilab that addresses the points made here. This more detailed plan should address the need for a Fermilab flagship project once DES is successfully completed. It should also provide more detailed information on the technical and human resources to be brought to bear, and include information on planned postdoc and possible student deployment across the planned activities, especially for new initiatives.

From Institutional Review outbrief slides (Feb 13 2015): Our community colleagues (Nygren, Stubbs, et al.) agree that we are doing well

Findings:

- The Cosmic Frontier team at FNAL is world-class, and continues to make major technical and scientific contributions in the dark sector, where we have clear signatures for new fundamental physics.

- The cosmic frontier work at FNAL is very well-aligned with P5 priorities.

- We note in particular the tight coupling between the theoretical, experimental/technical, scientific, computational, and the operations and management elements of the Cosmic Frontier program.

- The merit, feasibility and impact of the planned evolution of the effort are all high. The group has a sound long term plan, including engagement in DESI, LSST, SuperCDMS, LZ and ADMX, and Stage 4 polarization maps of the CMB. This plan is well-aligned with DOE's program for dark sector physics.

Strategic Elements

Two science directions: Dark Matter and Cosmic Surveys

- Mobility and synergy among experiments within each group
- Scientists coordinate effort according to needs of experiments at different stages
  - Builders build, etc.
- Unified by technical capabilities, scientific programs
- Combined use of data: organized by science, not by experiment
- Groups set strategic directions for R&D program and future experiments

Critical mass at Fermilab for each experiment

- A prominent team of scientists, postdocs and technical staff will make a substantial Fermilab imprint on each experiment

Unique Fermilab contributions for every experiment

- Fermilab is the best place to achieve some critical visible elements for success

Cosmic Program

P5 Driver	Experiments
Dark Matter	G1: PICO, Darkside, DAMIC, SuperCDMS Soudan G2: SuperCDMS SNOLAB, LZ, ADMX
Cosmic acceleration and neutrinos	Optical Surveys: DES, DESI, LSST Microwave Background Surveys: SPT-3G, CMB-S4
Explore the unknown	Holometer
Detector R&D	New techniques for future experiments
Astrophysics Theory	Strong coupling with particle astrophysics experiments

Fermilab's effort will consolidate into a smaller number of experiments with closer connections

Dark Matter

Astrophysical evidence suggests that most of our Galaxy is made of a new form of matter

- We only know about these particles from their gravity
- Experiments will constrain or measure their masses and interactions
- Theory suggests two detectable kinds of particles
  - Weakly Interacting Massive Particles (WIMPs)
  - Axions (solution to CP problem of strong interactions)

P5 recommends a diverse program for direct detection of WIMPs and axions

- Generation 1: Currently operating experiments
- Generation 2: Competitively selected projects, currently under design
  - SuperCDMS SNOLAB and LZ for WIMPs, ADMX for axions
- Generation 3: Currently in R&D
  - Will extend range of exploration in masses and interactions

Evolution of the Fermilab Dark Matter program

We are in a period of transition from G1 to G2

- Transition period leverages DOE support as others assume more responsibility for G1 experiments

The bulk of our effort in the next ten years will be on the G2 dark matter program

