



# Particle Astrophysics Program

Scott Dodelson

PAC Meeting, June 20, 2016

## Charge

- Does the current astrophysics plan respond to previous advice from the PAC?
- Are we prepared for the upcoming DOE Comparative Review?

## Previous Concerns/Advice

- ***Plan to leverage DES to help DESI, LSST*** (“leadership in the construction of the Dark Energy Camera and the ongoing execution of the Dark Energy Survey ... surprise that the involvement in the next dark energy optical projects, DESI and LSST, should be so modest.”)
- ***Dark Matter spread too thin?*** (“Making larger technical contributions to fewer experiments”)

## To help you answer the charge ...

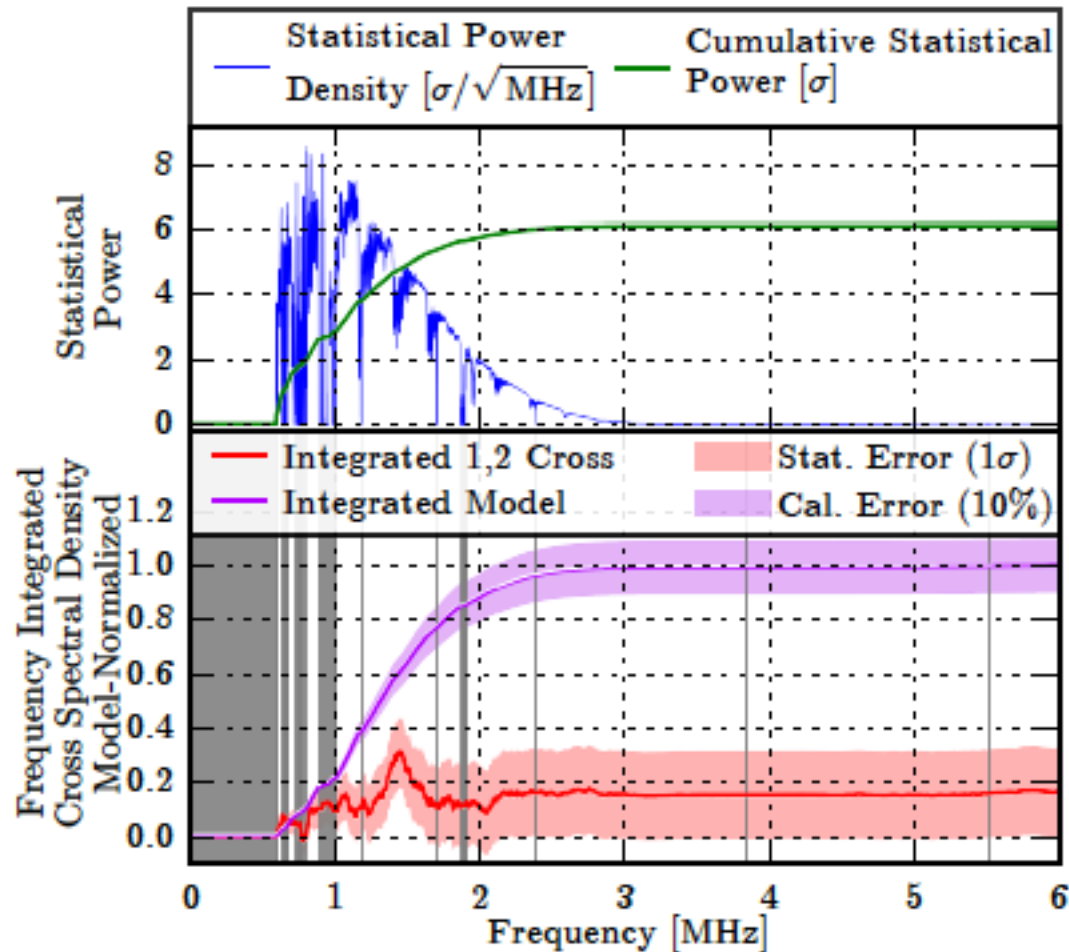
- ***Recent (since June 2015) Results***

These are fun/interesting, will be important for the Comparative Review, have helped shape the plan, and will give you a sense of how we have worked to address your concerns

- ***Plan***

Scientists leveraging Lab resources to make major technical and scientific contributions to a suite of experiments that are “intertwined”

