Cosmic Frontier at Fermilab

Overview of Experiments and Strategy

Craig Hogan
PAC, June 22, 2012

Cosmic Frontier Experiments at Fermilab

Dark Energy

Deep, precise surveys of the universe: map history of expansion and growth of structure to probe physics of cosmic acceleration

Dark Matter

Direct detection of WIMP dark matter particles

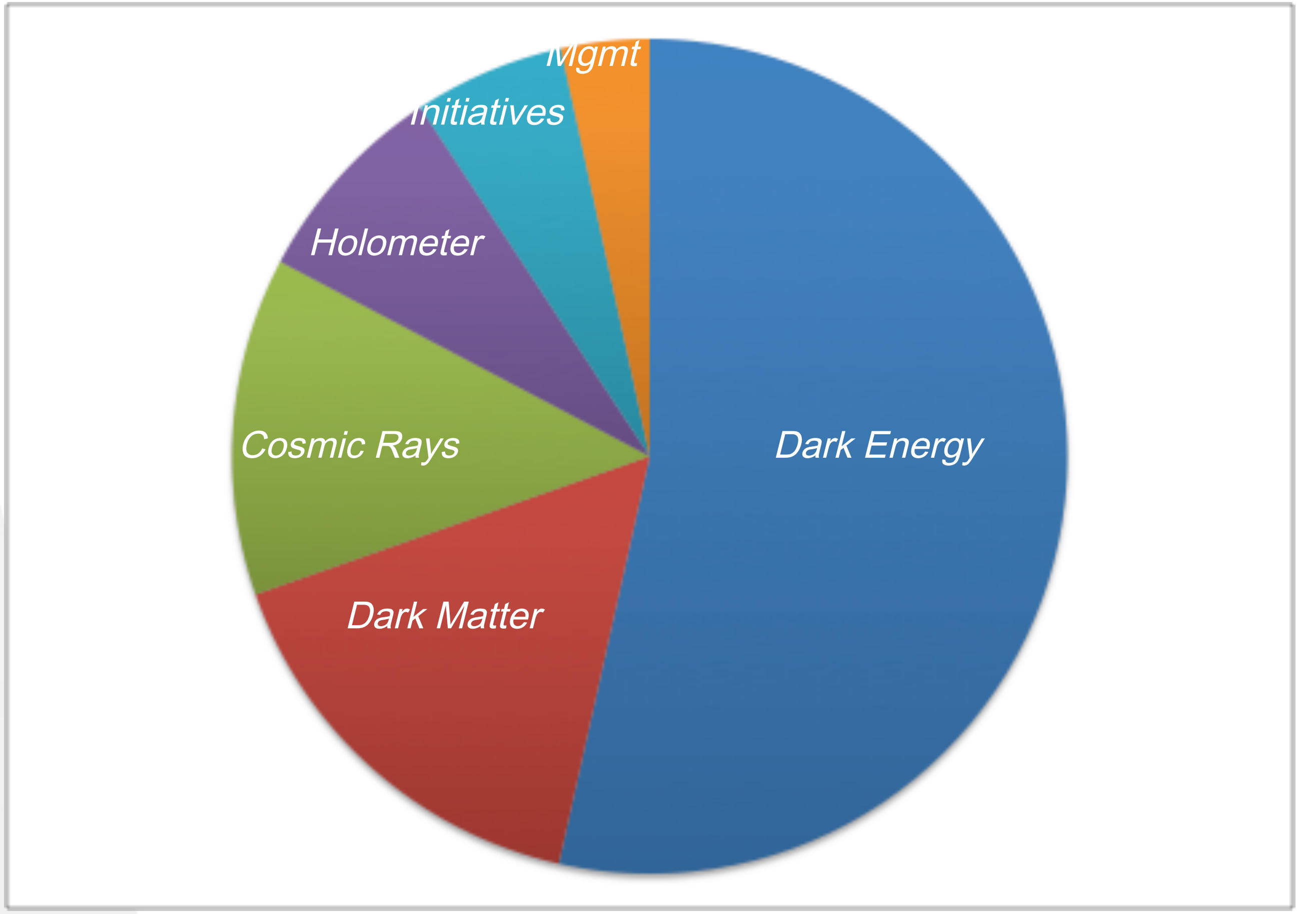
Highest Energy Cosmic Rays

Detailed study of rarest, largest cosmic ray showers

Quantum Spacetime and Unification

Measure Planckian position fluctuations

Cosmic Frontier Scientists- FY2011



42 scientists (counting 8 postdocs), 32 FTEs
Plus KA-14 astro theory group (5 scientists, 4 postdocs)

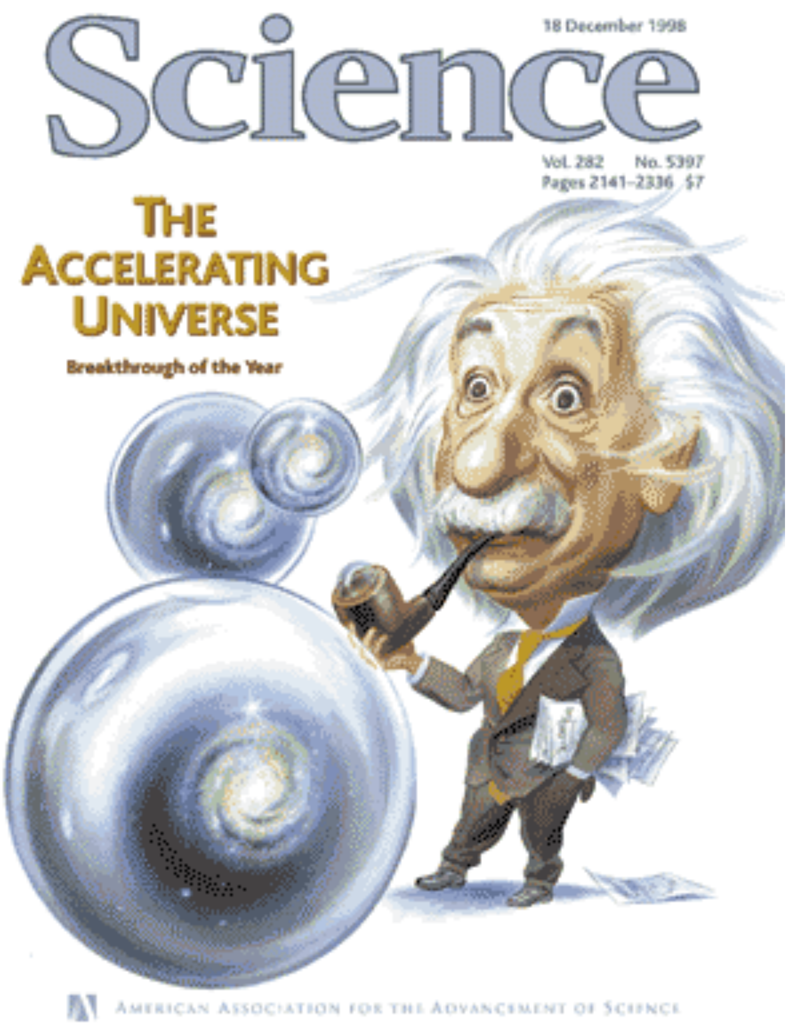
Fermilab

Dark Energy Science

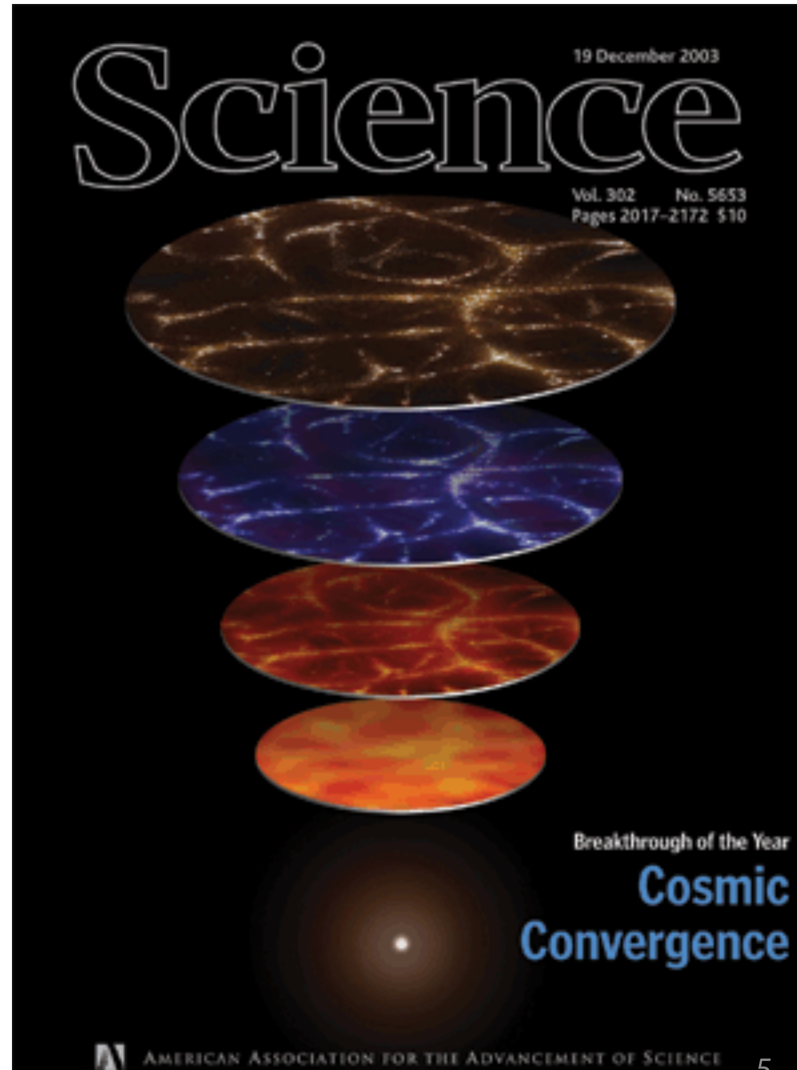
- Cosmic expansion is accelerating
- Physics is unknown
  - Energy or gravity?
- Experimental approach: measure the universe
  - Expansion history
  - Distribution of mass
  - Growth of structure
  - Use light from galaxies, quasars, cosmic background
- Progress driven by precision

Science Breakthroughs of the Year: 1998 and 2003

Cosmic acceleration



Precision cosmology (WMAP,SDSS)



Perlmutter, Riess, Schmidt: 2011 Nobel Prize in Physics, for discovery of Cosmic Acceleration

NEWSFOCU

Trifecta. Saul Perlmutter (*left*), Brian Schmidt (*center*), and Adam Riess shared the 2011 Nobel Prize in physics.