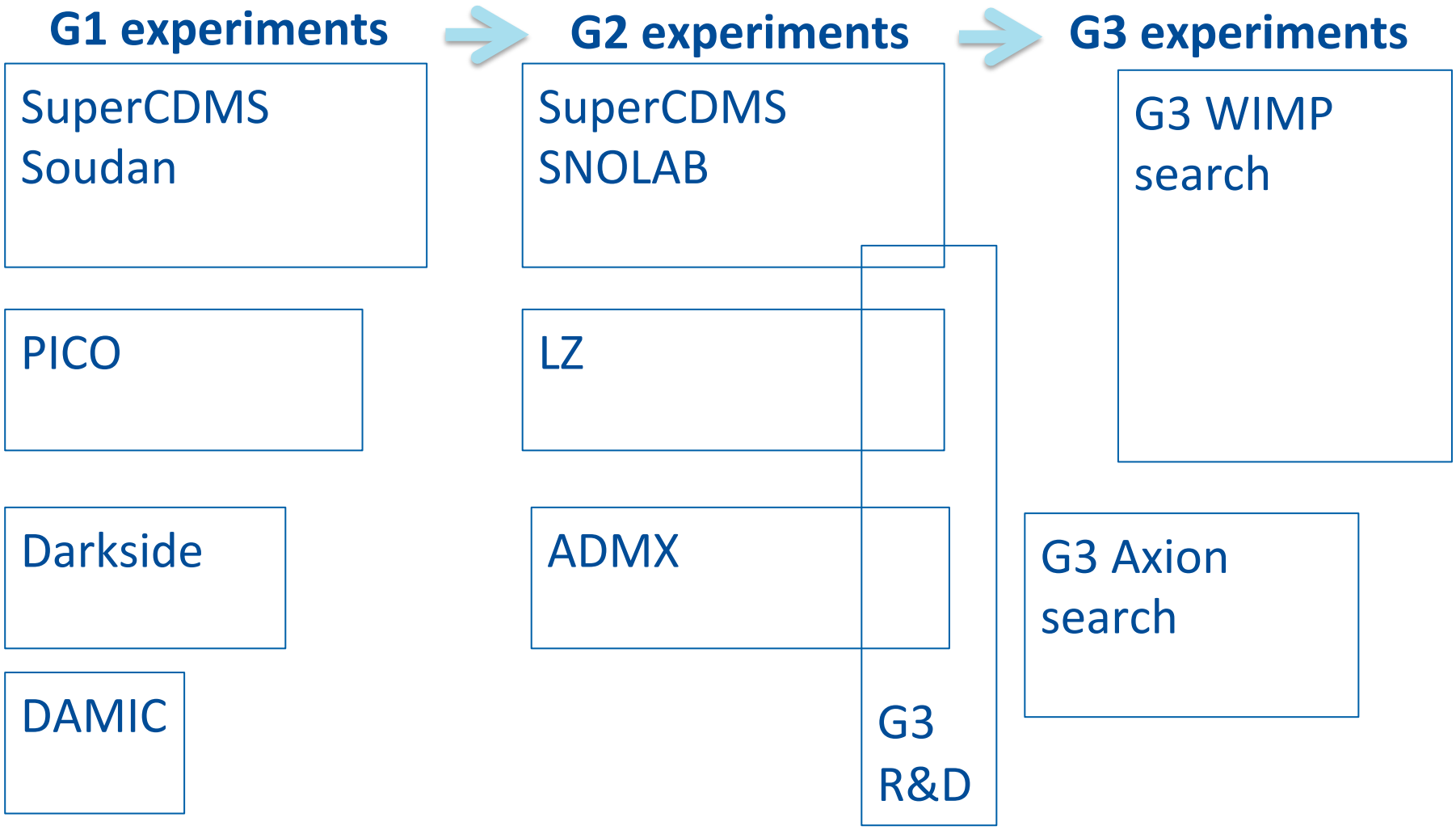
- SuperCDMS SNOLAB for low-mass WIMPS
- LZ for high-mass WIMPS
- ADMX and successors for axions

Effort will continue on R&D for future technologies

- We have convened a study group for G3 ideas
- e.g., R&D for higher axion mass search
- New techniques to extend WIMP searches to lower masses and cross sections

A broad and coherent program of dark matter experiment and theory combine to make Fermilab a world center

Evolution of Fermilab Dark Matter program



Fermilab Roles in G2 Dark Matter Experiments

Fermilab has been a lead lab in CDMS since 1997, will develop most of the SuperCDMS SNOLAB facility outside of the detectors

Fermilab participation in LZ and ADMX was invited by collaboration leaders, motivated by unique Fermilab scientific and technical experience and capabilities

- We are now collaborators on both, plan to do project work
- Our detailed roles are still taking shape

Experiment	Fermilab roles
SuperCDMS	Management, infrastructure, cryogenics/shielding/ electronics, operations, data analysis, science
LZ	Cryogenic and Xe veto design, process control, science
ADMX	High axion mass cavity development, axion science, analysis