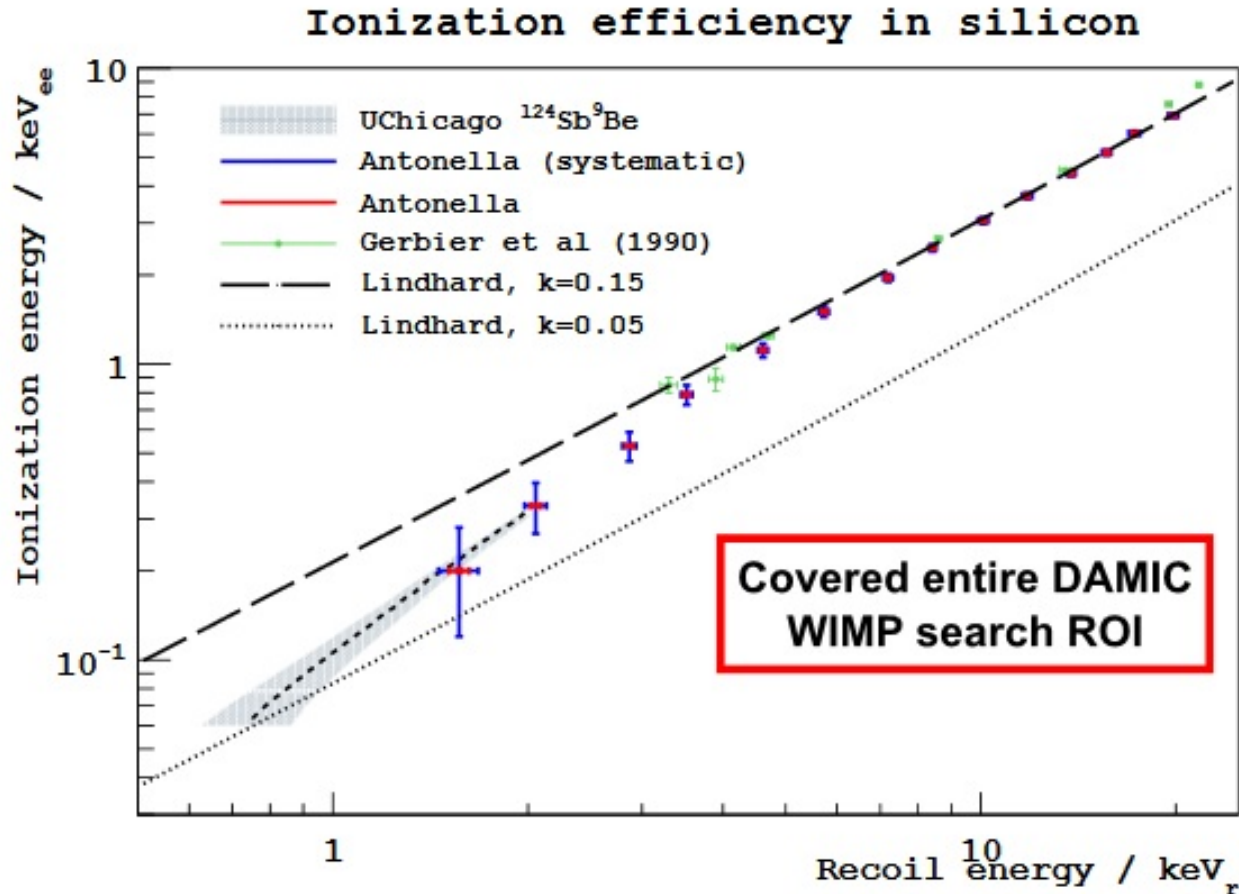
# Fermilab Holometer



Made possible by  
Early Career Award

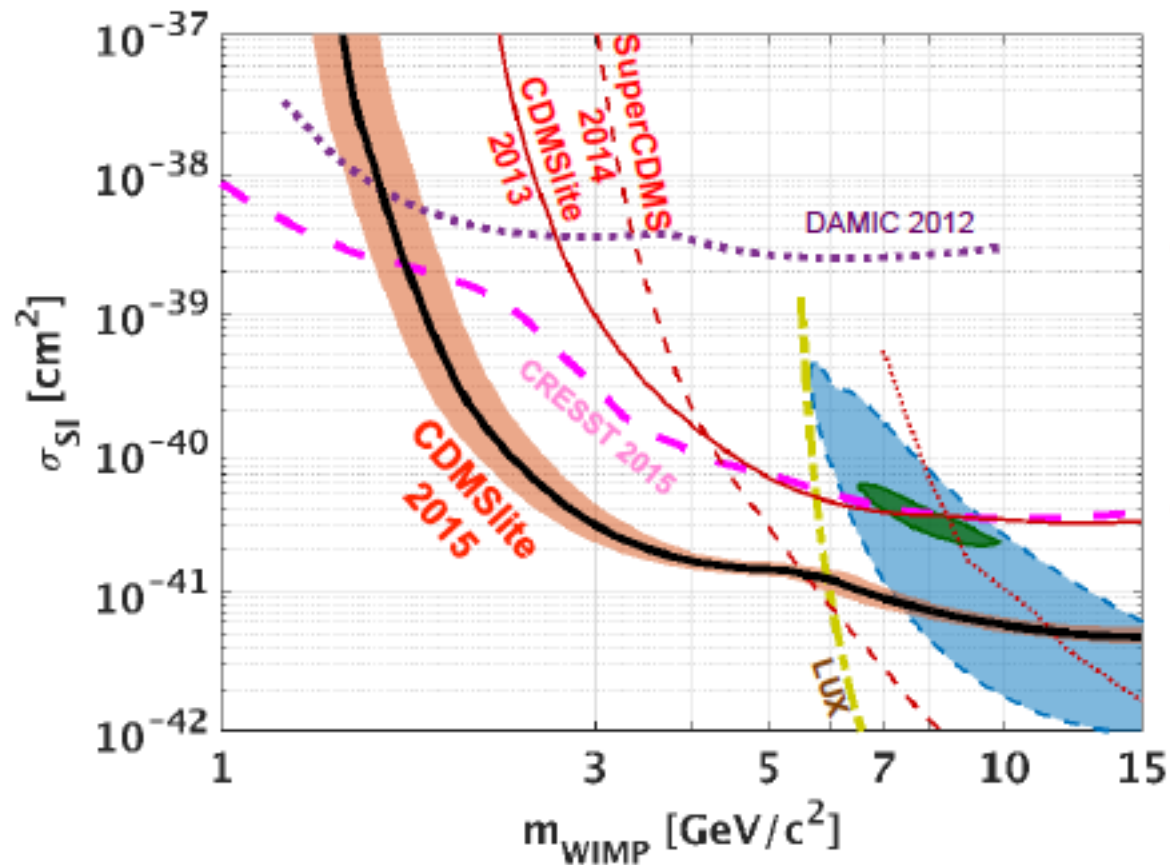
Chou et al. 2015

# Low Energy Nuclear Recoil Calibration



Critical for low mass DM experiments

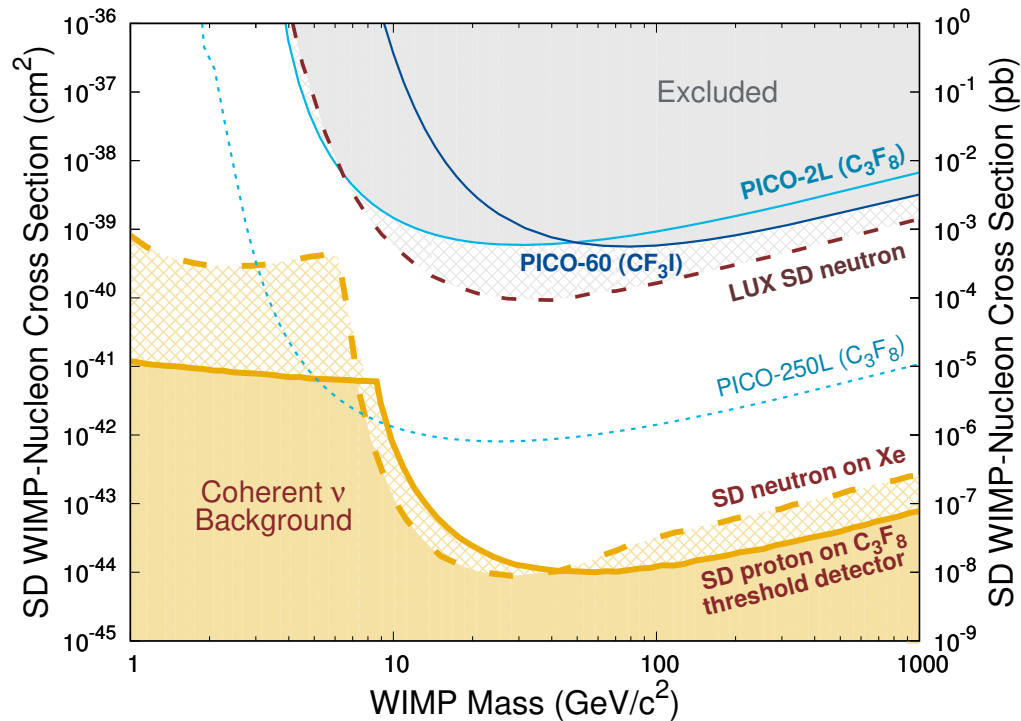
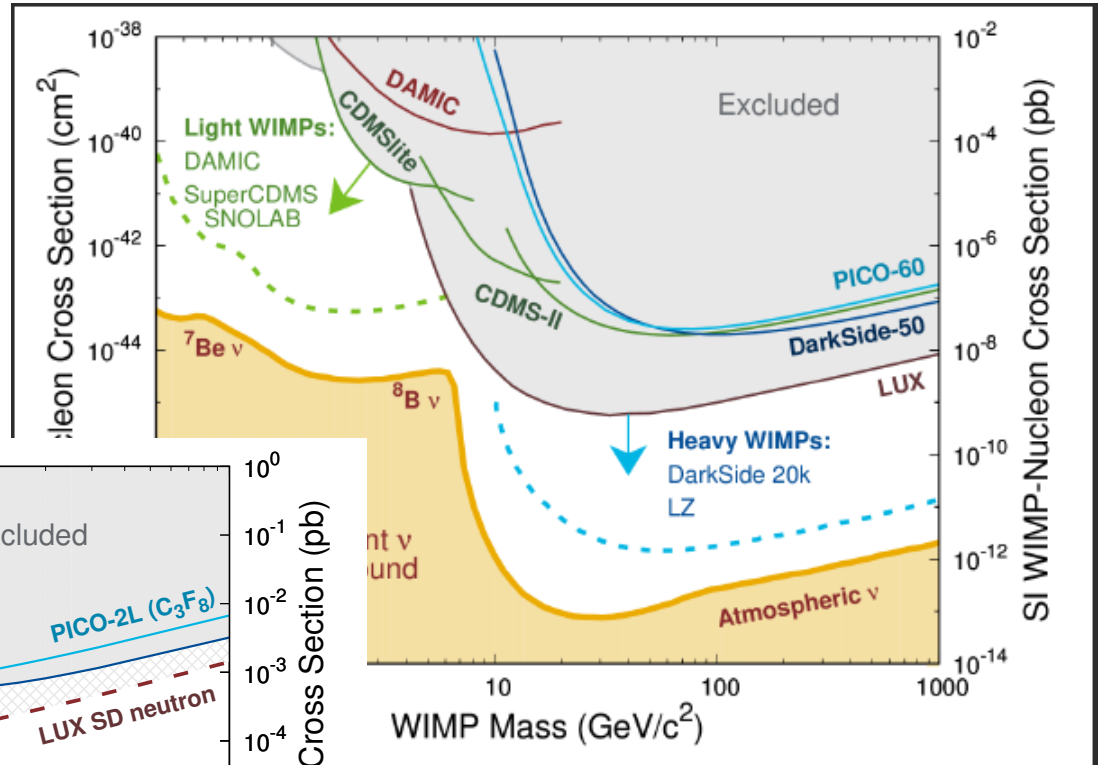
# CDMSLite