A Week in Stockholm

For the rival teams whose discovery of dark energy had transformed scientists' picture of the universe, the 2011 Nobel festivities were a flurry of jubilation, disappointment, and one-upmanship

EARLY MORNING ON 4 OCTOBER 2011, THE DAY THE PHYSICS Nobel was announced, astrophysicist Peter Garnavich was woken up by a phone call that came not from Stockholm but from his wife, Lara Arielle Phillips. Garnavich was asleep in a Chicago hotel room, preparing for a long day of travel. Arielle was calling from the couple's home in Indiana, where both are professors at the University of Notre Dame. "Is everything all right?" Garnavich asked groggily. "Yes, everything's fine," Arielle said, mildly apologetic. "The Nobel in physics has been awarded for the accelerating universe. It's going to Brian, Adam, and Saul."

Garnavich had known all along that this day would come. In the 13 years since two rival teams discovered the accelerating expansion of the universe—suggesting that three-quarters of the cosmos consists of a mysterious force termed dark energy—the consensus that the work

Bigger still. The universe is not only expanding but speeding up.

lic Radio that morning. "I was disapp... that I was disappointed," he would re... sachusetts, Harvard University astroph... had been the doctoral adviser to both S... his daughter when she asked angrily, '... Explaining the rules of the Nobel, wh... to more than three individuals, did no... care about any of that stuff, she wante... says. Later, when colleagues e-mailed... with condolence, Kirshner responded... he's known to direct at others and hi... that you don't win a Nobel Prize," he v...

The winners knew what the others v... Riess dug out from an avalanche of... to e-mail his gratitude to the High-z t... Riess, a professor at Johns Hopkins Uni...

Online
sciencemag.org
Podcast interview with author Yudhijit Bhattacharjee.

"We accept this... share. We are lu... adventure." Sch... lian National U... with a message... prize has been a... all know it is in... work." Perlmutter, a physicist at Lawre... tory (LBNL) in California and a profe... fornia, Berkeley, conveyed similar se... SCP. Later that day, a comment in the... Martin Rees acted as a salve for those v... have been fairer, and would send a les...

would win a Nobel Prize had come to be matched by a growing certainty about who the individual winners might be. The Shaw Prize, awarded in 2006, had already singled them out: Brian Schmidt and Adam Riess from the High-z Supernova Search Team—which Garnavich was a part of—and Saul Perlmutter, leader of the competing Supernova Cosmology Project (SCP). Yet, when his wife named the winners, all he could say was, "Shit." The disappointment of being left out was far more intense than Garnavich had imagined.

"I had thought this was really going to happen a long time from now, and I didn't have to deal with it, but now I did have to deal with it," says Garnavich, a genial 53-year-old with a perpetual smile. At the same time, he felt relieved that the Nobel committee had not given the prize to Perlmutter alone. "The jockeying for which team was first in making the discovery had gone on for a long time, and there was a worry that maybe the Nobel committee wouldn't have seen that."

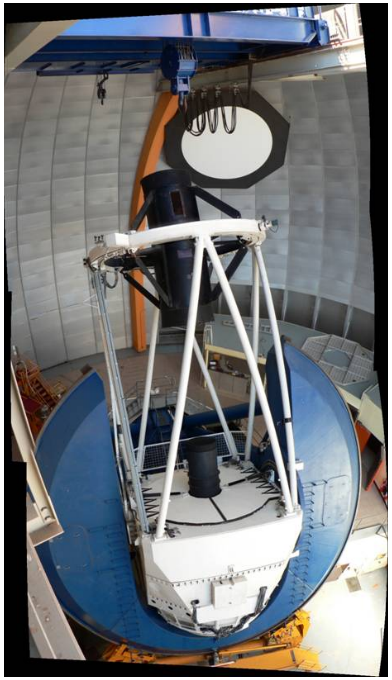
Garnavich wasn't... of pride and pain. N... balding astronomer... College Station, wh... in 1994 along with... breath when he hea...

26 6 APRIL 2012 VOL 336 SCIENCE www.sciencemag.org

Two teams

High-z team in Stockholm, Dec 2011

Blanco Telescope at CTIO: critical instrument for discovery of cosmic acceleration



Fermilab Dark Energy Program

Dark Energy Survey (2012-2017)

Will soon extend ultra wide, precision imaging to Hubble distance for the first time; factor ~5 improvement in Dark Energy precision

Dark Energy Spectrometer/BigBOSS (~2018-2022)

Obtain ~10^7 spectra to z>1, still better Dark Energy precision

Large Synoptic Survey Telescope (~2022-2032)

wider, faster, deeper imaging; total data ~100 times DES

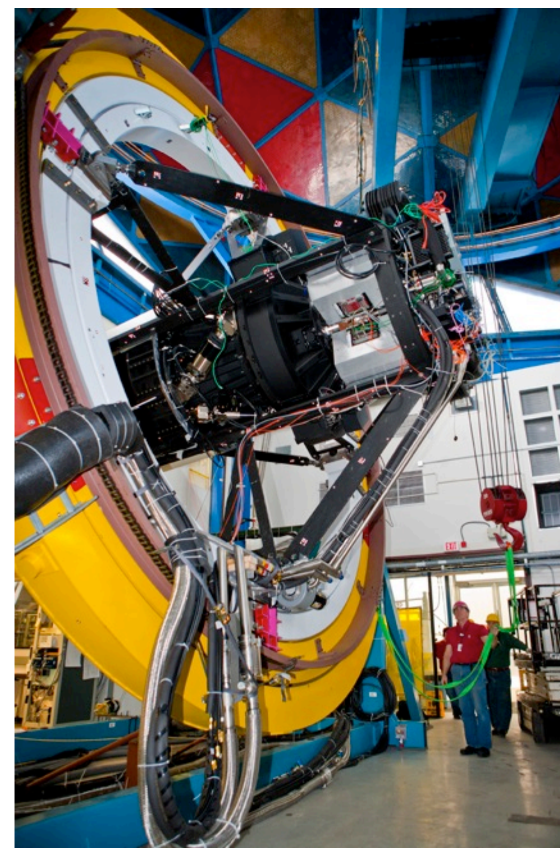
Dark Energy Survey

Next big step in cosmic surveys

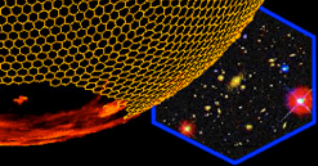
Wide, Deep (z>1), Precise

DE Camera project led by Fermilab

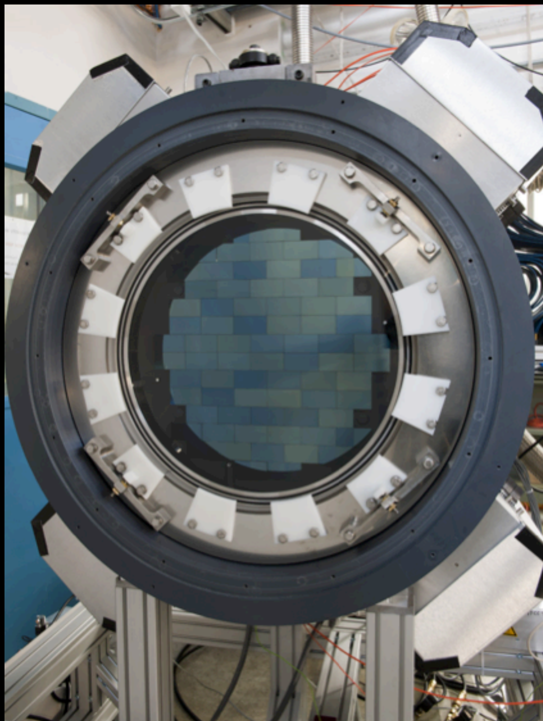
Survey starts in 2012, then runs 5 years

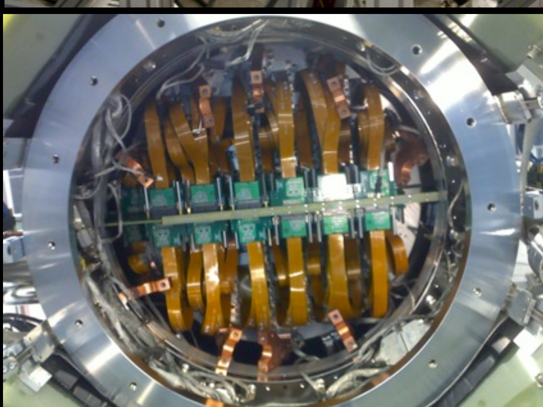


DECam under construction at Fermilab



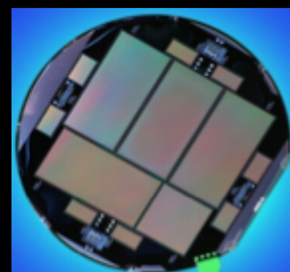
DECam Imager and CCD

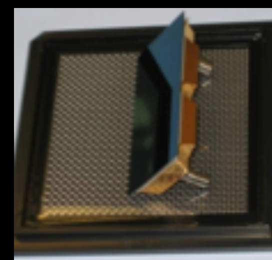


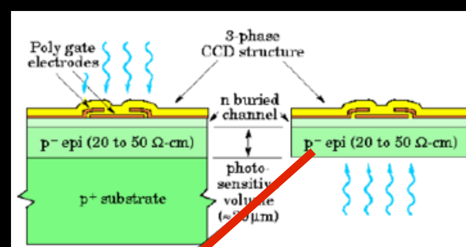


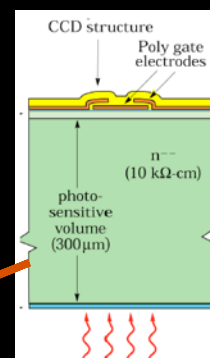
Most of the R&D of the imager is at Sidet of Fermilab

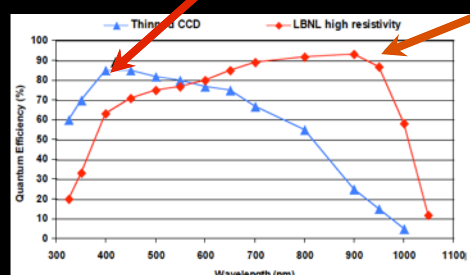
Sixty two 2k x 4k CCDs for imaging
Twelve 2k x 2k CCDs for focusing and guiding











Red sensitive CCD wafers designed by LBNL and processed at LBNL and DALSA

- QE > 50% at 1000 nm
- 250 microns thick
- Pixel size: 15 microns
- readout speed: 250 kpix/sec
- 2 RO channels/detector
- readout time: ~ 17 sec