Cosmic Surveys

Precision measurements of cosmic structure and evolution probe new physics

- Order of magnitude improvement is possible with new experiments
- Will probe acceleration, neutrino masses and new dark sector physics

Three kinds of survey

- Wide, deep optical imaging (DES, LSST)
  - Probes evolution and structure via supernovae, galaxy distribution and photometry
- Wide, deep spectroscopic surveys of galaxies and quasars (DESI)
  - Increase precision of redshift measurements and enable additional probes
- Maps of cosmic microwave background polarization (SPT 3G, CMB S4)
  - Adds high precision at earliest times, largest distances, largest scales, information on lensing, tensor modes,…

The three kinds of survey are most powerful when combined

Fermilab can be a world center for this synergy

Future of Fermilab's Cosmic Survey Group

Fermilab effort will broaden from mostly DES today

- Effort moving to DESI, LSST, and CMB
- Mix of effort will change over time (design, construction, operations,…)
- Depends on contributions, experiment needs and schedules
- Many capabilities naturally transplant from optical to CMB surveys
  - e.g., electronics, DAQ, data management, detector assembly and testing, cryostat engineering and integration

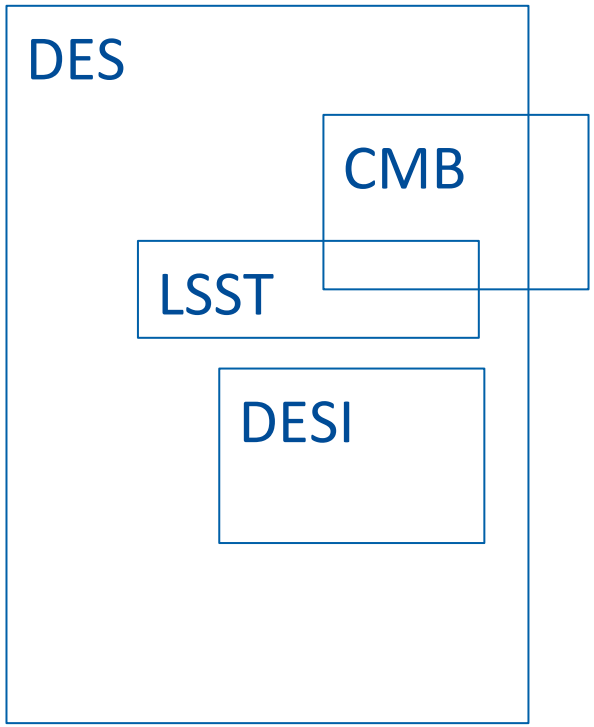
Cosmic Survey Group will develop strong, overlapping teams

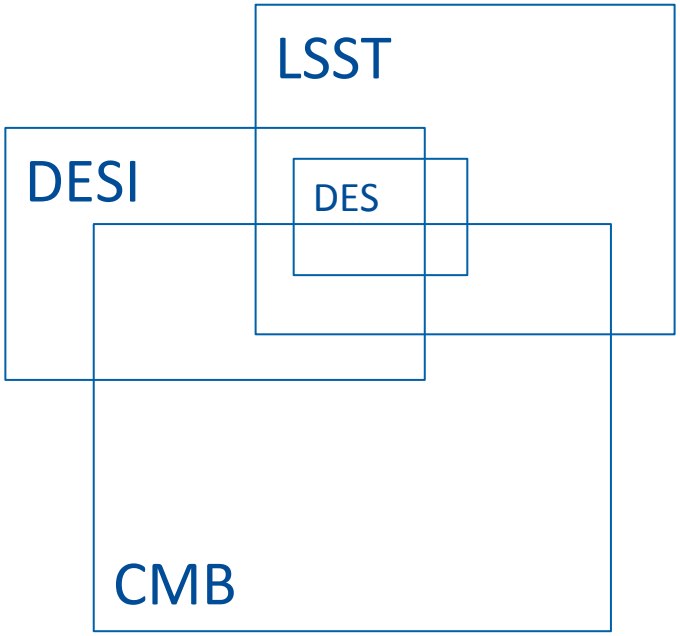
- There will be a critical mass, and clearly identified unique Fermilab contributions, to DESI, LSST, and CMB
- CMB S4 likely to be the largest building effort