Uses phonons to amplify low-E ionization signal

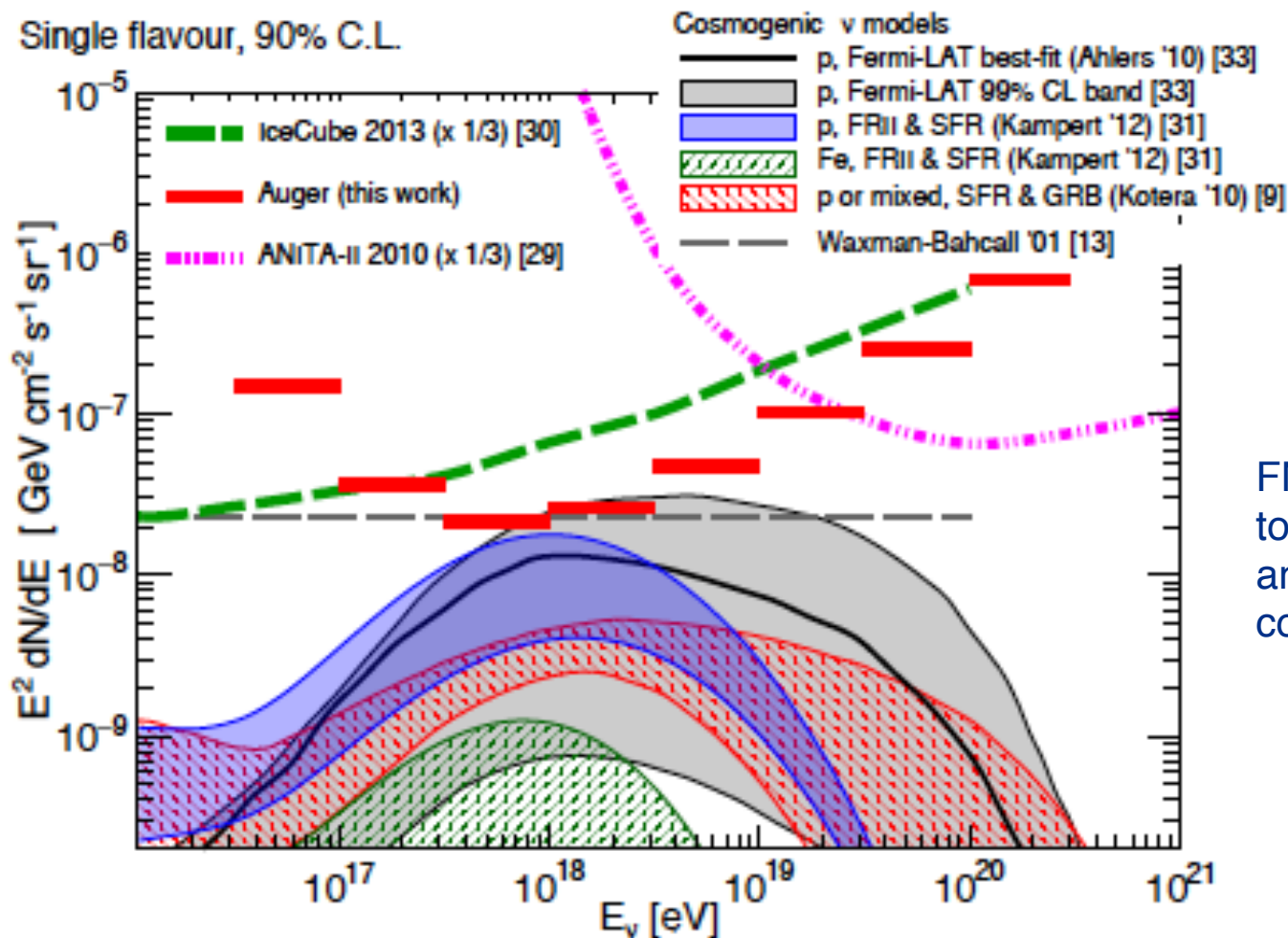
# FNAL Dark Matter

Spin-Independent →



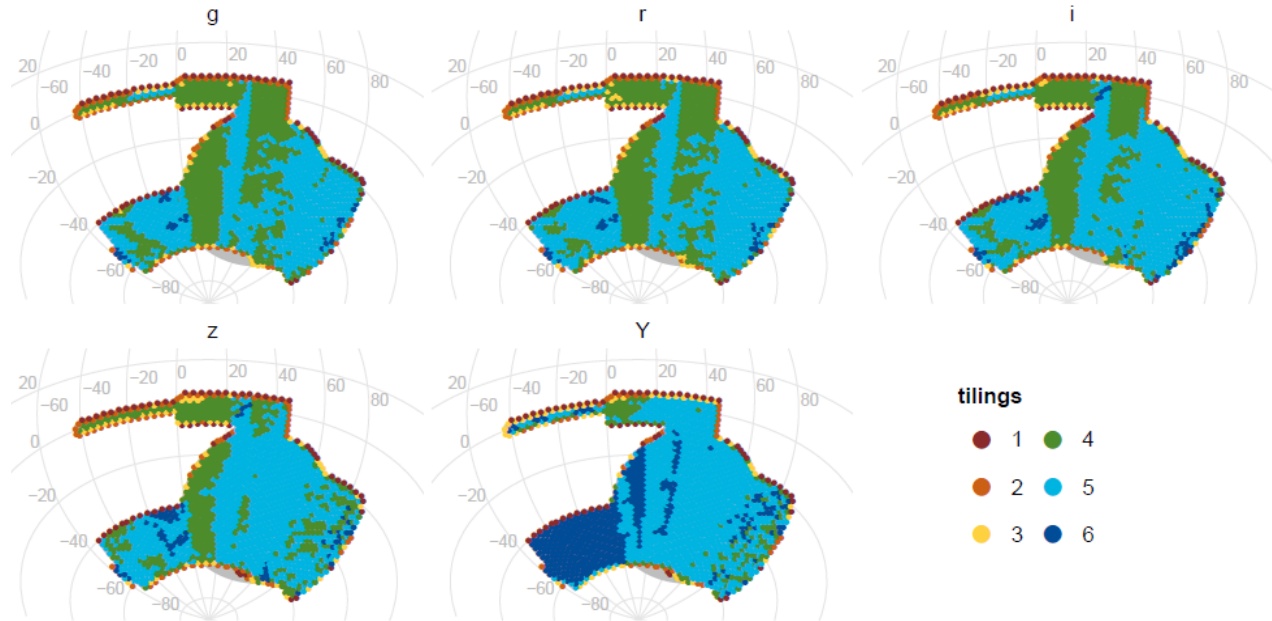
← Spin-Dependent

# Pierre Auger constrains the diffuse neutrino flux



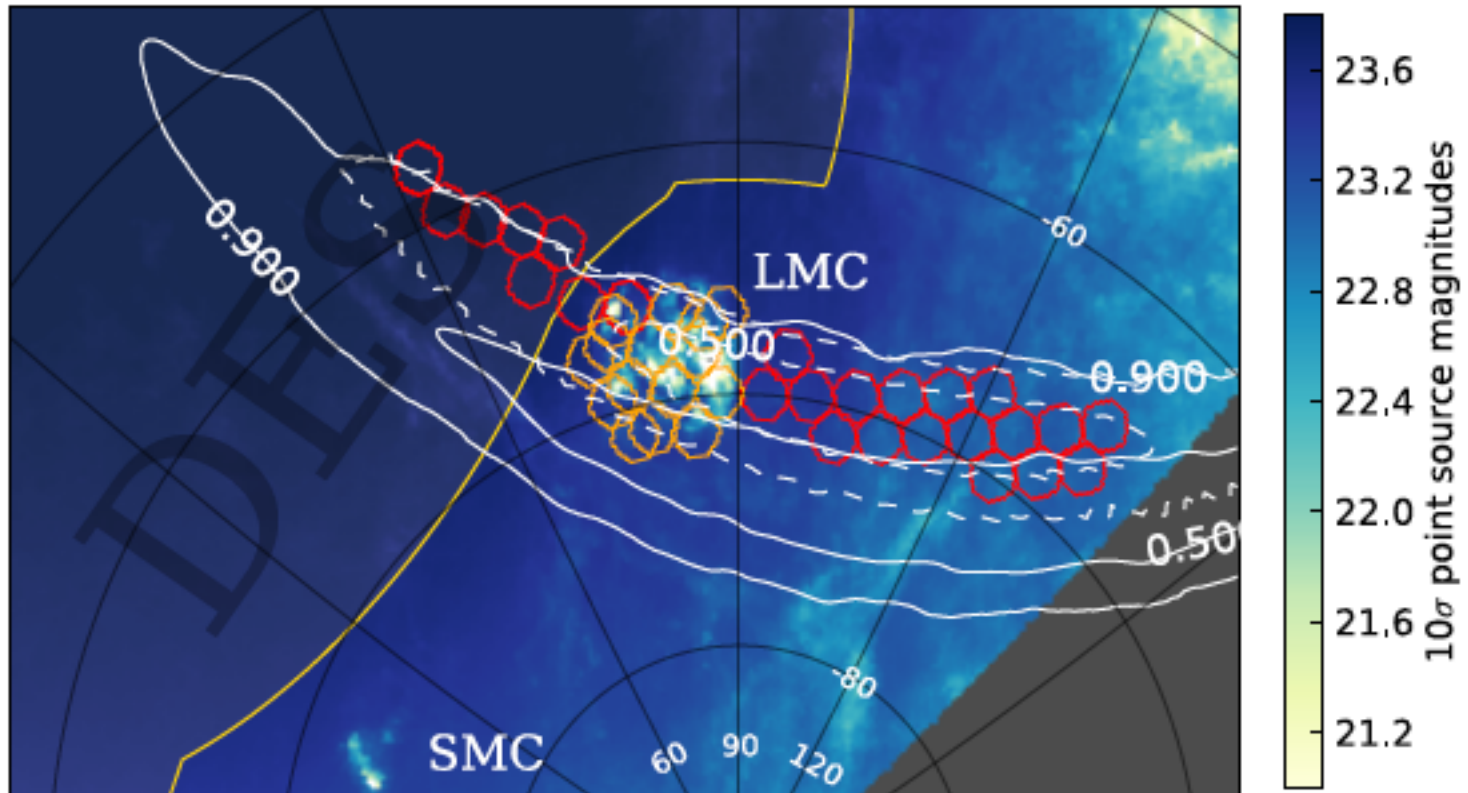
FNAL critical  
to building  
and led  
construction

# Dark Energy Survey



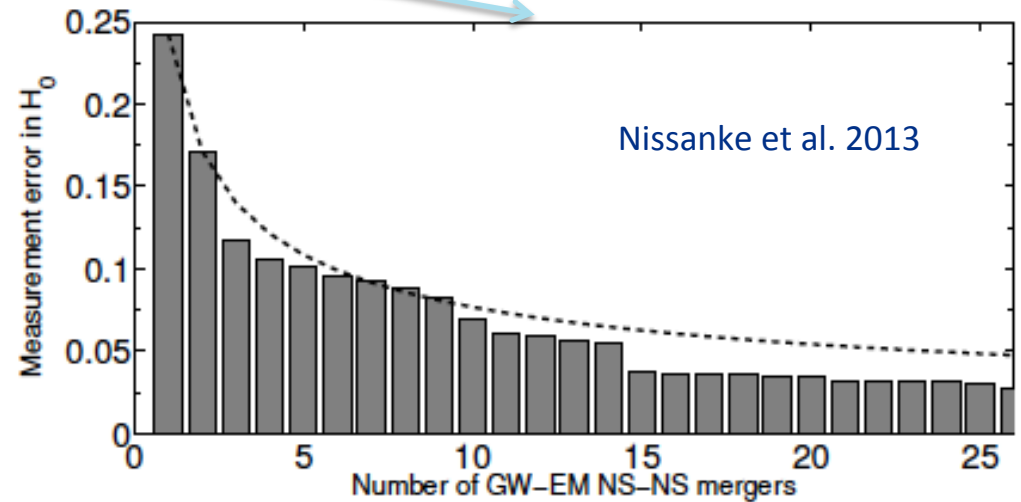
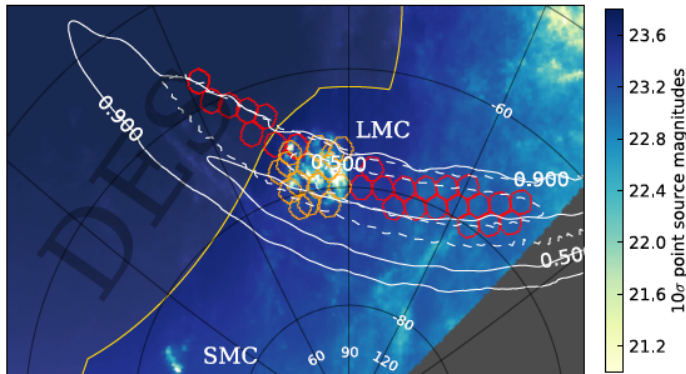
- Completed 3<sup>rd</sup> year (of 5 or 6)
- ~70 papers to date, mostly on Science Verification (~150 sq deg)
- Currently working on Y1 (~1500 sq deg)
- Aim to get out Y3 science (full area, but not full depth) results by the end of 2017
- Overlap of ~2500 sq deg with CMB experiment South Pole Telescope

# Searching for Optical Counterpart of LIGO event



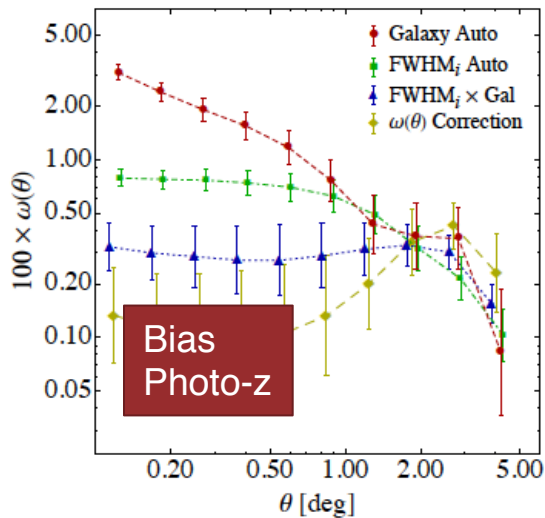
Soares-Santos et al. 2016

# Our interest is in cosmological applications



# Probes of the Clustering of Matter → Physics (Neutrino Mass, Dark Energy, Inflation)

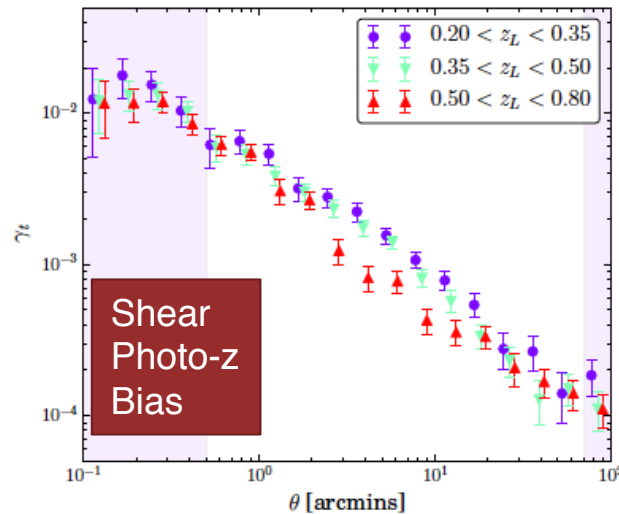
## Galaxy-Galaxy



Crocce et al. 2015

Galaxy distribution traces matter distribution; relation is called *bias*

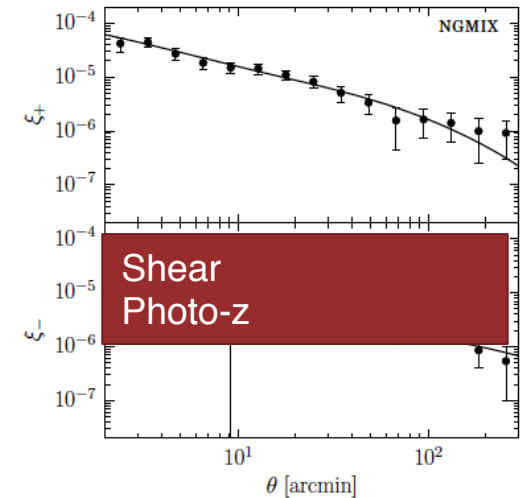
## Galaxy-Shear



Clampitt et al. 2016

Distortions of shapes of background galaxies due to mass associated with foreground galaxies