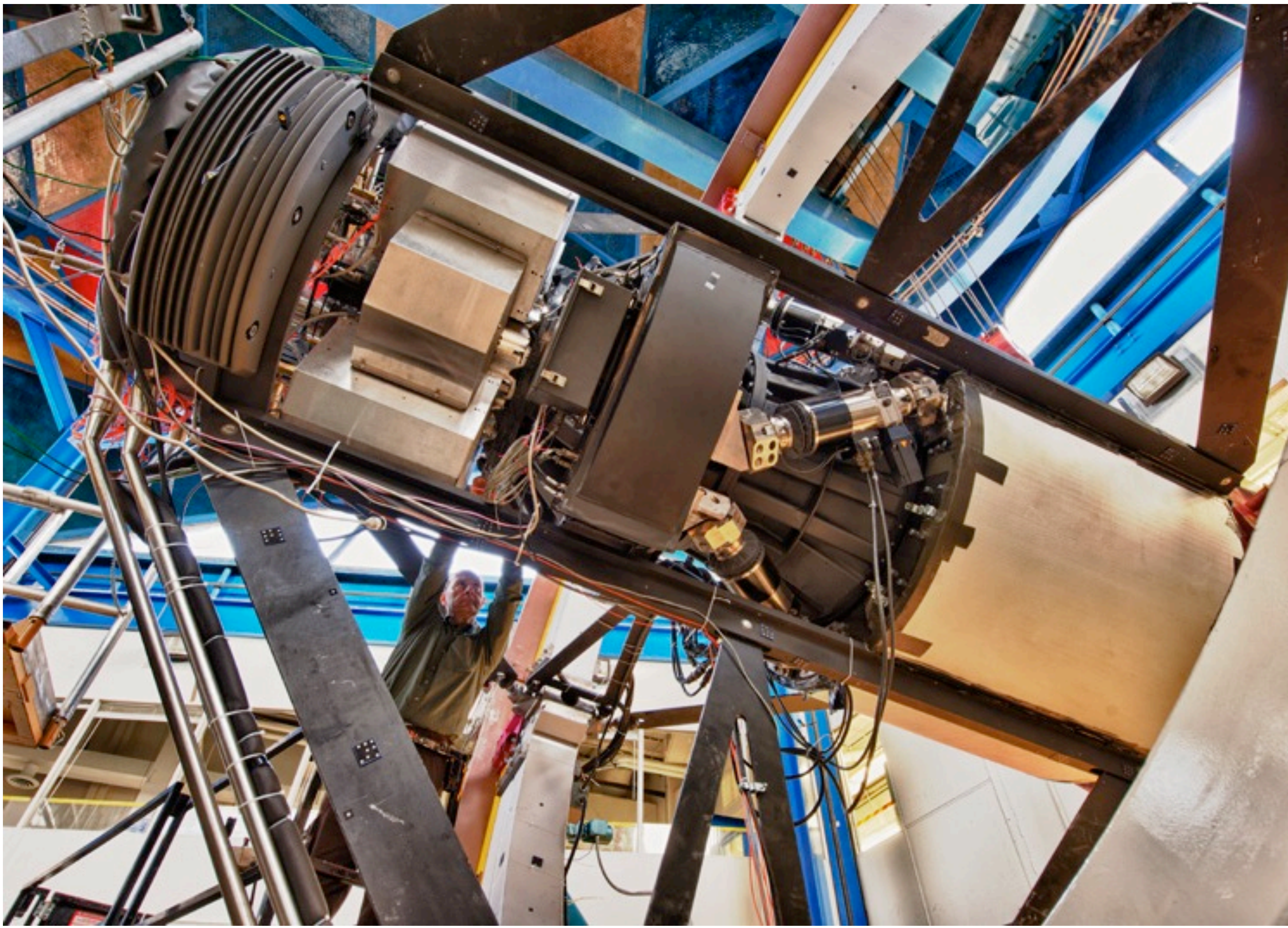
Bare diced wafters were delivered to Fermilab

CCDs are packaged and tested at Fermilab

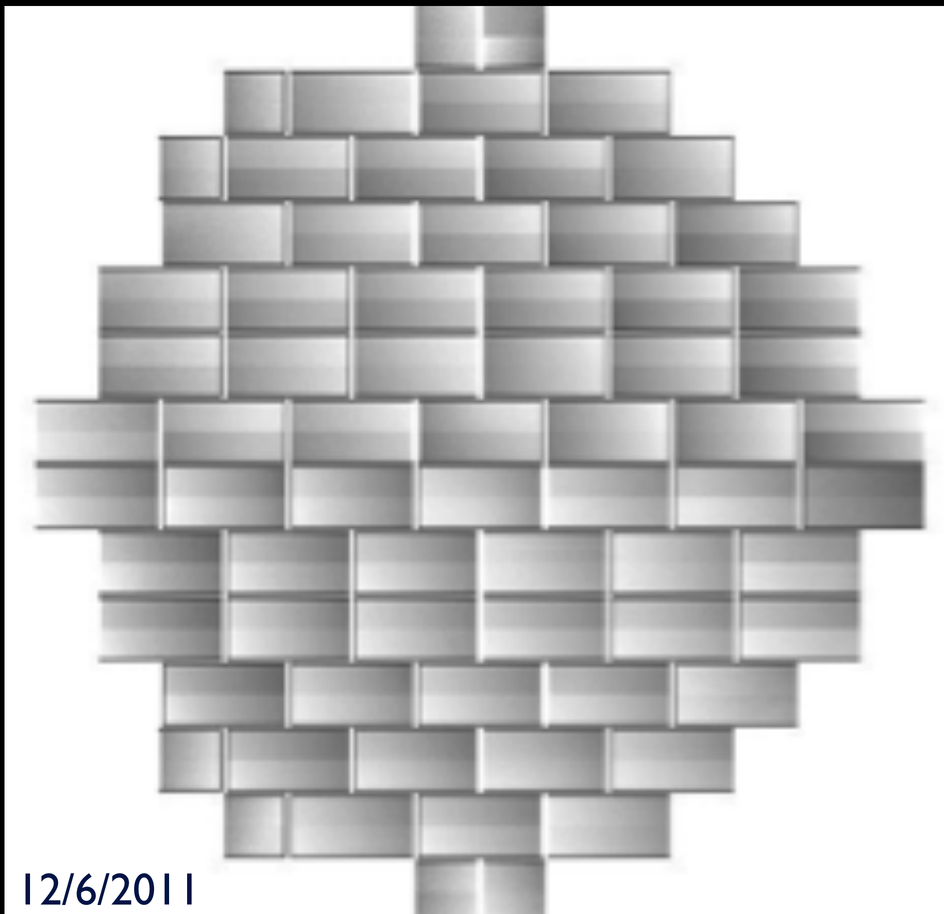
Size of **each** DECam CCD
62.94 mm x 30.72 mm

Size of iphone CCD: 4.54 mm x 3.39 mm

DECam at Fermilab



First DECam Flat Image@CTIO

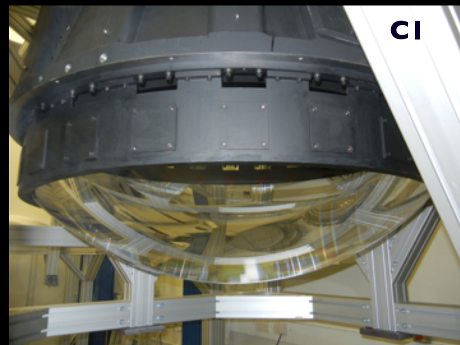


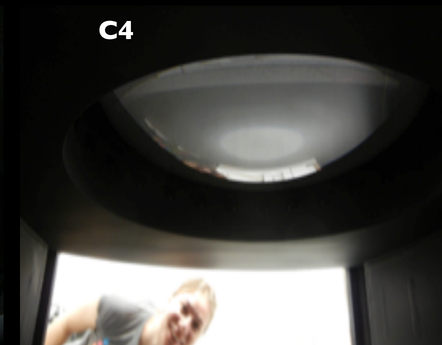
The old Mosaic Camera
at Blanco Telescope

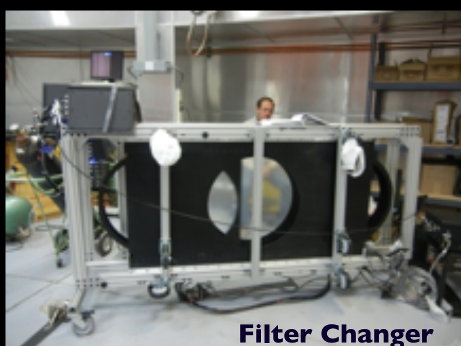
Successful Mock Observing to test the SISPI
and Imager readout @ CTIO control room