Their scientific efforts will be coordinated and reinforce each other

Evolution of the Fermilab Cosmic Survey Group

Today → **~ 6 years from now**





Fermilab roles in survey experiments

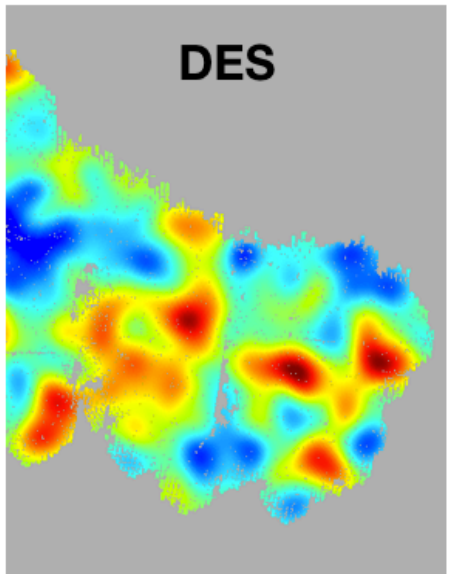
Experiment	Fermilab technical roles
DES	Project (DECAM), operations, management, calibration, science, collaboration leadership (incl. Director), computing, data management
DESI	Detector packaging and testing, corrector system, telemetry database, Platemaker software, co-Project Scientist
LSST	Dark Energy Science framework, survey operations (end to end quality, calibrations, survey strategy), level 3 software
CMB	Detector packaging and testing, cryostat design and assembly, integration

Fermilab leadership in cosmic surveys started with SDSS in 1990

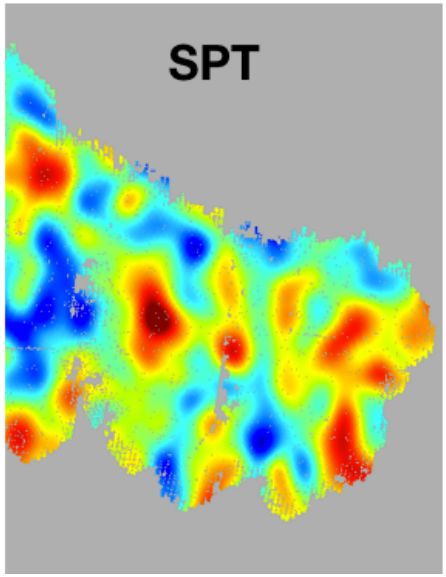
Continues now with leadership of DES

Leads to coordinated science efforts on DESI, LSST, and CMB

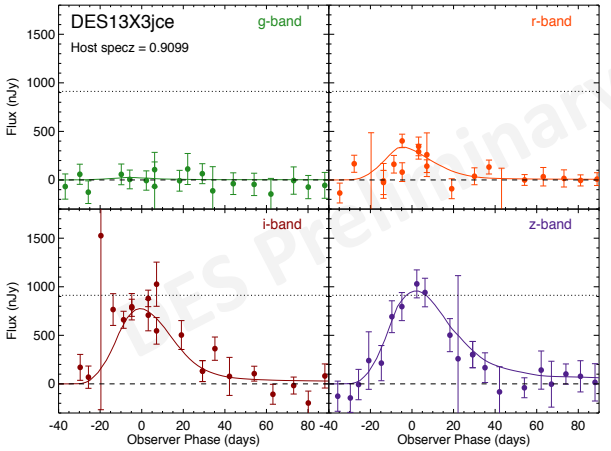
Top priority in next 5 years: DES science results



DES SV galaxies, 0.2<z<1.2



SPT gravitational lensing



>1000 SNe Ia light curves so far

Fermilab is responsible for delivering success

- Includes all aspects of operations and collaboration-wide science
- Already demonstrates synergy with CMB
- Has now become the world's leading deep imaging survey