## Shear-Shear

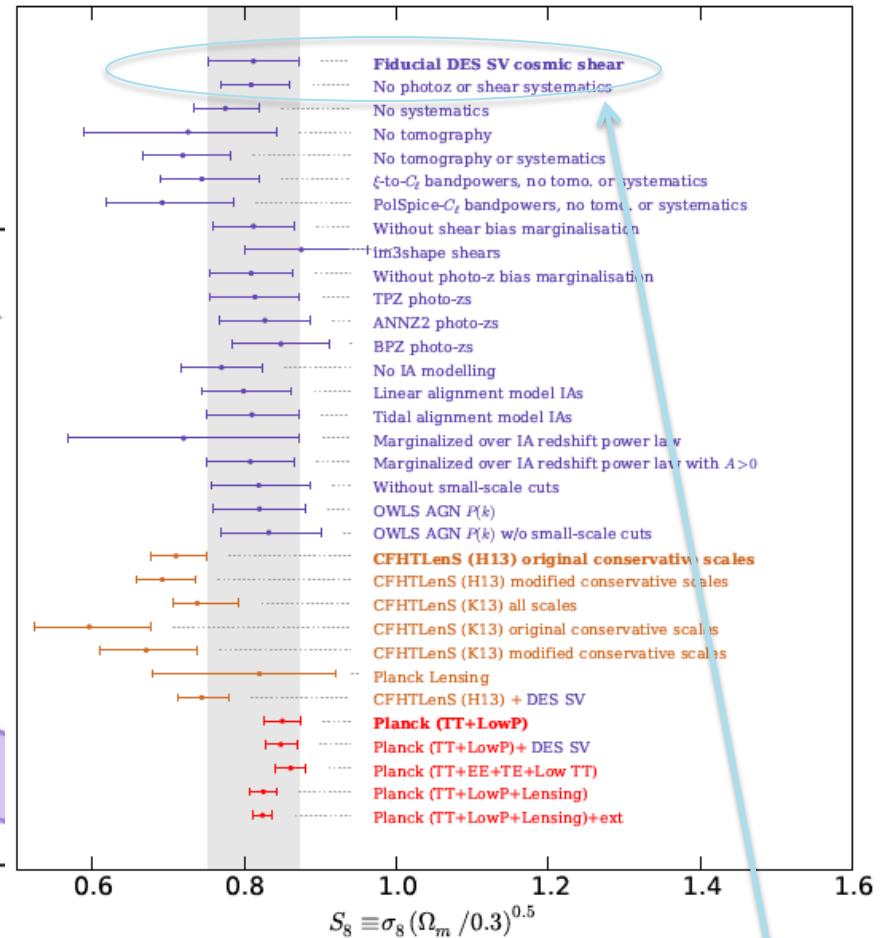
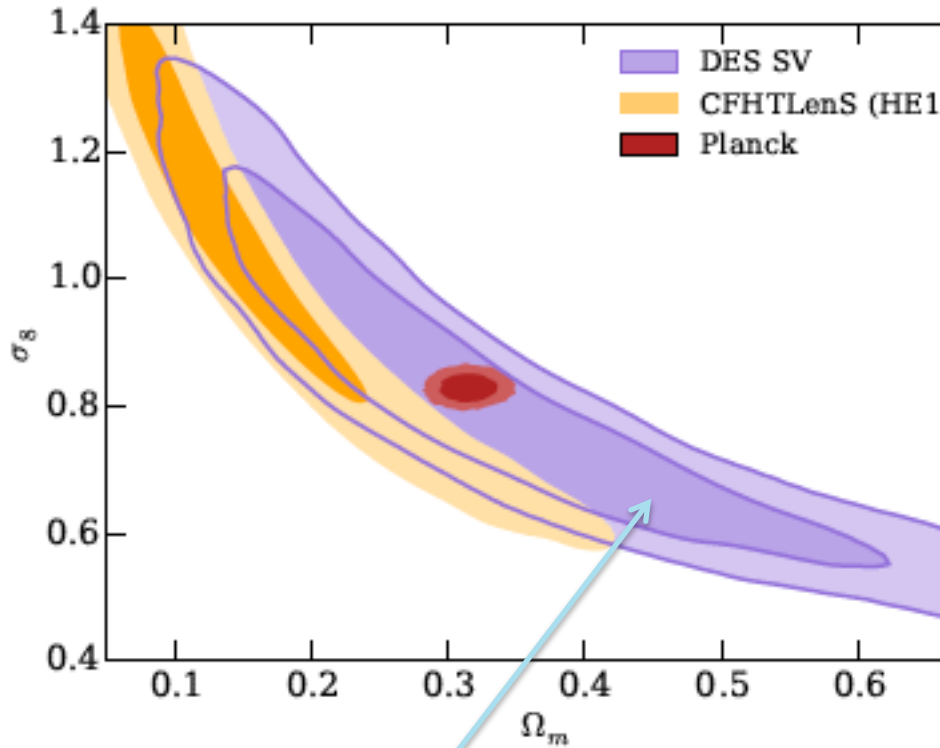


Becker et al. 2015

Correlations of shapes of background galaxies due to all mass along the line of sight

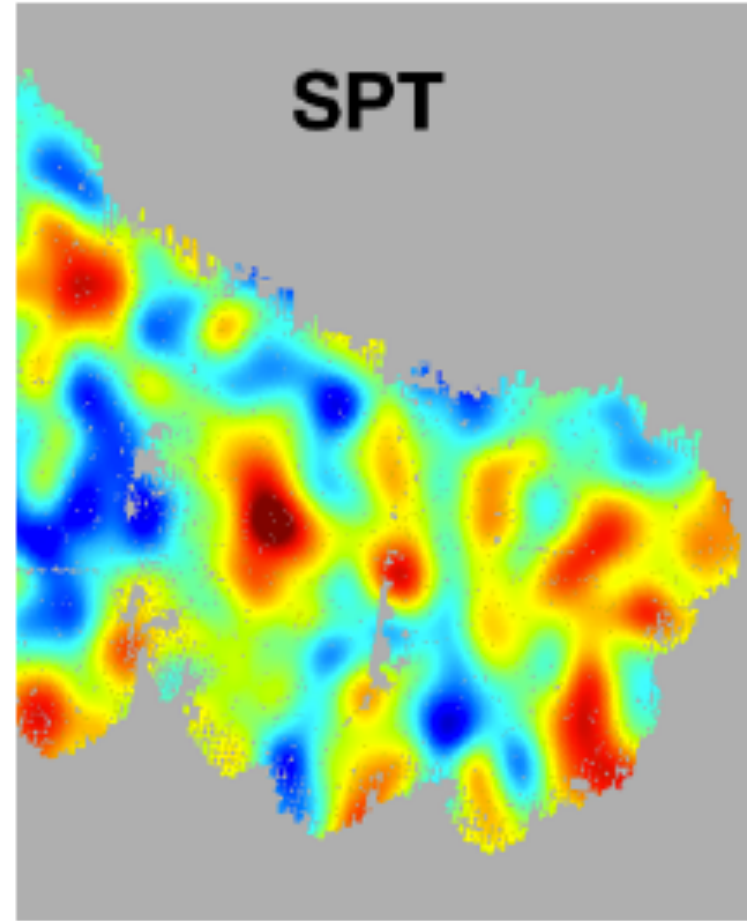
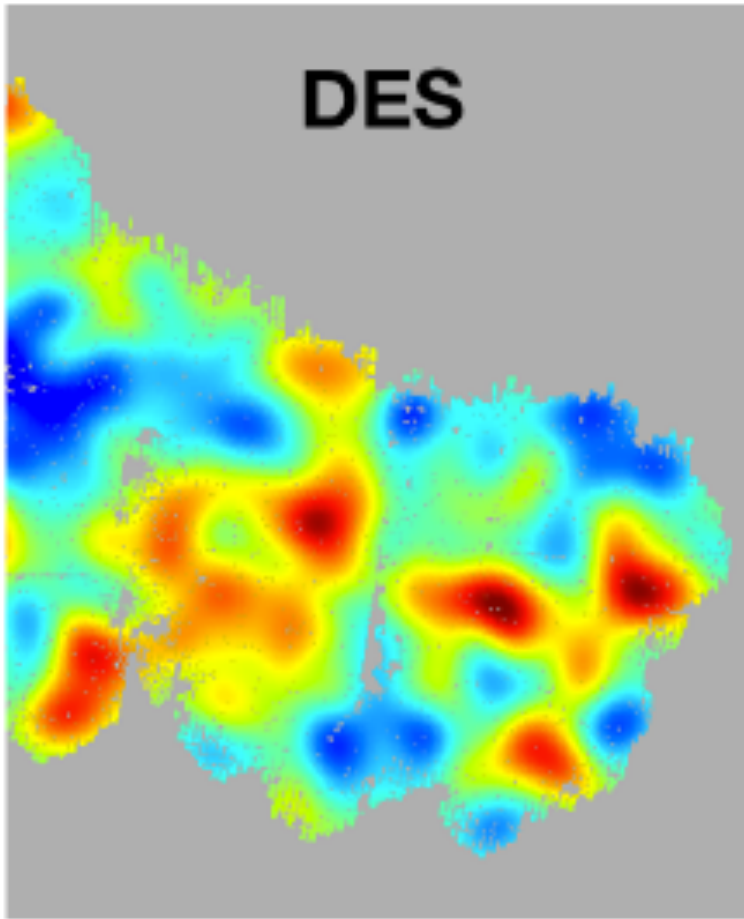
# Our first cosmological result

Abbott et al. 2015



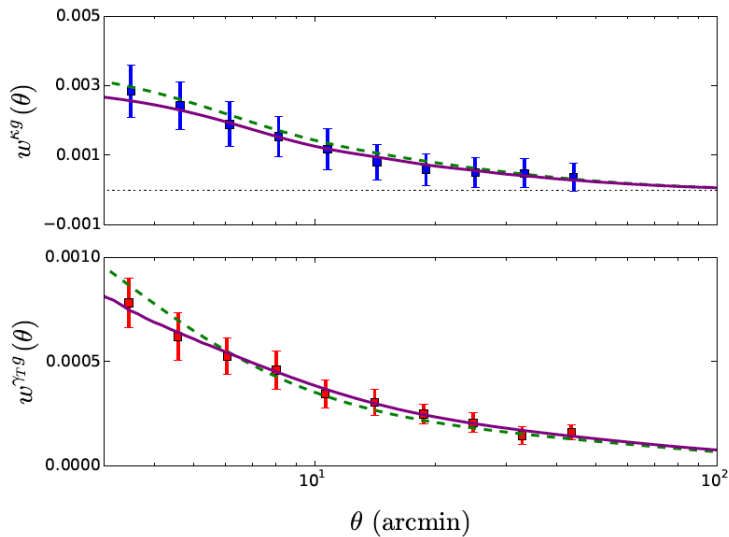
- Careful accounting of systematics eliminated tension with Planck
- Systematics, especially photo-z errors, will be much more important with Y1 data (something LSST is thinking about)

## SPT provides “lensing maps”



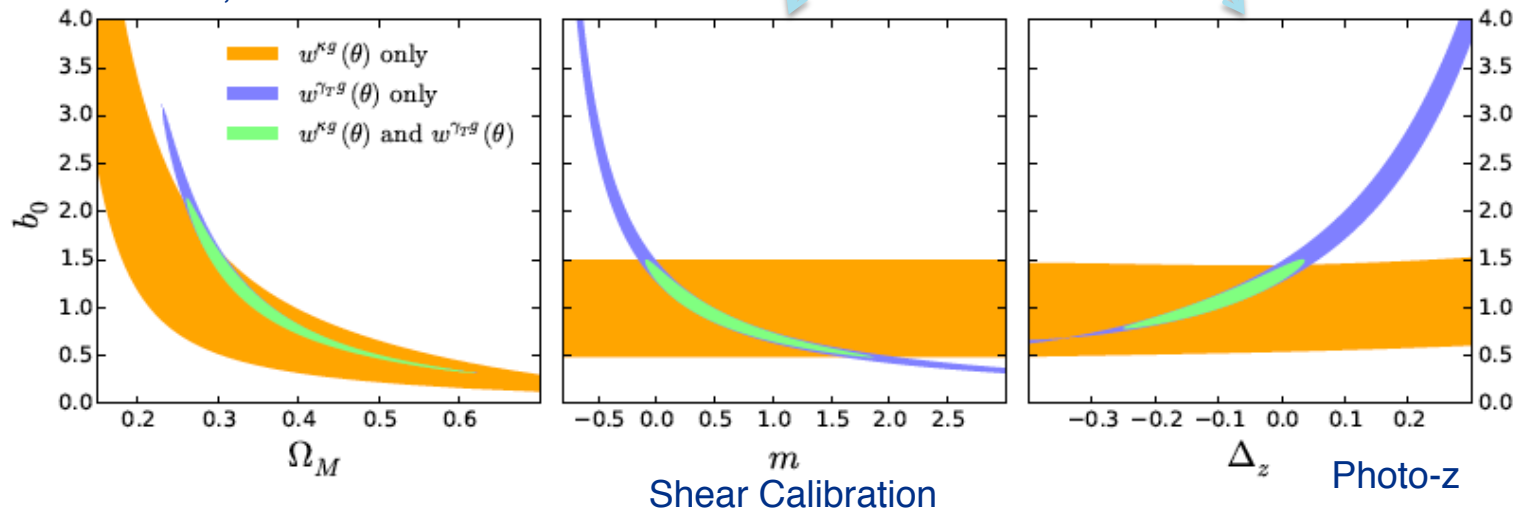
DES galaxies provide (some of) the mass that SPT maps