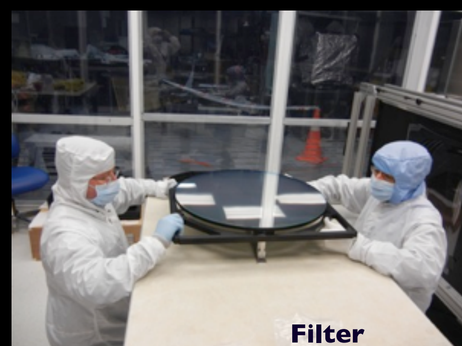
1/23/2012

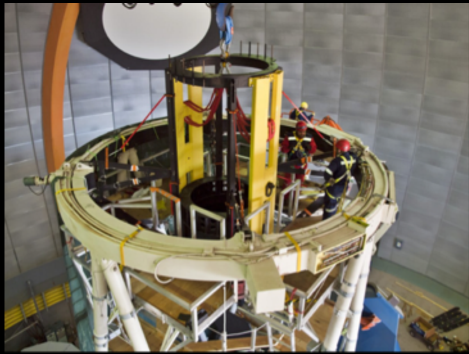
Other Parts @ CTIO, now being installed





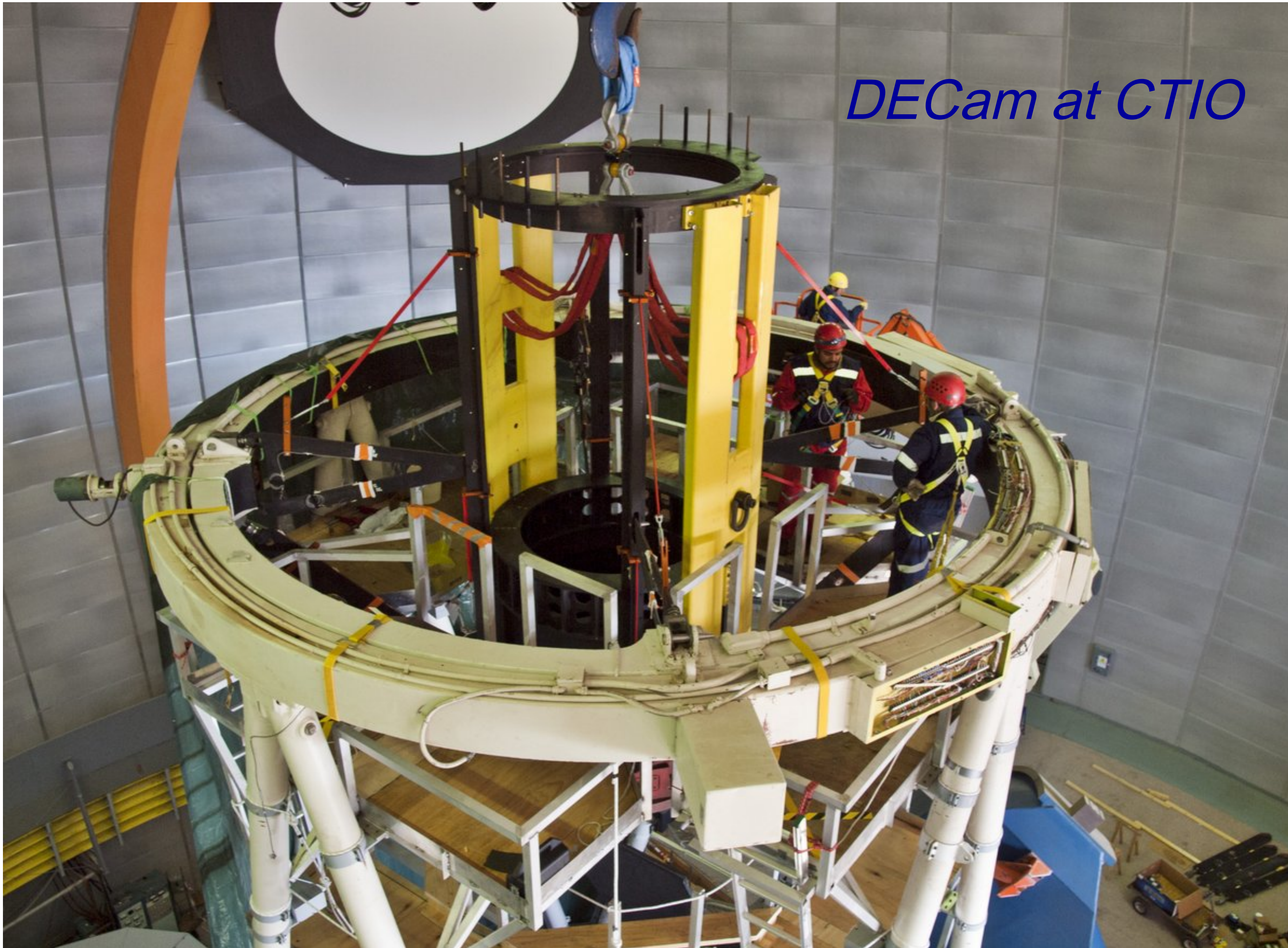






Assembly and installation of these parts are ongoing at CTIO now

DECam at CTIO



Dark Energy Survey (DES)

Science: probe dark energy using 4 methods:

- Galaxy Clusters
- Weak Lensing
- Large-scale structure including Baryon Acoustic Oscillations
- Type Ia Supernovae

Experimental set-up:
DECam: 570-Megapixel, 3 sq-deg FoV optical/NIR camera with 5-element optical corrector, mounted on Blanco telescope at Cerro Tololo Inter-American Observatory (CTIO) in Chile

DES will measure photometric redshifts and shapes for 300 million galaxies over 5000 sq-deg and 4000 SNe Ia to redshift z~1, largest digital survey to date
"Stage III" Dark Energy experiment

Collaboration: ~200 scientists from 5 countries

Partnership: US: DOE & NSF-AST, with contributions from Spain, UK, Brazil, Germany, and participating institutions

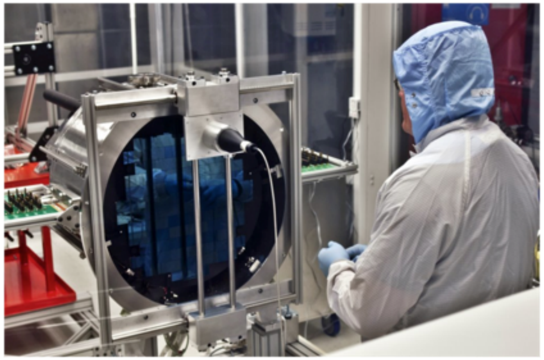
DES status and plans

Current Status:
Camera is being installed
CD-4 complete: June 6, 2012

Plan for future:

- First light for camera on the sky expected September 2012
- DECam commissioning Sept. 2012
- Science Verification observations Oct.-Nov. 2012
- Survey Starts December 2012
- Survey operations ~Dec. 2012-late 2017 (525 nights over 5 years)
- Initial science results 2013-2014

DECam imager at CTIO



Cleaning of DECam C1 lens at CTIO

DES operations

- New challenges
  - Unprecedented demands on CTIO and NCSA
  - May 2012 operations review highlighted need for better planning and coordination
- New plan for data management system
  - Fermilab is now contributing significantly to development
- New survey operations plan under development
- New functions for FNAL
  - Installation, testing, science verification, survey operations, data management, analysis and science support
  - FNAL scientists transitioning effort to new tasks

LSST

DOE camera project

- Led by SLAC; Fermilab proposes to build detector database

NSF project: everything else

- Led by AURA/LSSTC; Fermilab proposes to build parts of data management system: “develop use cases, requirements, and prototypes”

DOE/LSST Dark Energy Science Collaboration

- Now being formed; Fermilab proposes to build science analysis framework; FNAL scientists on collaboration

DES is a pathfinder

- Individual frames comparably deep, but 3X smaller, take 3X longer
- Real data like LSST will be flowing this year; impacts many LSST systems

Dark Energy Spectroscopy

- DES and LSST now almost assured
- "Rocky III" panel convened by DOE to recommend a path forward
  - Report this summer
- Likely agreement on wide, deep spectroscopic surveys as next step
  - Deeper than SDSS: back to $z>1$
  - Volume for statistics, depth for expansion history
  - Economical way to achieve Stage IV Dark Energy FOM
- BigBOSS now in R&D
- Successor to DES: DESpec

DESpec is Fermilab's next Dark Energy initiative

Why Spectroscopy

- "The universe is the detector"
- Benefits of higher resolution spectra
  - Redshifts: precise mapping in 3D, velocity structure, correlations
  - Character of sources
  - Absorption lines: line-of-sight gas
- Some DE science impacts are clear (e.g. BAO)
- Others are more subtle (e.g. modified gravity)
- Some are not yet dreamt of
- Like SDSS but deeper
  - Proven impact of SDSS comprehensive survey
- Spectra synergize with photometry
  - Sample selection is important
  - "tracking and calorimetry for the same events"

DOE Legacy: 3D map of cosmic web

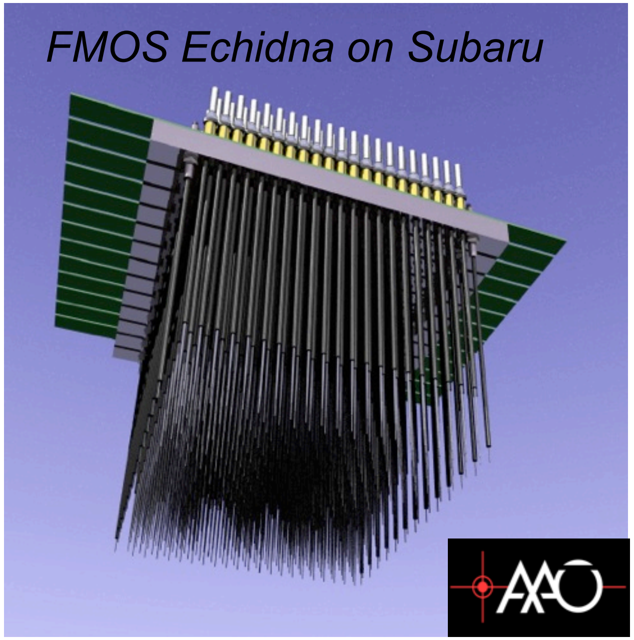
BigBOSS and DESpec will create a comprehensive map of all large-scale cosmic structure on our past light cone, since it formed… within a decade

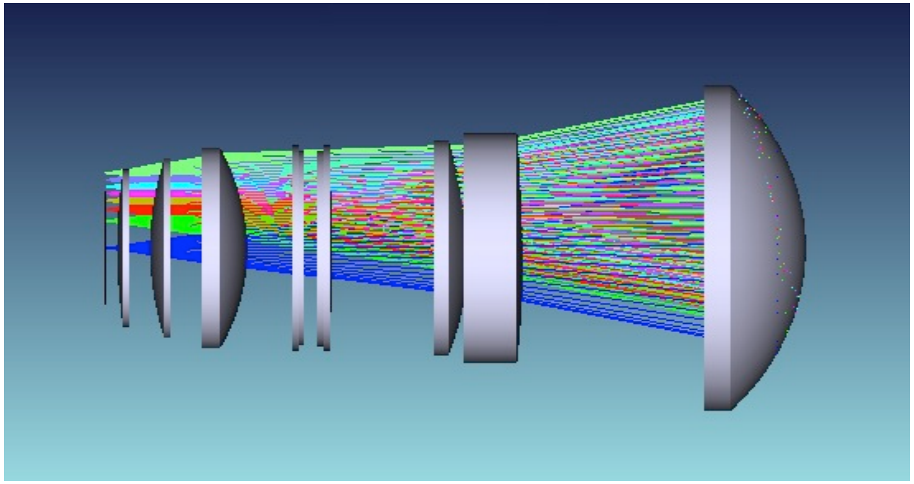
- Complete map of linear structure in *k* space
  - Power of many 3D modes for dark energy, inflation physics
- Two teams, two hemispheres
  - a feature not a bug
  - Independent techniques, confirmation
  - Faster progress
  - Synergy in R&D

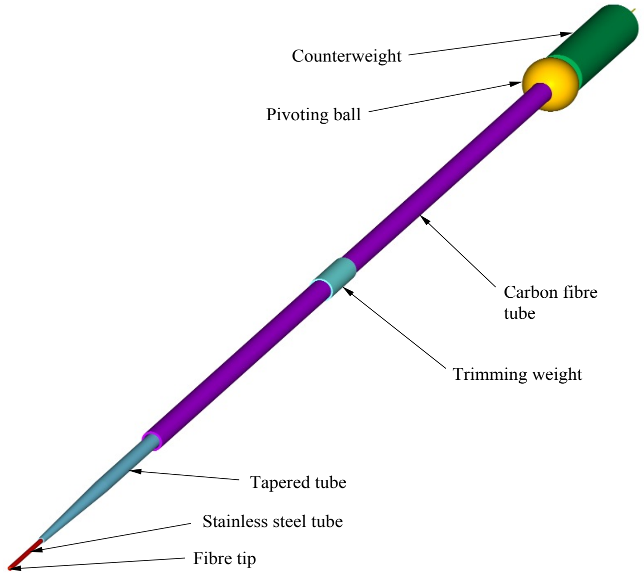
- What DOE does best: large scale, high quality, high impact and visibility, project discipline