If LSST stays on schedule, it will supplant the DES dataset in ~2022

Fermilab scientists will bring many lessons learned from DES to LSST

Fermilab Roles in CMB experiments

- SPT-3G camera is now being built and tested at Fermilab
  - Builds on Fermilab experience with CMS, QUIET, DECam
  - Deploys at South Pole in 2016
  - Close collaboration with U Chicago and ANL
  - Group is growing
- Fermilab is helping to shape CMB-S4
  - Design, collaboration and consortium building now underway
  - Joint effort of all HEP labs and broad university community
- Fermilab technical roles in both
  - Camera design, fabrication, integration
  - Detector testing, packaging

Cosmic R&D for Future Experiments

Fermilab helps shape the far future program by developing enabling technologies

- Generic Detector R&D has led to new technologies and experiments
- LDRD is a new opportunity for development

New synergies and capabilities at Fermilab

- New sub-Kelvin cryogenics facilities: CDMS, CMB, MKIDs, ADMX
- Initiatives and collaborations with U Chicago, ANL, NU
- Unique MKIDs optical arrays (w/UCSB et al.)
- RF cavities: axion detectors and accelerator program

P5 recommends sustained commitment to technical innovation

- That effort should be aligned with future cosmic experiments
  - Study groups: What are the future experiments beyond P5?

Cosmic Theory

Fermilab's Theoretical Astrophysics Group

- Works to extract fundamental physics from cosmic data
- Brings versatility in modeling, phenomenology, statistics
- Simulation, model building, projection, analysis, tool development
- Gravity, particle phenomenology, complex astrophysical systems

Shapes and leads the experimental program

- Leadership in Fermilab and national program for >30 years
- Many experimental programs conceived in the theory group
- Close involvement includes important leadership positions in experimental collaborations (Frieman in DES, Dodelson in LSST)
- Creates scientific connections among experiments

Broad outline of a long term plan

World leading group in dark matter direct detection
- Search for WIMPs and axions with three G2 experiments
- Connected by science and by technical base
- R&D towards generation 3

World leading group in cosmic surveys
- Dominant effort on DES will migrate to DESI, LSST and CMB
- Commitment to launch CMB S4 with broad partnership
- Connected by science and by technical base
- Maximize technical and scientific synergy between techniques
- R&D aligned with future experimental opportunities

World leading particle astro theory
- Leads program to discoveries and opportunities

What is the process to get there?

Migration of scientist effort over the next five to ten years

Dark matter: G1 effort mostly migrates to 3 prominent G2 teams

- Three Fermilab G2 experimental groups will amplify each other
- They will also work together towards developing G3

Cosmic Surveys: from (mostly) DES now to a unified Fermilab survey group that supports prominent contributions to DESI, LSST, and CMB S4

- Top priority in the next five years: scientific success of DES
- Hardware and development effort now focused on DESI, CMB
- New survey group will combine experiments for maximum science impact and overall benefit to HEP program

R&D: build towards farther future surveys and G3 dark matter

- Small total FTE, aligned with specific future experimental directions in the two main thrusts

Theory: maintain a strong group engaged with current and future experiments

FCPA Scientist Retreat and Survey

We held a retreat and surveyed our scientists

- Data is informal and incomplete, but we were able to map out substantially where the current group is headed
- Includes personal plans of key individuals
- Migration is close to plan
- There is a plausible way to staff the bulk of the program from existing personnel
- Details will depend on retirements and experimental roles

Survey data in FTEs (informal, incomplete, ….)

Thrust	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Dark Matter	**10.1**	**12.1**	**11.4**	**11.7**	**11.8**	**13.3**	**13.2**	**12.9**	**12.9**	**12.9**	**12.9**
G1	5.4	4.1	1.1	0.9	0.4	0.0	0.0	0.0	0.0	0.0	0.0
G2	4.7	8.0	9.3	9.7	8.9	7.8	6.4	4.4	3.9	3.4	3.3
G3	0.0	0.0	1.1	1.1	2.5	5.6	6.9	8.6	9.0	9.6	9.7
Surveys	**15.1**	**16.5**	**16.9**	**16.8**	**16.8**	**17.0**	**17.3**	**17.0**	**16.8**	**16.8**	**16.7**
DES	10.6	10.2	9.3	8.6	7.5	4.7	2.8	1.7	0.7	0.2	0.1
DESI	2.1	2.3	3.1	3.3	4.0	4.4	4.4	3.8	3.3	3.0	2.9
LSST	0.3	0.7	1.0	1.3	1.8	3.0	4.4	5.3	5.6	5.9	6.0
CMB	2.1	3.2	3.4	3.4	3.4	4.2	4.3	4.3	4.3	4.3	4.3
R&D	1.6	2.0	3.8	3.7	3.6	2.6	2.7	2.9	2.7	2.7	2.7