# Galaxy-shear + DES gals X SPT mass

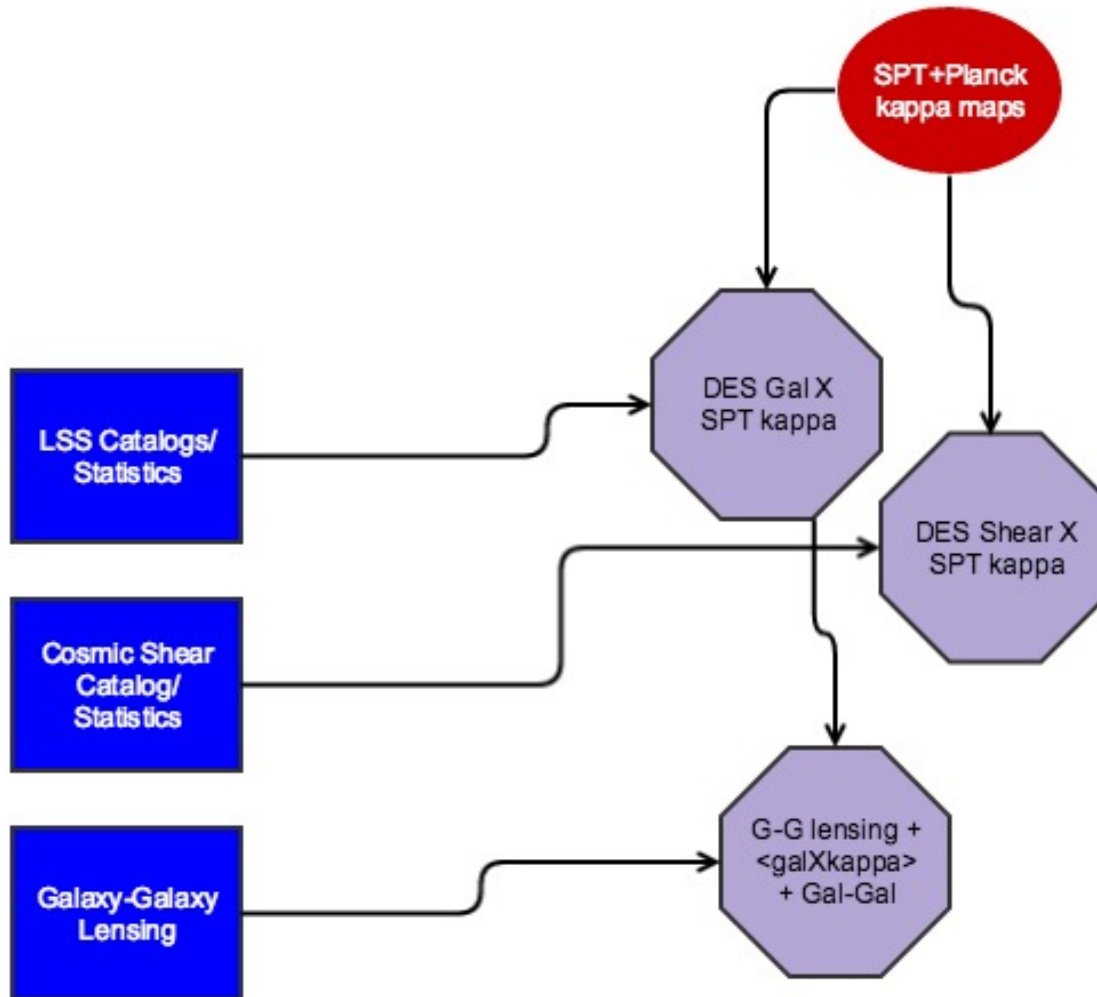


Potentially constrains 2 most important systematics

Baxter, Clampitt, Giannantonio, Dodelson et al. 2016

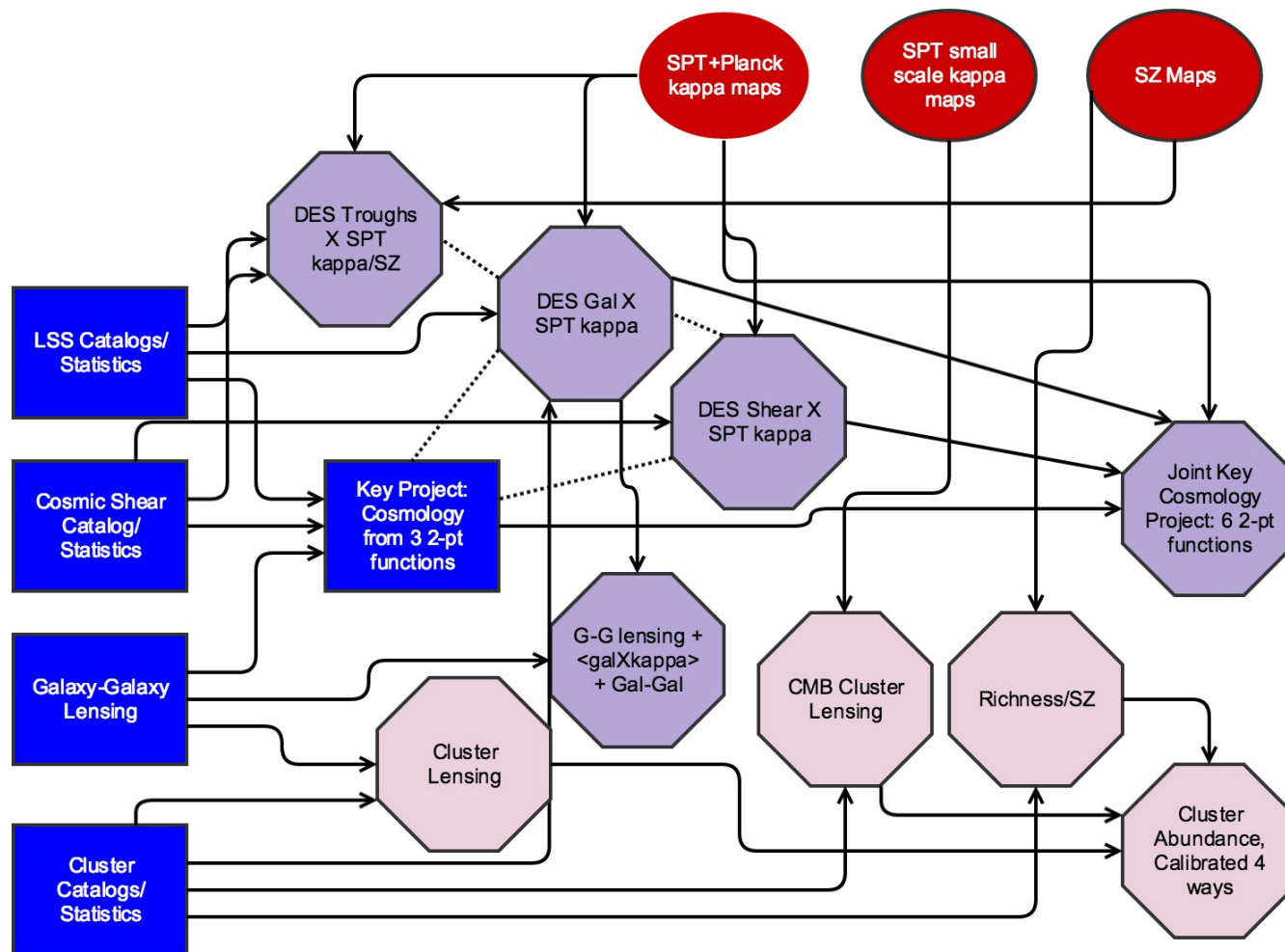


# Combining DES with SPT



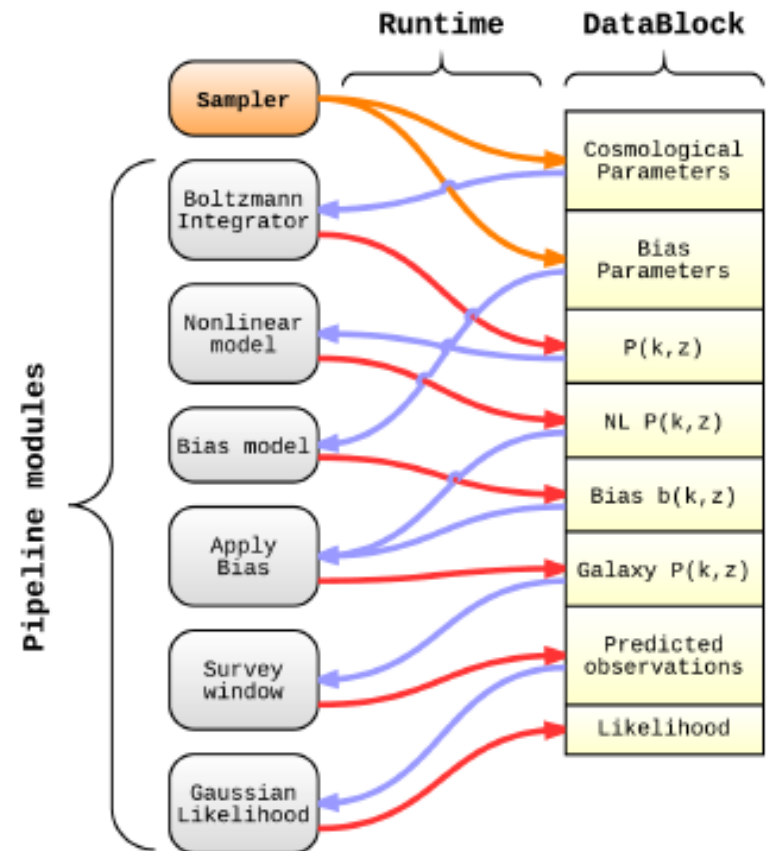
We did all this on SV data. Now we are set to **think big** on Y1 data: put the pieces together to reduce systematics and extract cosmological information

# Aiming for 2-3 Key Projects by year-end



# Software Framework that enables members of collaborations to work together and combine multiple probes

- Modular
- Easy rules for data passing
- Combine with other experiments (Planck, BOSS, ...)
- Funded by OHEP Computing, DES ops, Manchester, UChicago
- SD, Jennings worked with Scientific Computing Division
- In wide use not only within DES