Dark Energy Spectrometer (DESpec)

DESpec concept: build a new focal plane module with robotic optical fiber positioners, for simultaneous spectroscopy of ~4000 galaxies







DESpec Concept

- 4000-object prime focus spectrograph for the Blanco 4m, ***interchangeable with DECam imager***, 3.8 sq. deg. FOV
- Use DECam infrastructure (cage, barrel, hexapod, most optics, shutter, 20 spare CCDs,…)
- Redshifts for ~7 million DES galaxies (in ~270 nights), ~20 million from DES+LSST (~800 nights): critically sample linear structure
- Enhance Dark Energy reach of DES: Stage IV DETF
- Uniquely synergize with DES and LSST: same sky
- White paper with science case and baseline design in final draft
- Total construction cost ~$40M including 47% contingency
- workshop at KICP, May 30-31,

http://kicp-workshops.uchicago.edu/DESpec2012/index.php

Strong points of DESpec

- High performance, low cost, low risk
  - CTIO Site, DECam components in place
  - Other proven heritage, e.g. fiber positioning system
- Synergy in southern hemisphere
  - Retain use of DECam
  - DES, LSST: quality targets/optimal survey design
  - Enhances DES, LSST science reach
  - Gemini, ESO/VLT, LCO, etc: followup
  - SPT, ACT, SKA: CMB lensing/correlation, 21cm
  - competition in southern hemisphere: ESO 4MOST proposal
- Strong team
  - Includes DES partners, e.g. UCL (optics), TAM (spectrographs)
  - AAO: world experts on massive robotic fiber surveys

Weak point of DESpec

- Access to the telescope is not yet arranged

  This is the main obstacle to progress

- Reason for optimism: almost everyone *should* want this to happen
  - Broad impact, many users (like SDSS)
  - High science per dollar
  - Best use for Blanco in LSST era taking advantage of wide field; best way to complement LSST
  - We have kept quiet pending AST portfolio review
  - Quiet phase should end now
  - Need to resolve the access issue

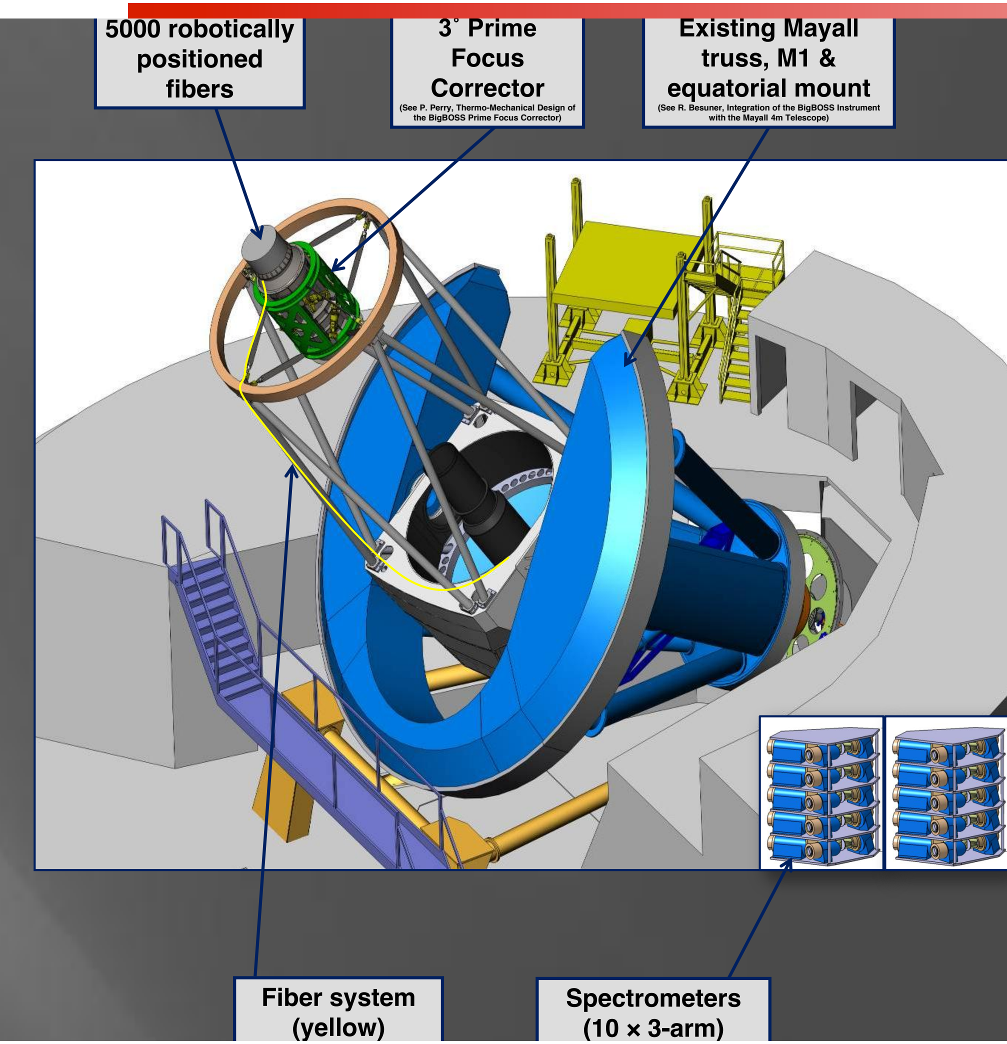
Next Steps for DESpec

- Ongoing, iterative and parallel activities at Fermilab and partner institutions:
  - Develop science case(s)
  - Detailed survey design, operations model
  - Detailed instrument reference design
  - R&D on some subsystems
  - detailed engineering and costing
  - Build partnership, community
- Proposal preparation this summer
  - Upgrade white paper: engineering cost estimates
  - PAC already recommended a Director's Review
  - Will implement this and seek Stage I approval

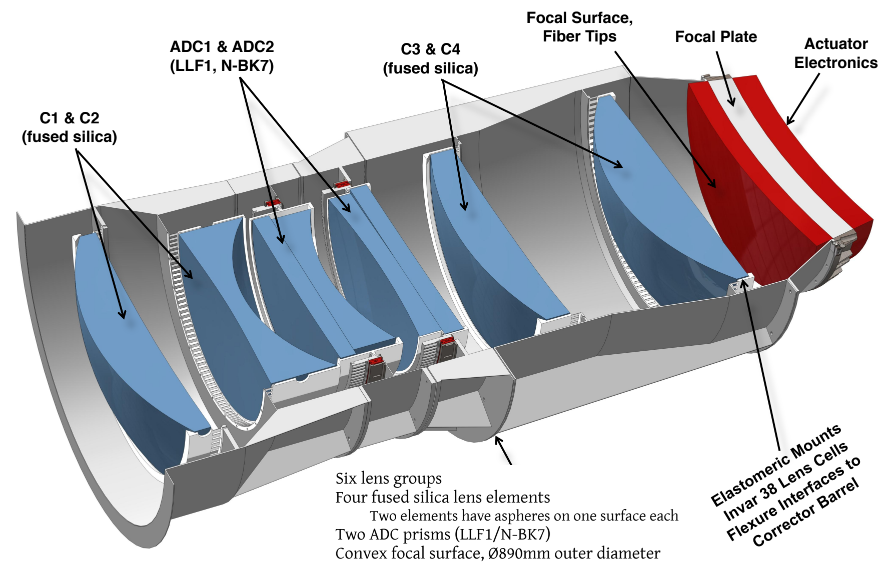
BigBOSS

- Similar concept and science reach to DESpec
  - Led by Berkeley Lab
  - Starts from scratch (no DECam parts)
  - Mayall telescope on Kitt Peak, near twin of Blanco at CTIO
  - Northern Hemisphere
- DES will produce some targets for BigBOSS
  - DES survey modified its footprint-- nudged north
  - ~500 square degree overlap now planned
  - Other target selection from SDSS, WISE, PTF, PanSTARRS
- Fermilab technical roles in BigBOSS
  - Packaging/testing of CCDs, design/construction of corrrector
  - Fermilab lead scientist not part of DESpec
- Fermilab is planning on both surveys
  - Complementary timelines, designs, scope, hemispheres
  - Downselect, descope or merger might be necessary, but now is too early
  - Designs are highly modular, much technology is shareable

BigBOSS



BigBOSS 3° wide-field corrector



Dark Energy strategy: summary

Dark Energy Science

Support (operations, computing, software, consulting, interaction) for DES collaboration; visitors program; will evolve into LSST role

Wide, Deep Spectroscopic Surveys

Fermilab **will lead DESpec** and participate in BigBOSS; opportunity for historic DOE legacy

Large Synoptic Survey Telescope

Fermilab technical roles in camera and data management, and participation in LSST Dark Energy Science Collaboration

WIMP Dark Matter Detection

Basic principle: detect collisions of Galactic Weakly Interacting Dark Matter particles with nuclei

Basic challenge: rare events require exquisite control of experimental backgrounds

Advances require larger detector masses with zero background

Detectors now have sensitivity to make a discovery

Mass and detailed interactions of particles are unknown; pursue multiple technologies now, downselect later

WIMP Dark Matter at Fermilab

CDMS: Cryogenic Ge detectors have demonstrated background rejection and have excellent sensitivity to low-mass WIMPs

G1: 10 kg, Soudan G2: 100 kg, SNOLAB G3: 1500 kg, ??

COUPP: Bubble chambers promise best spin-dependent WIMP discovery potential

G1: 60kg, SNOLAB G2: 500 kg, SNOLAB G3: ??, ??

Darkside: Liquid argon has best intrinsic background rejection and may be the right path towards high-mass WIMP discovery

G1: 50 kg (Gran Sasso) G2: 1000 kg, Gran Sasso G3: 10000 kg, ??