Implementation

A modest growth in research effort will achieve a critical mass

- Main issue: ~3 more experimental postdoc positions (total 12)
- Allows 6 for each of 2 major experimental groups
- + 2 more theory postdocs (total 5)
- Fermilab offers a uniquely broad, hands-on training environment where experiment meets theory

Will need to add new scientists in the next few years

- To be shaped along with experiment plans
- ~ 3 new staff in the next few years
- New staff will be needed to match new Fermilab roles in CMB
- If necessary, funds captured from retirement replacements and departures to other frontiers

Current Activities to Advance the Strategy

Study Groups for future projects beyond P5
- Will invite visitors, shape R&D, broaden horizons
- Cosmic Surveys, led by J. Frieman
- Dark Matter, led by L. Hsu

Hiring postdocs on new experiments
- Successful recent recruitment on CMB, CDMS
- Need more cosmic survey postdocs (DES science!)

Ongoing recruitment onto new projects
- Migration as staff ramp down current activities
- Some new aspiring migrants from other frontiers

Planning with four labs on CMB roles
- Technical principals, lab administrators, DOE, consulting scientists

Planning with SLAC, other labs, and DESC on Fermilab LSST roles
- Preparation for operations proposal in about a year

January PAC concerns

- Evolve towards larger technical contributions to fewer experiments
  - We are moving this direction, but slowly, paced by science
  - A true flagship, if any, is another generation away
- Better connections of DES to DESI and LSST
  - This is a key component of our strategy
- Concerns about CMB (manpower, other labs, universities)
  - Our planning is closely coordinated with DOE, other labs, and university scientists
  - Our role is designed to fit well with existing FNAL capabilities and with our other survey efforts
- Neutrino astrophysics opportunity with LBNF
  - Should be within the scope of a Fermilab theory search

Cosmic Science – Lab Goals and Objectives

- Use the cosmos to understand cosmic acceleration and physics of neutrinos
  - Complete operations of first DES science run in 2018 and extract dark energy science
  - Complete the SPT-3G camera by 2017
  - Deliver barrel, plate maker, online database and CCD testing for DESI (2019)
  - Advance computing and software resources for LSST, enabling science at first light (2022)
  - Achieve CD status for CMB-S4
- Drive towards discovery and study of particle dark matter
  - Support G1 operations of through 2017, improving upon world-leading results
  - Develop tunable high-Q RF cavities for the ADMX G2 high frequency axion search
  - Build SuperCDMS-SNOLAB with commissioning by 2019
  - Provide time-critical expertise and scientific insight to enable LZ to take data in 2019
- Develop new ways to probe the cosmos
  - R&D of superconducting technologies for future large surveys and CMB experiments
  - Continue development of detector technologies for dark matter, with eye for G3
  - Design new RF structures and magnets to explore the full axion DM parameter space
- Serve as hub for cosmological data and data analyses
  - Establish infrastructure to capitalize on multi-wavelength observations of the universe
  - Host workshops, establish visitors program, enable cross-collaboration communication

Summary: where we are headed

Dark Matter Direct Detection
- G2 WIMP and axion searches
- Connected and enabled by lab scientific and technical capabilities
- Explore techniques for the ultimate search, G3

Cosmic Surveys
- Precision measurements of the universe for fundamental physics
- Dominant effort on DES migrates to DESI, LSST and CMB
- Connected and enabled by lab scientific and technical capabilities

Exploration of new directions
- Theory connects experiments and explores future options
- R&D aligned with future experimental opportunities