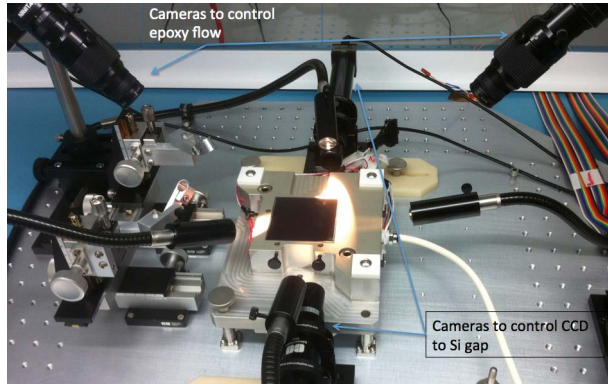
**CosmoSIS: Cosmological Survey Inference System**

<https://bitbucket.org/joezuntz/cosmosis/wiki/Home>

# The Plan

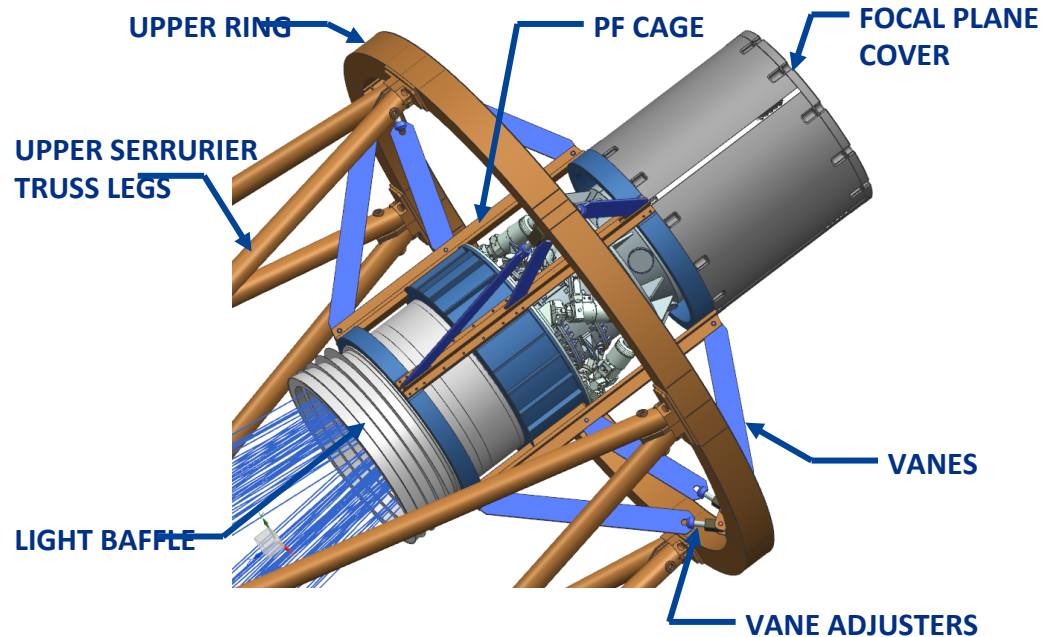
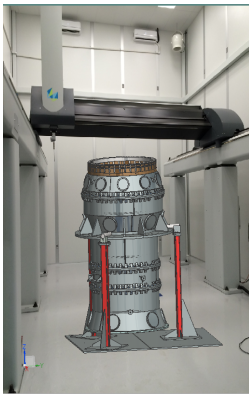
- Help build DESI now
- Transition to LSST as DES ends
- Leverage expertise developed in G1 to make major contributions to the G2 program
- Continue to exploit the connectivity of these efforts, both scientific and technical
- Replace scientists with postdocs

# DESI: FNAL working with LBL to ensure success



Just as for DECam, FNAL packages and tests CCD's

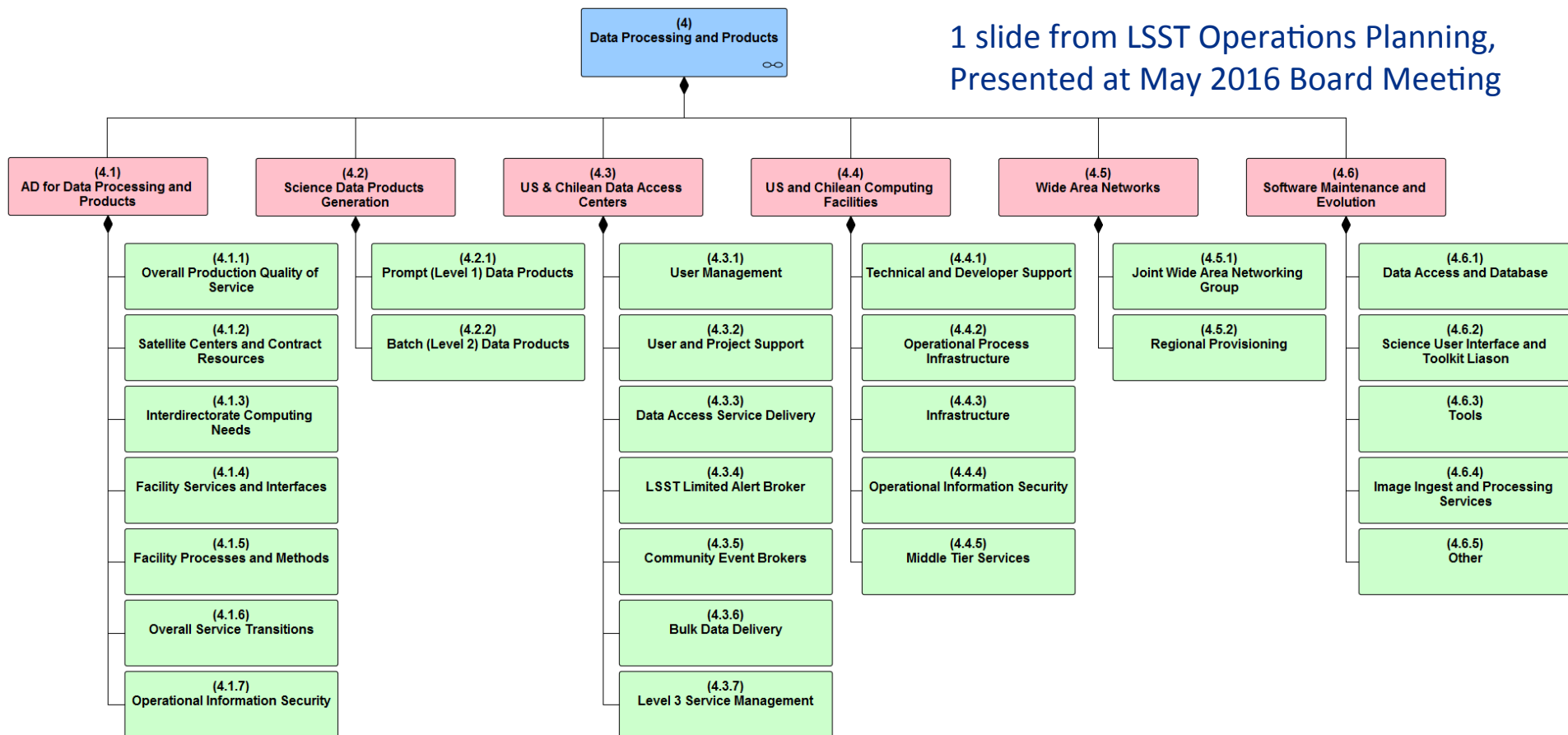
Coordinate  
Measuring  
Machine →  
Precise  
Alignment



FNAL responsible for Cage,  
just as in DECam

# Transition to LSST: Survey Operations

1 slide from LSST Operations Planning,  
Presented at May 2016 Board Meeting



Working with SLAC to leverage DOE resources @FNAL (20+ years of experience operating surveys) to help LSST succeed

# Transition to LSST: Survey Operations

## 4.1 Data Processing and Products

**Brian Yanny** is the DESDM Project Scientist and is responsible for the items called out in all the sub-tasks of 4.1. He would be an excellent candidate for AD.

## 4.2, 4.6, and 5.5 Producing Science Products

The tasks described in 4.2, 4.6 and 5.5 are tightly coupled. Fermilab scientists currently work closely with NCSA to make sure that these are delivered for DES. Among the people who contribute here beyond those mentioned above are: **Steve Kent**, **Marcelle Soares-Santos**, and **Huan Lin**.

## 4.5: Wide Area Networks

Fermilab has a strong Core Computing Networking group that could take on some of this. ESnet passes nearby NCSA, but is not directly connected to NCSA at this time. Fermilab has experts and contacts with the ESnet infrastructure, **Liz Buckley-Geer** with a deep high energy and astro combined background can help bridge the Fermilab infrastructure expertise with NCSA's LSST issues.

Excerpt from working document in collaboration with Dave MacFarlane and Tom Abel.

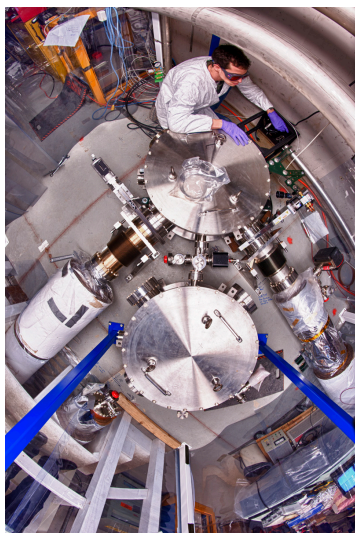
Takeaway: Some of the needs described in LSST Survey Operations plan are a good fit to expertise at FNAL. Timing of transferring ~5FTE's from DES ops → LSST ops seems to work.

# Transition to LSST: Dark Energy Science Collaboration

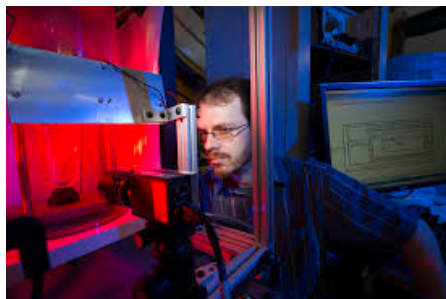
- Propagate forward on photometric redshifts, Galaxy Clusters, Supernovae, Strong Lensing, Combined Probes
- Level 3 Software Framework: Extend *CosmoSIS* to include LSST project tools and more
- Combine with SPT-3G, CMB-S4

Main message: Will migrate to LSST as DES ramps down armed with lots of expertise

# We are very proud of our roles in ...



Holometer



Coupp/PICO

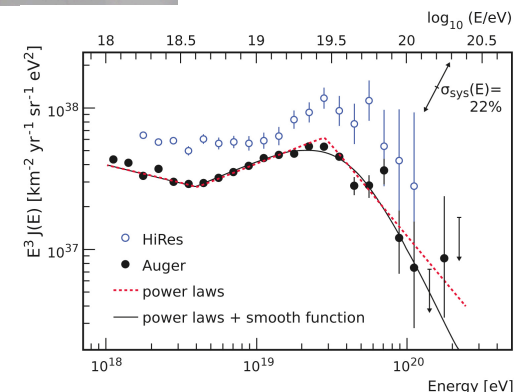
Note: We helped start these but some of them (DAMIC, PICO) adopted by community and likely to continue

DAMIC



Auger

But, following your advice and recognizing funding limitations, we are ramping down effort in these activities (0 FTE total by FY18)\*



## The Dark Matter Program → G2

Strategy: Leverage capabilities developed on G1 and elsewhere at the Lab to make significant contributions to G2 experiments