Generation 2 experiments reach the middle of the theoretical range expected for "standard WIMPs"

CDMS – Cryogenic Dark Matter Search

Science: Direct Detection of Weakly Interacting Massive Particles (WIMPs) that may make up Dark Matter

- ‘Conventional’ WIMP candidates (MSSM, Kaluza-Klein)
- ‘Dark sector’ particles (low-mass WIMPs)
- Axions from the sun and/or the galaxy
- Lightly-ionizing particles

Basic experimental setup: Ge crystals with charge and phonon sensors, operated at cryogenic temperatures, surrounded by layered shielding in a deep underground laboratory

- DOE provided the Soudan infrastructure, cryogenics, shielding and much of the detector payload

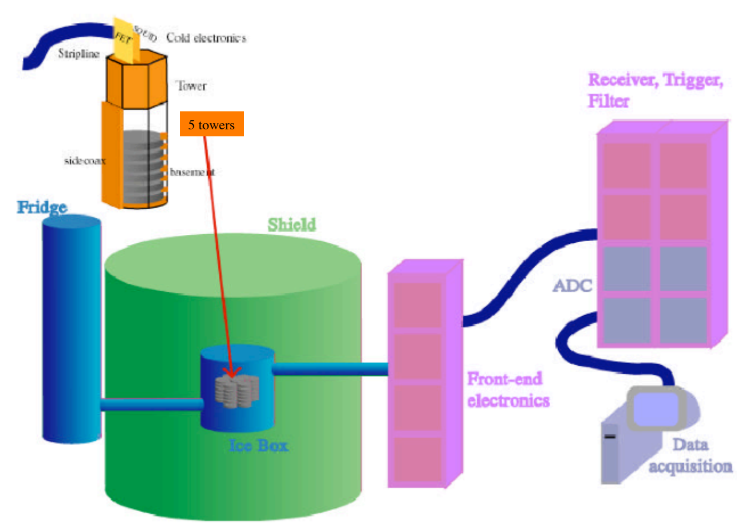
Collaboration: 80 scientists from the US and Canada

Partnership: US (DOE, NSF) with contributions from Canada

Current Status:
CDMS II operated at Soudan from 2004-2009 with 4 kg payload
SuperCDMS Soudan will operate with 10 kg 2012-2013
FNAL manages operations with DOE funding

Recent News:
New results on low-mass WIMPS and annual modulation

Plan for future:
SuperCDMS SNOLAB 100 kg will be proposed in G2 process



Schematic of the CDMS experiment

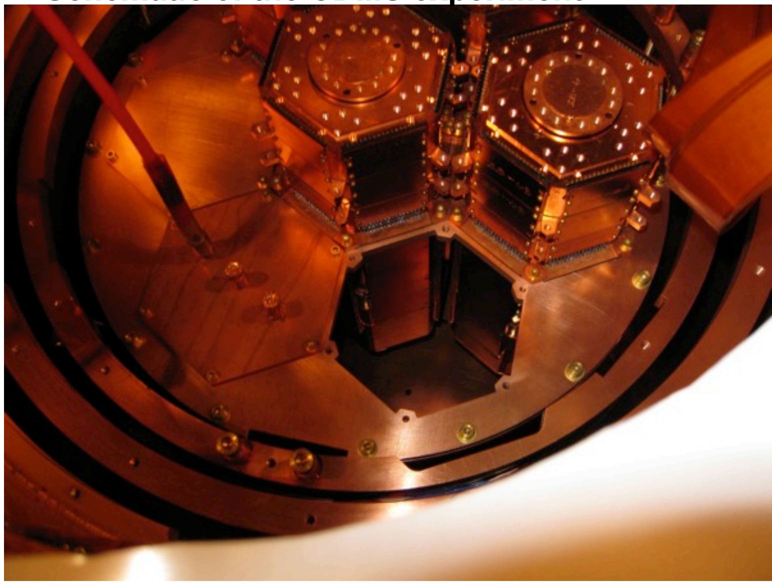


Photo showing iZIP tower installation at Soudan

CDMS – Cryogenic Dark Matter Search

Science status & recent results:

Continuing to extract interesting science from CDMS-II data, especially concerning low-mass WIMPS

2011 Highlights:

Analysis of data between trigger threshold and previous analysis threshold allowed greatly improved limits on low-mass WIMPs

Rule out DAMA/LIBRA and CoGeNT WIMP signals

Statistical analysis of CDMS rates revealed no significant annual modulation, again in conflict with purported WIMP signals from DAMA/LIBRA and CoGeNT

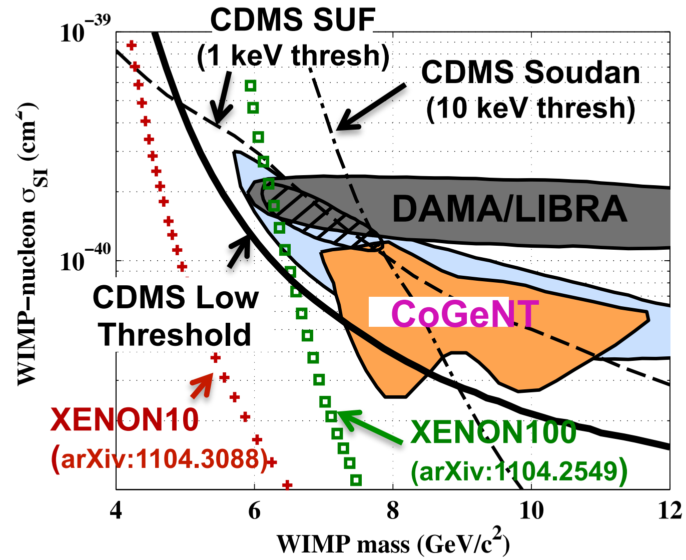
2012 Plan:

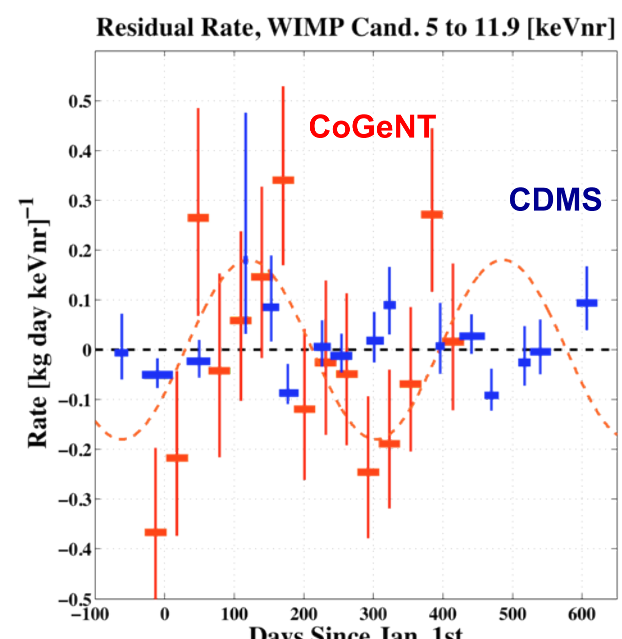
Analysis of first data from SuperCDMS Soudan to determine background rejection power of new iZIP detectors

Future Plans:

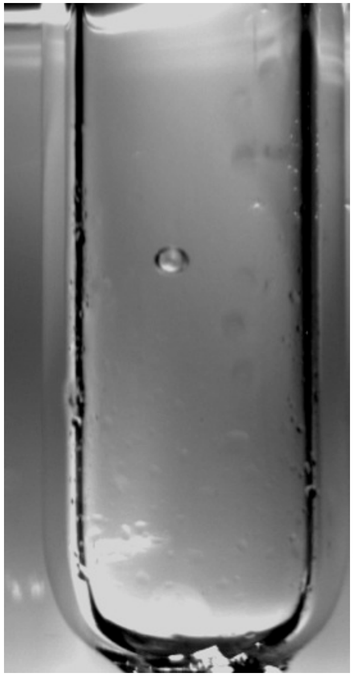
Two year data set from SuperCDMS Soudan will yield x5 improvement in WIMP sensitivity compared with CDMS II

SuperCDMS SNOLAB will provide another order of magnitude improvement in WIMP sensitivity





COUPP- Chicagoland Observatory for Underground Particle Physics



Detection of WIMP dark matter particles with bubble chambers. Thermodynamic conditions for bubble nucleation are manipulated to make chambers insensitive to gamma backgrounds.

COUPP-4kg: Currently operating deep underground at SNOLAB. First results announced in 2011.

COUPP-60kg: Installation in 2012.

Collaboration: 20 scientists from University of Chicago, Fermilab, Indiana University, SNOLAB, Virginia Tech.

Partnership: DOE, NSF, SNOLAB (Canada). DOE providing management and most construction resources.

Plan for future: Proposed COUPP-500 would increase target mass and sensitivity by an order of magnitude. R&D funded by NSF-S4.

COUPP- Chicagoland Observatory for Underground Particle Physics

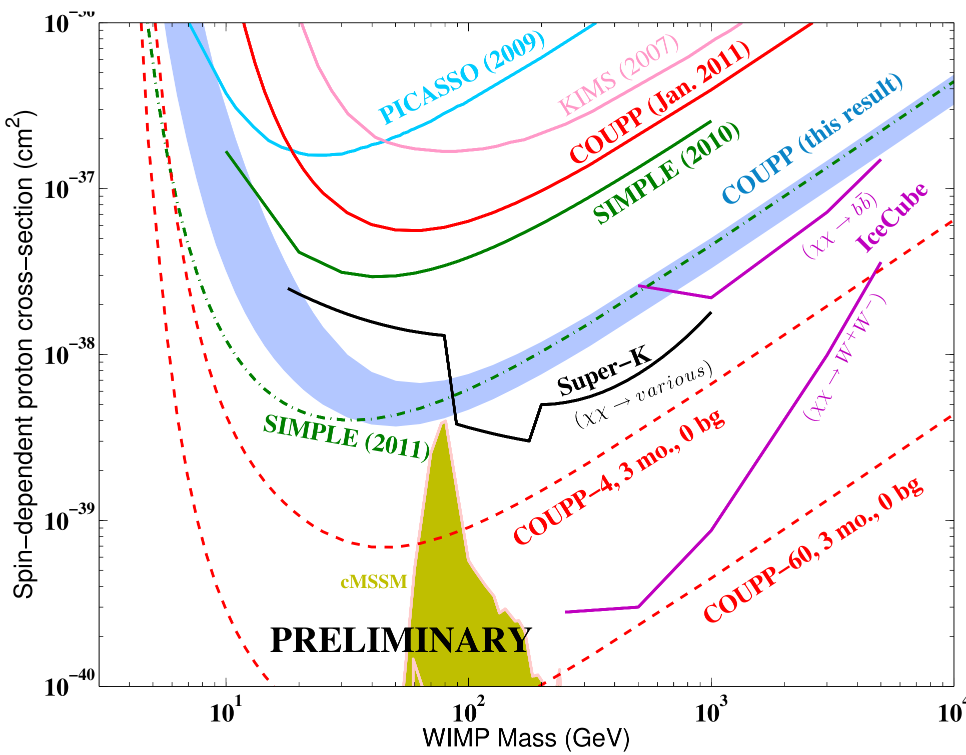
First results from COUPP-4 at SNOLAB

- In 553 kg-day exposure: 20 single-bubble nuclear recoil candidate events and 3 multiple bubble events from neutrons.
- New acoustic measurement technique rejected backgrounds due to alpha particles at >99% level.
- World's best cross section limits for spin-dependent WIMP-proton scattering above 20 GeV.