**SuperCDMS:** Cryogenically operated solid state detectors

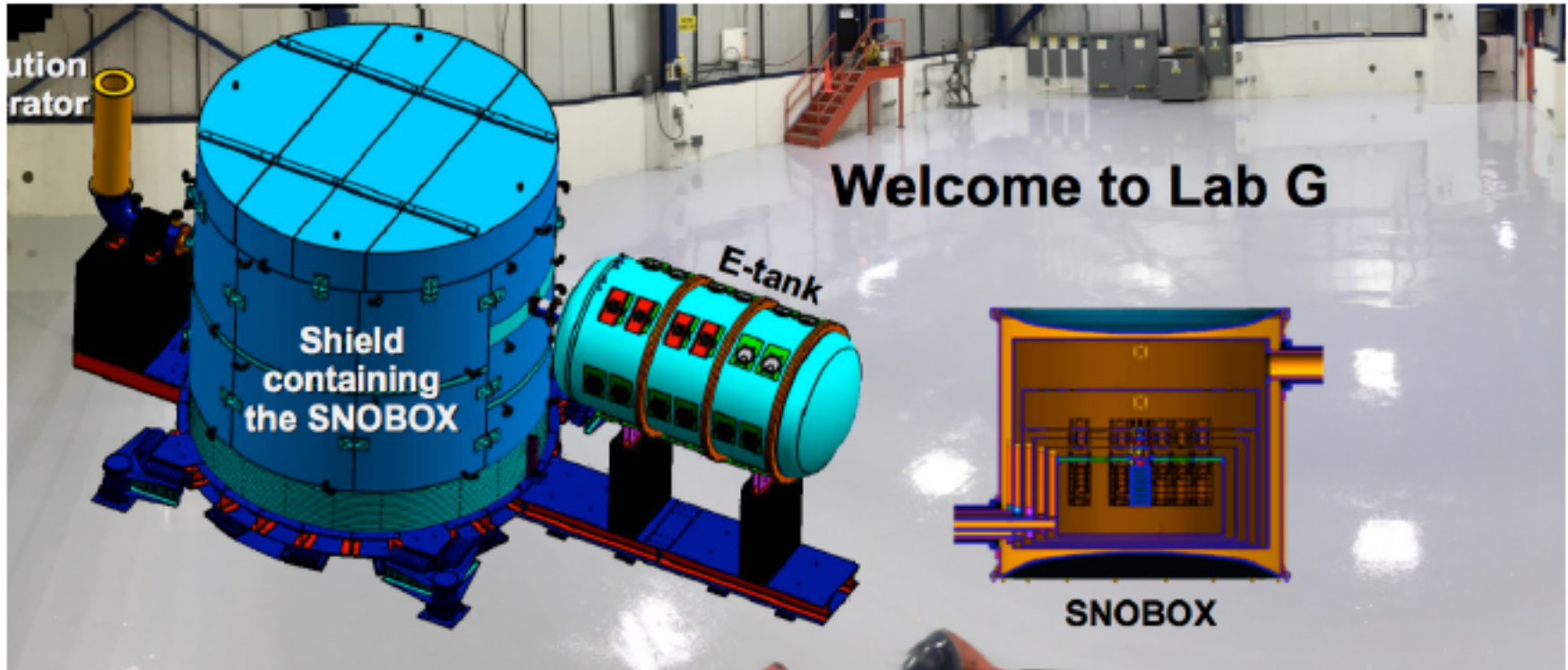
**LZ:** 7 ton Liquid Xenon Time Projection Chamber

**ADMX:** Search for axion conversion to photons in RF cavities with magnetic fields

# SuperCDMS @ SnoLab

Obvious, given our past leadership, scientific interest, and technical expertise

## Cryogenic System Test at Fermilab (planned 2018)



# LZ

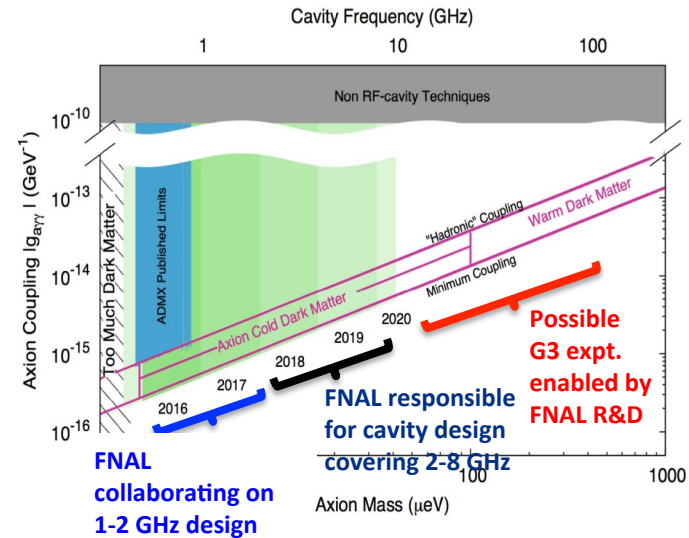
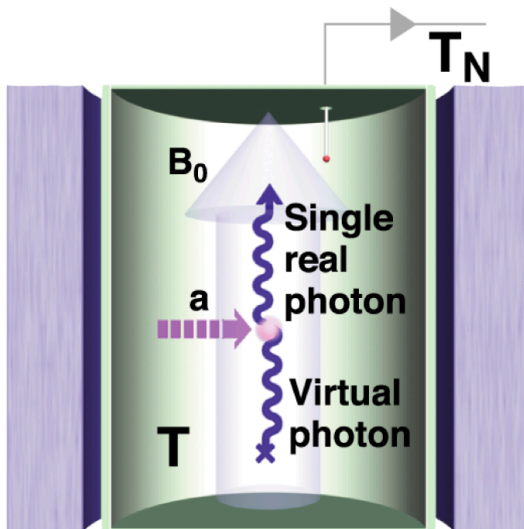
- 1 l of liquid = 600 l of gas: transitions need to be managed very carefully
- Exploit cryogenics expertise from LAr to enable phase transition of 500 slpm gas Xenon circulation system
- Xe Recovery: FNAL co-lead on ensuring safe recovery of xenon in emergency - single largest cost in the experiment
- Purification to ensure  $e^-$  drift without encountering impurities



Liquid Xe tower for phase exchange

# ADMX

- Natural, given our history and the Lab's RF cavity expertise
- Leveraging large DOE investments in accelerator RF cavities to help axion detection.
- Leveraging large DOD investments in quantum computing qubits to reduce photon noise enabling the push to high frequency.



# Our Program: Roles and Responsibilities

DES	Director, Deputy Director, Operations Scientist, Science Committee Co-Chair, Data Management Project Scientist, Data Management Release Scientist, Calibration Scientist, Survey Scientist, co-conveners of 5 science Working Groups, EPO co-coordinator, Speakers Bureau Chair, Early Career Scientist Chair
DESI	Project Scientist; L2 manager for design and construction of barrel; L2 co-manager for integration, testing, and commissioning; L3 manager for CCD packaging/testing; L3 manager for Instrument Control System databases
LSST	DESC: Co-convener, Software and Infrastructure WG; Member, Collaboration Council; DES Project Liaison. LSSTC: Member, Board of Directors
SPT3G CMBS4	<u>SPT-3G</u> : Deputy Project Manager: L2 manager for the Cryostat; L2 manager for Integration and Deployment; L3 manager for Detector Cryostat; L3 manager for Optics Cryostat; L3 manager for milli-Kelvin Stage; L3 manager for Integration
Super- CDMS	Collaboration Spokesperson; Deputy Project Manager; L2 manager for cryogenics; L2 manager for calibration; L2 manager for system integration; Thesis and Publications Chair
LZ	Physics Coordinator, Instrument Scientist; L3 Manager for Purification Tower; L3 Manager Slow Controls Interface; L3 Manager for Xenon Skin System; Co-L3 Manager for Slow Control System
ADMX	Lead for design/prototyping of RF cavities for upcoming 2-8 GHz search; Participate in design of 1-2 GHz cavities; project management support

# Our Program: The Matrix you asked for

	Technical Contributions	Science Roles	FTE Scientists and Postdocs (2016-19-22)
DES	DECam, Survey Operations (Calibration, Data Management, Data Quality, ...)	SN, Strong Lensing, Cross-Correlations, Photometric redshifts, Clusters, Dwarf Galaxies, GW follow-up, ...	11→6.5→0
DESI	CCDs, Corrector support, online database, fiber mapping	Milky Way, Cross-Correlations	2→2→3
LSST	Survey Ops, Scientific Computing	DES Redux	1→3.5→9
SPT3G CMBS4	Camera	Cross-correlations, De-Lensing, Clusters	2→4.5
Super- CDMS	Cryogenics, Shielding, Electronics, Calibration	Low mass	5→4
LZ	Cryogenics, Purification, Process Control	Simulations, Event Reconstruction	2→3
ADMX	RF Cavities	High frequency/ high mass, Noise suppression	1.5→2

**Reduction in FTE: 28 in FY16 → 25 in FY19**



# This is the best point in space-time to be a cosmologist

- **Dark Energy** Survey discovers dwarf galaxies used to probe **Dark Matter**
- **CMB** polarization experiments designed to probe inflation minimize systematics in **DES**
- CCD's used in **DES** recycled to create one of the most powerful low-mass **dark matter** experiments
- **RF Cavity** expertise from decades of operating **accelerators** helps produce fields that can detect **axions**
- **Neutrino** LAr program led to crucial role in G2 **Dark matter** experiments, LZ and DarkSide
- **Gravitational wave** sources may be detected with **DES/LSST** and provide a new way to measure cosmological distances
- **Theorists** are all young and attractive, motivate dark matter searches, identify B-modes as probe of inflation, direct surveys, introduce new analysis methods and tools, simulate the universe, and help plan the future.

# External Validation

- Successful competition for resources : LDRD (CMB, axions, DAMIC ...)
- Heising-Simons grant for ADMX; SciDAC for sims and OHEP Computing and New Initiative from KICP for CosmoSIS
- Early Career Award for Holometer; PECASE Award → DAMIC, FRA Strategic Collaborative Initiative for DES/LIGO
- Prizes and URA funding: 2 postdocs won the Tollestrup Award, URA visiting awards (workshops, many visitors)
- International visitors fully funded come to Fermilab to work with us
- Dozens of students (mostly UC) work with us
- Institutional Review (sub-committee of 2-3 spent week delving into Lab's cosmic program) very positive

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The Fermilab Cosmic Frontier team has assembled and is successfully curating an excellent, and well-integrated, blend of skills across the engineering, computational, scientific, and managerial elements of the program.

The Fermilab Cosmic Frontier scientific staff is among the world leaders in this domain. Recent appointments follow in this tradition.

The technical, scientific management and computational staff have been essential to the lab's success in executing international projects at remote sites that integrate diverse teams into doing dark sector physics.

The Fermilab Cosmic Frontier team is fully integrated into the broader community, and is seen as a partner in executing these projects.