2012 plan

- Increase sensitivity of COUPP-4 by replacing neutron-emitting components.
- Improved calibrations to reduce efficiency uncertainties.
- COUPP-60 to begin operation at SNOLab.

Spin-dependent WIMP Limits



DarkSide-50 (FNAL E-1000)

Science Search for Dark Matter in the form of Weakly Interacting Massive Particles

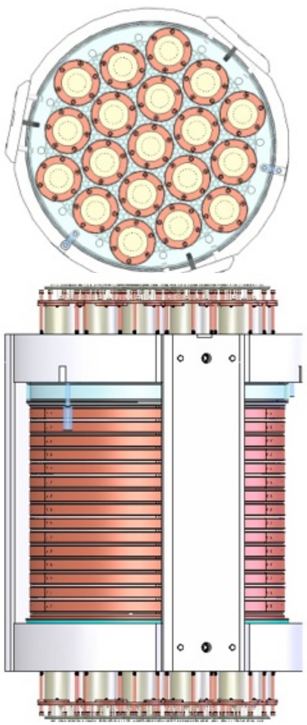
Experiment setup:
50 kg low radioactivity liquid Argon dual-phase TPC (left below) inside a 4m spherical Neutron Scintillator Veto (left center) inside an existing 10 m high and 11 m diameter cylindrical Water Tank (right center) under a mountain (right) at the Laboratori Nazionali del Gran Sasso (LNGS), Italy. **Key features** are the use **of low radioactivity Argon, low radioactivity photosensors**, and a highly efficient **Neutron veto using boron-loaded scintillator**.

DOE funds the Argon detector, the Argon system, management, and PMTs for the Neutron Veto.

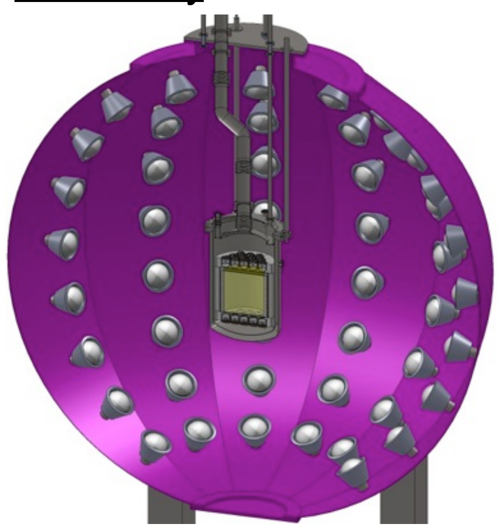
Collaboration: 60 scientists from China, Italy, Russia and the U.S.A.

Partnerships: US (DOE, NSF) with major contributions from I.N.F.N.

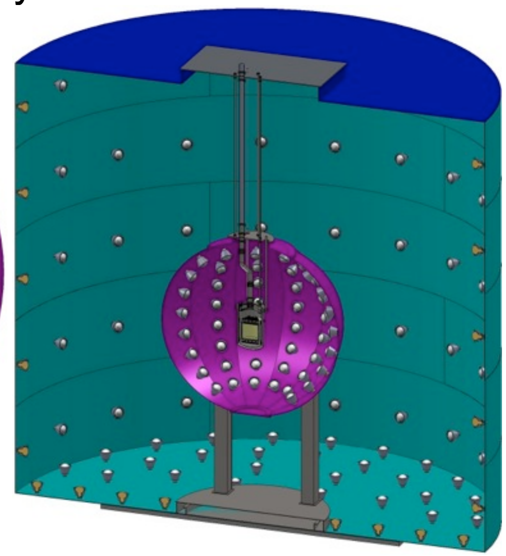
Sensitivity: 10^{-45} cm^2 in 3 year run



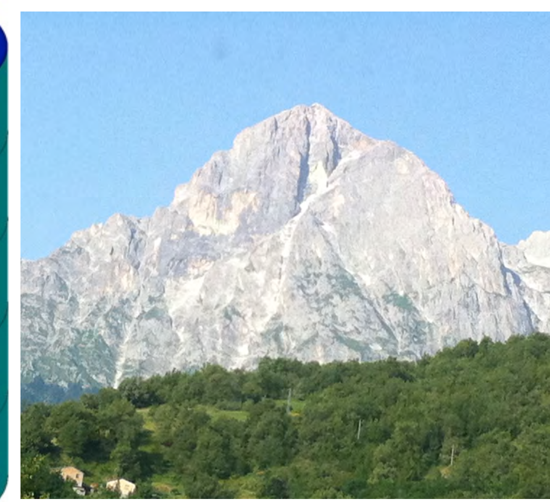
Dual-Phase TPC



4 m diameter Neutron Veto



10 m x 11 m Water Tank



4000 m Mountain

DarkSide-50 (FNAL E-1000)

Current Status: .

Final design and construction of components ongoing in Italy and the U.S.

Prototype - DarkSide-10 - operating at L.N.G.S. since 6/2011

Purification of argon by distillation to >99.95% (At FNAL)

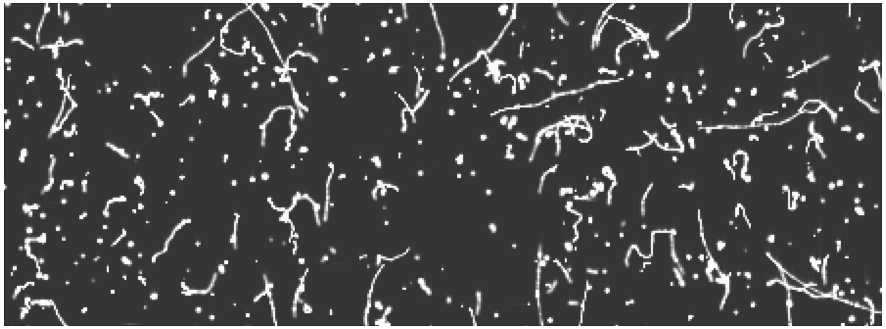
Schedule: Start commissioning at end of 2012.

DS-10 Assembly at LNGS

DS-10 Cryostat in water shield at LNGS

Argon Purification plant at Fermilab

DAMIC: Dark Matter with CCDs



Juan Estrada's PECASE project: use DECam CCDs as state of the art detectors for low mass WIMPs

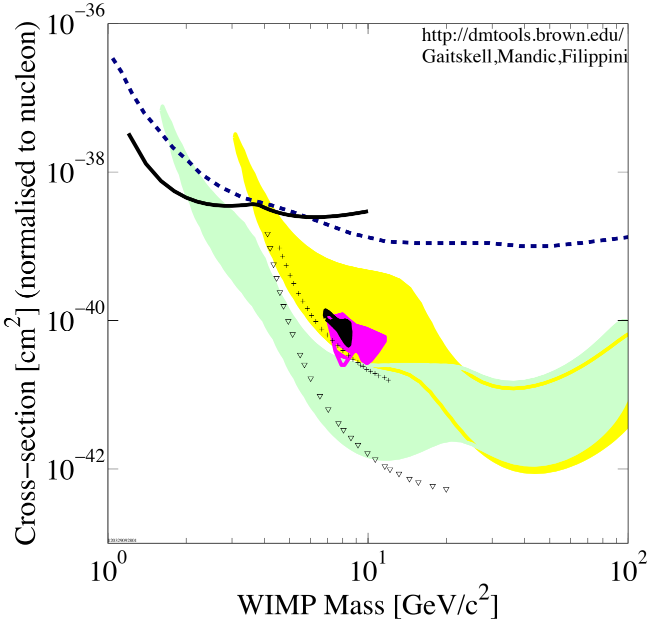


FIG. 13: Cross section upper limit at 90% C.L. for the DAMIC results (solid black) compared to CRESST 2001 (dashed blue), XENON10 [40] (triangles) and CDMS [41] (crosses). The shaded areas correspond to the 5-sigma contour consistent with the DAMA/LIBRA annual modulation signal (yellow: no ion channeling, green: ion channeling) [39]. The magenta contour corresponds to the DM interpretation of the CoGent observed excess and the black contour is the region of interest for the CoGent annual modulation signal [4].

WIMP Dark Matter strategy

DOE plans community-led strategy on direct and indirect detection

G2 R&D competition underway this spring (NSF) and summer (DOE)

Successful projects will be funded for R&D in FY13

Downselect at end of FY13 for construction phase in FY14 MIE

FNAL projects are all contenders

Fermilab plans to stay with WIMPS at least to the G3 scale

Pursue technology now in R&D: DAMIC (CCD)

Highest Energy Cosmic Rays – Pierre Auger

World's leading experiment on the highest energy particles, fully operational since 2008

Fermilab is the lead lab in a large international consortium

Energy spectrum

- Seeing the GZK cutoff or learning about sources?

Anisotropy

- Do the highest energy cosmic rays point towards matter concentrations? Can we learn about the acceleration mechanism?

Composition

- Learning about sources, or something new in hadronic cross sections at the highest energies? Comparison with LHC: Auger center of mass collision energies up to ~100 TeV

Pierre Auger Observatory

Observatory: installed over a 3000 km^2 site in Argentina – data taking started in 2004

24 fluorescence telescopes;

1600 surface Cherenkov detectors;

Enhancements: 3 high elevation fluorescence telescopes, 60 infill detectors, muon counter array.

Collaboration & Partnership: Large international collaboration of 19 institutions, 463 people. Fermilab hosts the Project Office.

High Energy Particle Strategy

December 2011 Director’s review commended achievements and continued value

Recommends continued support for next 2-3 years, with review of DOE participation following that

Continued participation must be more than just management; possible new radio technologies for shower measurement

No current plans to hire additional staff in this area

Quantum Geometry and Unification

Laboratory experiments address new fundamental physics (matter, energy, space and time), far beyond the TeV scale

Fermilab Holometer will probe Planck-scale quantum geometry

Dual, correlated 40-meter Michelson interterferometers now under construction, first science results expected next year

Future experiments may explore new interactions of axion-like particles, dark sector photons, or other BSM effects

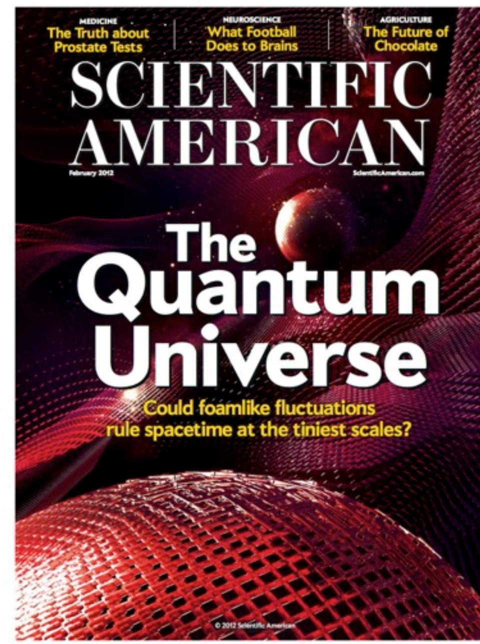
Fermilab E-990: Holometer

Science: Planck scale physics of space-time

- Holographic information content normalized by black hole entropy bound
- New collective position degrees of freedom in emergent space-time
- Exotic transverse position noise predicted to grow with propagation distance
  → Needs large, 2D, high frequency apparatus

Basic experimental setup:
Two neighboring 40m Michelson interferometers measure correlated beamsplitter position jitter at MHz frequency
Sensitivity limited by photon shot noise $<10^{-20}$ m/rtHz
(Planck spectral density)

Collaboration:
20 scientists/students from 5 institutions
Funding: DOE, NASA, NSF,
Aaron Chou DOE Early Career Award



NOT quantum foam!

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Holometer status and plans

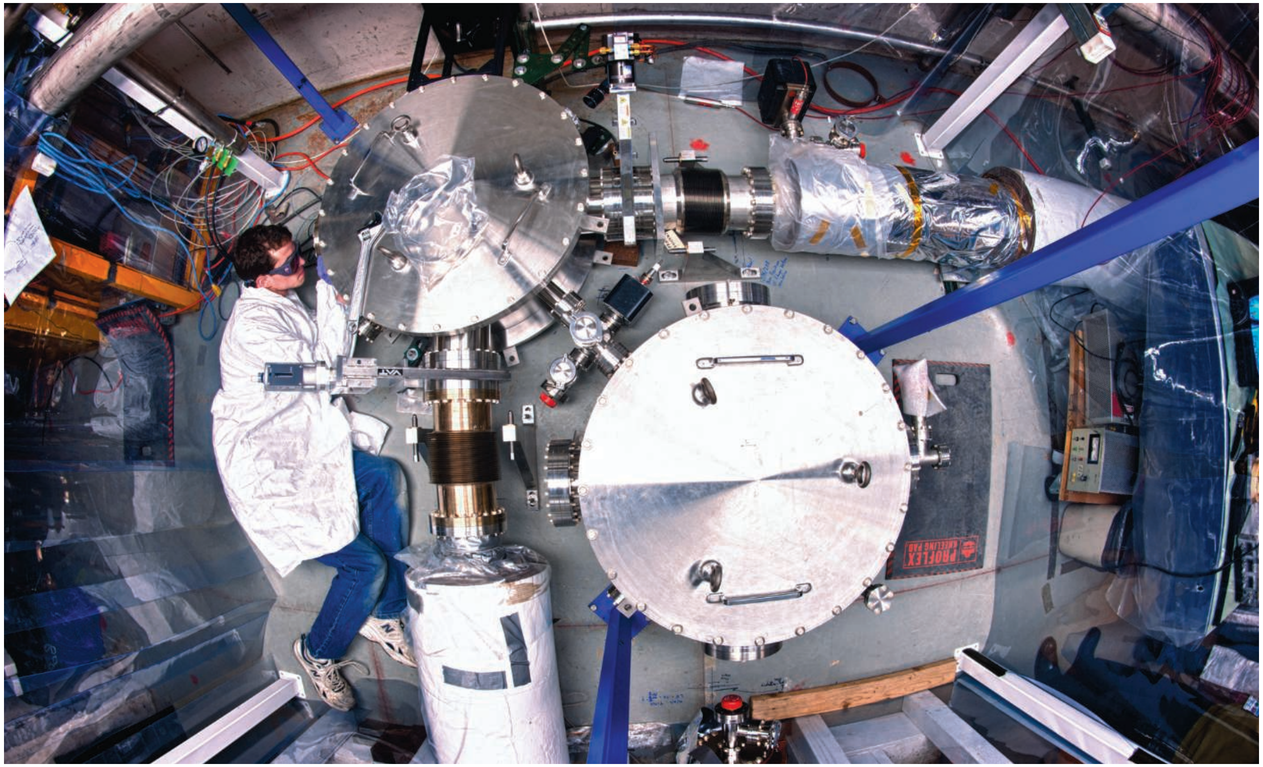
Status:

100W power-recycled interferometer demonstrated
5-arm vacuum system complete
Commissioning LIGO digital control system

2012-13 plan
Operate two interferometers in nested configuration
Begin to probe space-time behavior in a never-before-tested regime

Future:
Goal is sub-Planck position noise spectral density
If non-conventional noise detected, test consistency with the noise model
-- Check predicted spectral features
-- Use back-to-back configuration to null the signal
-- Check predicted scaling with interferometer length

Not a test of the holographic principle!
Drives theorists nuts!



Hands-on. Student Benjamin Brubaker tinkers with the Fermilab holometer.

Not everyone cheers the effort, however. In fact, Leonard Susskind, a theorist at Stanford University in Palo Alto, California, and co-inventor of the holographic principle, says the experiment has nothing to do with his brainchild. "The idea that this tests anything of interest is silly," he says, before refusing to elaborate and abruptly hanging up the phone. Others say they worry that the experiment will give quantum-gravity research a bad name.

Black holes and causal diamonds

To understand the holographic principle, it helps to view spacetime the way it's portrayed in Einstein's special theory of relativity. Imagine a particle coasting through space, and draw its "world line" on a graph with time on the vertical axis and position plotted horizontally (see top figure, p. 148). From the particle's viewpoint, it is always right "here," so the line is vertical. Now mark two points or events on the line. From the earlier one, imagine that light rays go out in all directions to form a cone on the graph. Nothing travels faster than light, so the interior of the "light cone" contains all

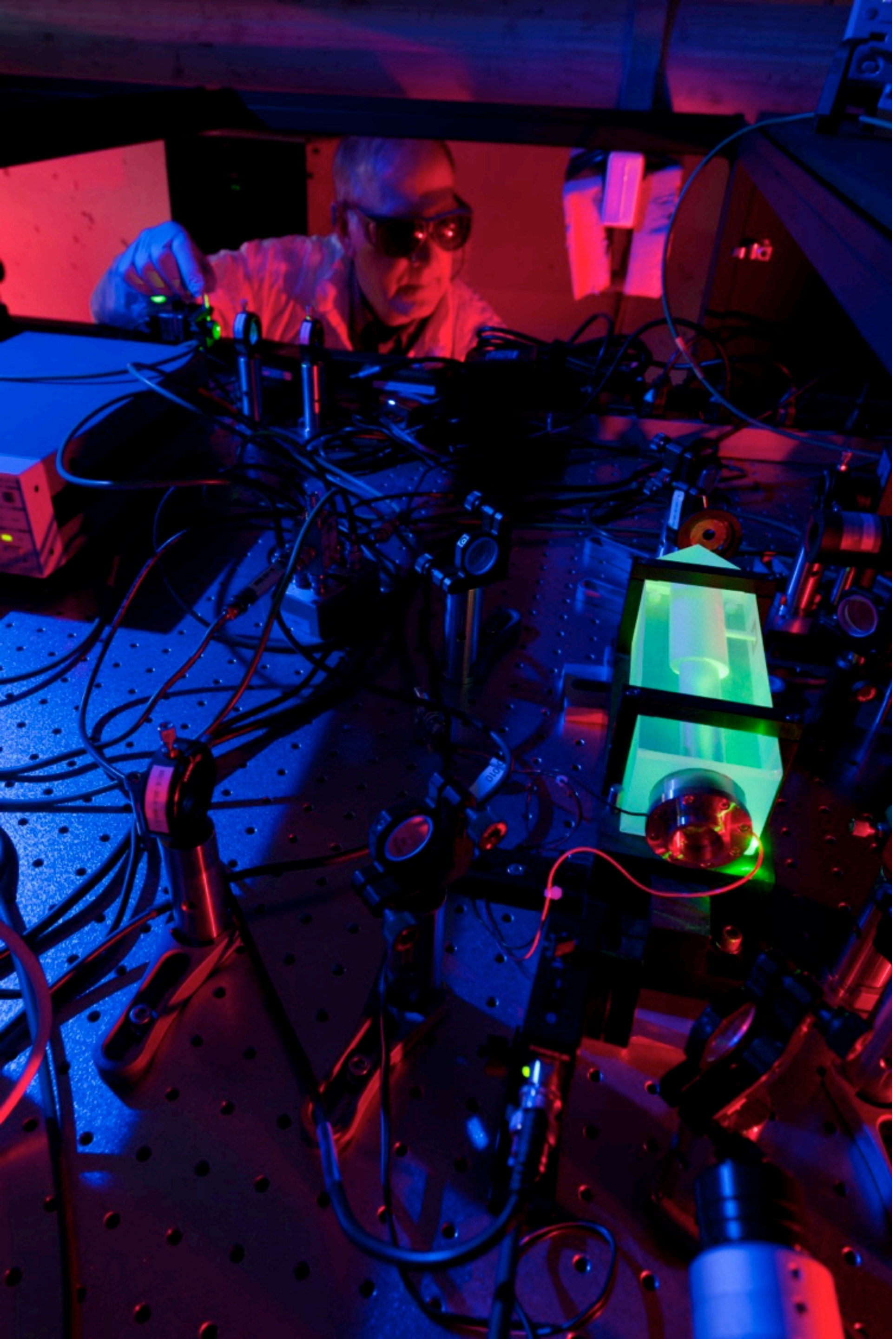
PHYSICS

Sparks Fly Over Shoestring Test Of 'Holographic Principle'

A team of physicists says it can use lasers to see whether the universe stores information like a hologram. But some key theorists think the test won't fly

BATAVIA, ILLINOIS—The experiment looks like a do-it-yourself project, the scientific

in a room increases with the room's volume, not the area of its walls. If the holographic

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Quantum Geometry strategy

- Holometer experiment active for next 2 or 3 years
- Terminate after sub-Planck scale limit is achieved (determined by photon shot noise)
- If signal suggests presence of quantum-geometrical fluctuations, follow up with longer arms, better null configurations, and other improvements
- If no fluctuations are detected at sub-Planckian level, apply laser technology to search for axion-like particles, dark-sector photons, or other physics beyond the standard model
    - Experimental configurations now being explored

Long Term Cosmic Frontier Strategy

Dark Energy: likely to dominate FNAL effort into the next decade; will advance into massive spectroscopic surveys

Dark Matter: up to ~10 ton scale over the next decade, then move on if no WIMPs

Highest Energy Particles: FNAL will likely phase out over time

Holometry/Unification: plan depends on what we find in next few years

Other new things: CMB possible if a suitable Fermilab role emerges; DAMIC or other new dark matter technologies may move forward, depending on what we find