## We think we're on the right track but ...

- Requires reduction in DE effort and future R&D
- Eliminates possibility of opening up Center to the broader community: We could be a Cosmology Hub



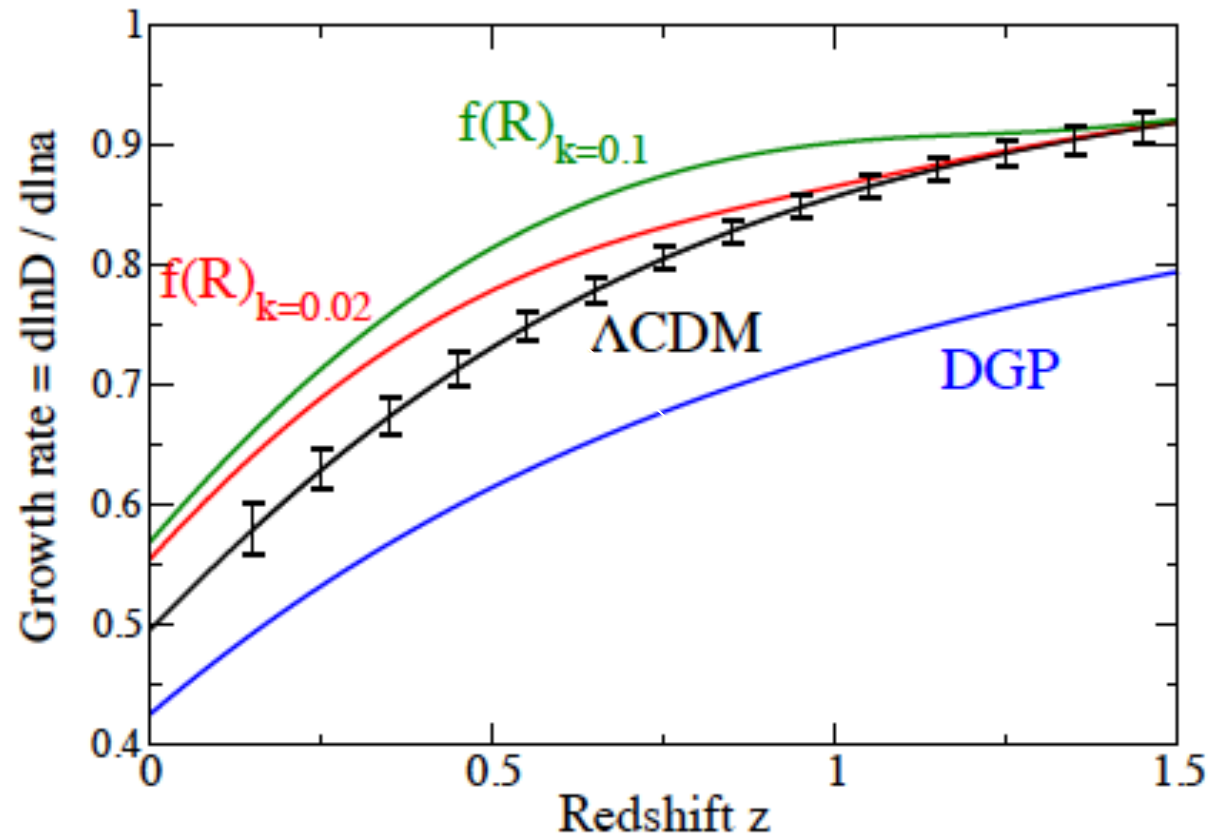
- Trying hard to get some funding for these via LDRD, FWP's, FRA Strategic Collaborative Initiatives, URA Visiting Scholars Program, and upcoming Comparative Review
- (PAC endorsement for a small increment would help!)

# Backup Slides

# Growth differs in Modified Gravity Models

## Glossary:

- $f(R)$  – modified gravity model
- DGP – modified gravity model
- $\Lambda$ CDM – dark energy mode, with DE=cosmological constant
- DESI – *Dark Energy Spectroscopic Instrument*, big survey to start in 2018
- Snowmass: year-long process, during which high energy physics community made science case for different projects



*Snowmass: Huterer et al. 2014*

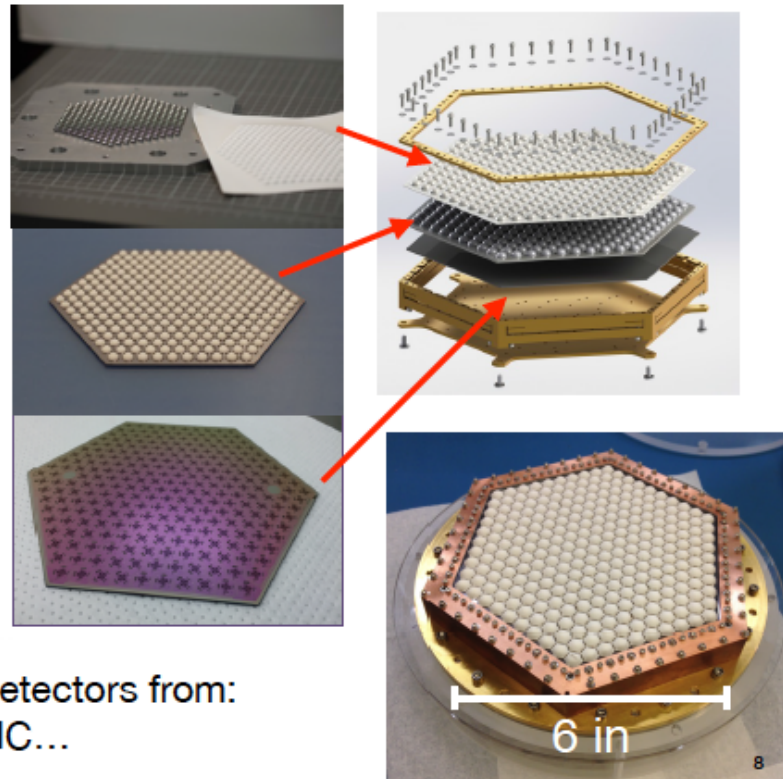
## More details from User's Meeting

- <https://indico.fnal.gov/conferenceOtherViews.py?view=standard&confId=10495>
- Gordan Krnjaic: DM theory
- Alan Robinson: DM experiments
- Adam Anderson: SPT-3G and S4
- Brian Nord: DES
- Alex Drlica-Wagner: Tollestrup Award

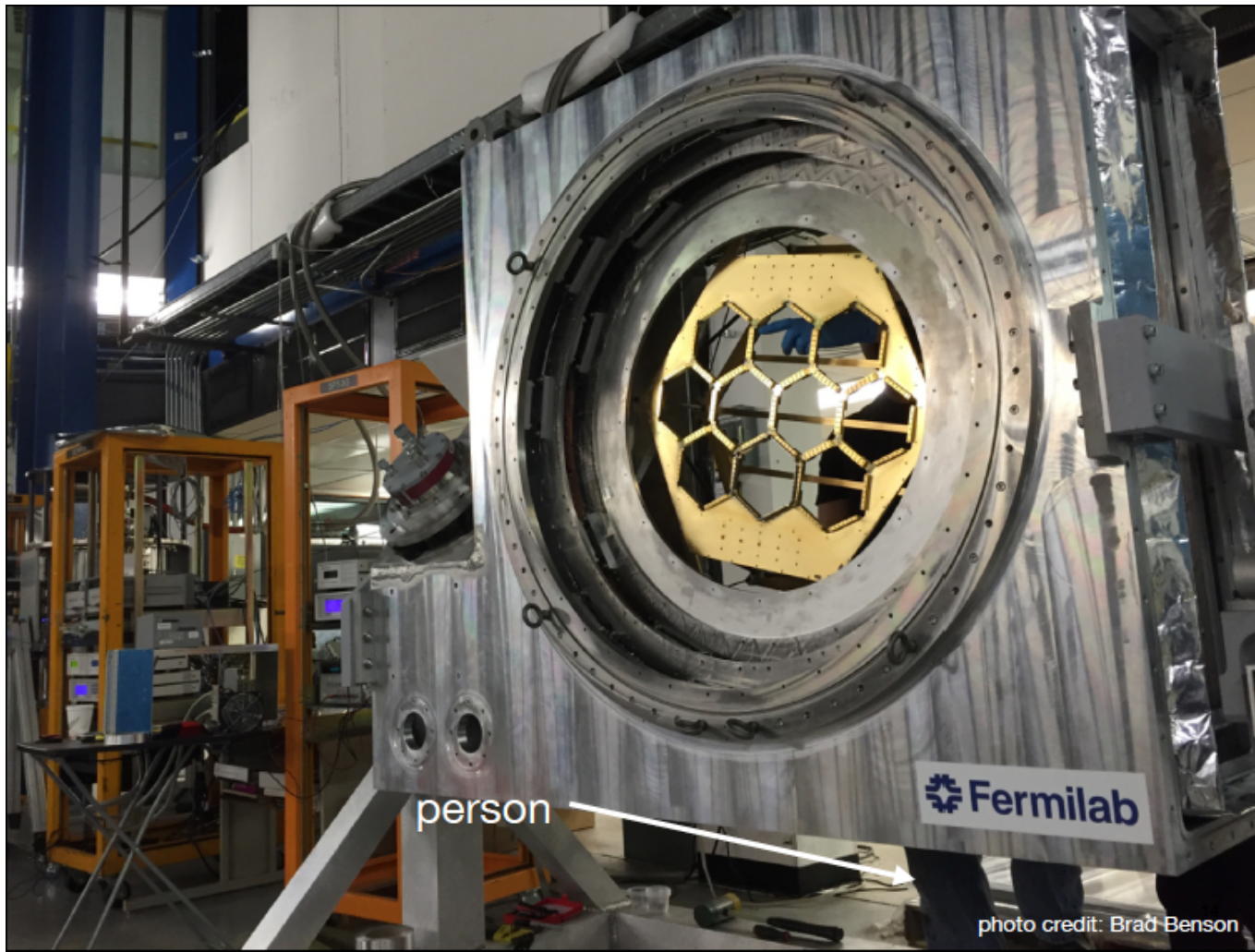
## Detector Modules

- 271 pixels per wafer
- 10x detector wafers in focal plane
- Detector wafers coupled to array of alumina lenslets, anti-reflective coating
- Assembly, packaging, wire bonding all at Fermilab at SiDet

Major expertise in silicon detectors from:  
CMS, DES, DAMIC...



# SPT-3G



## Commissioning and Timeline

- Ongoing:
  - Cryostats assembled at Fermilab, currently testing
  - Optics assembly
  - Detector and electronics testing at Fermilab and elsewhere
- Oct. 2016: Ship to South Pole
- Nov. 2016 - Feb. 2017: Commissioning at pole
- 2017: First data


 Fermilab

photo credit: Brad Benson

# Excerpts from Theory Review-2014

**Findings:** The group is extremely strong and very active. It is making significant progress in fundamental research using astrophysical observations, such as SDSS, CMB observations, and high-energy particle astrophysics.

**Comments:** The group has a strong impact and visibility. It compares favorably with other groups in the Cosmic Frontier, and, more generally, it is one of the best theoretical groups supported by HEP DOE across the Frontiers. There is palpable synergy between 5 staff members, and good record mentoring postdocs and students.

**Comments:** The proposed work is broad in spectrum and deep in its anticipated impact. This research will have important implications for theory. It will also help advance several future DOE funded projects, including LSST, DES, and CMB detectors.

**Comments:** All staff members are leading scientists with international recognition. Dodelson stands out due to the breadth and impact of his contributions. Frieman is one of the recognized leaders in cosmology. Gnedin is doing cutting-edge research in numerical astrophysics and cosmology. Hooper is very prolific in high-energy astrophysics. Stebbins' work in cosmology is well recognized.

# DarkSide

## Fermilab Darkside 20K FWP

	FY16	FY17	FY18
M&S (k\$)	250	297	266
SWF	0.5	1.5	1.5
Total (k\$)	401	800	800

- Strategic mandate of high importance to INFN
- Reduce  $^{39}\text{Ar}$  by cryogenic distillation; development of fluid handling system
- Starting in FY17, Project Director, Jim Strait