DECam
A New Instrument for the Dark Energy Survey

Klaus Honscheid, Ohio State University
DPF 2009, Detroit
For the DES Collaboration

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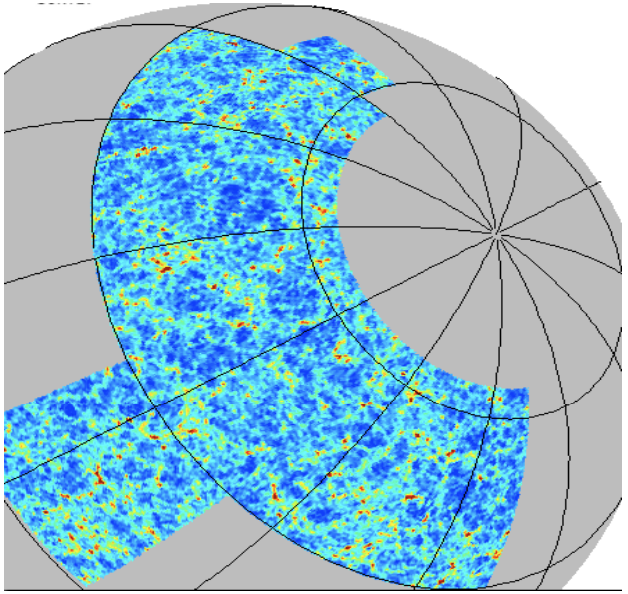
The Dark Energy Survey

- Project:
  - Perform a 5000 sq. deg. survey of the southern galactic cap using the CTIO Blanco 4-m telescope.
  - In 5 filter bands (u,g,r,i,Y) plus near-infrared information from the VHS Vista Survey.Expect $\Delta z \sim 0.02$ for galaxy clusters up to redshifts of z ~ 1.3
  - Measure dark energy with 4 complementary techniques

    Cluster counts, weak lensing, baryonic acoustic oscillations, supernovae



- New Instrument (DECam):
  - Replace the PF cage with a new 2.2 FOV, 520 Mega pixel CCD camera and optics

- Time scales:
  - Instrument Construction 2008-2011
  - Survey: 525 nights during Oct.–Feb. 2011-2016
  - 30% of the telescope time

The Blanco 4m Telescope on Cerro Tololo

CTIO is in the process of upgrading the Blanco 4 m telescope :

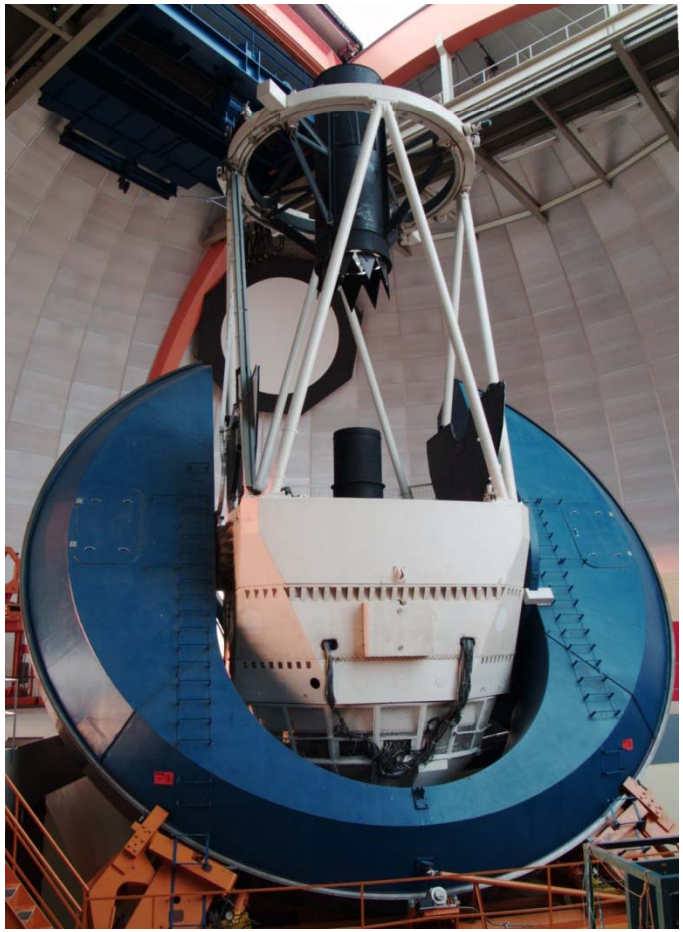
New Control System

- Slew specification: 2º in less than 17 seconds
- Tracking drift < 0.5”/min; jitter < 0.1” rms
- Accept 1 Hz guiding corrections

Repair primary mirror support

Status:

- (Almost) Complete
- Commissioning under way



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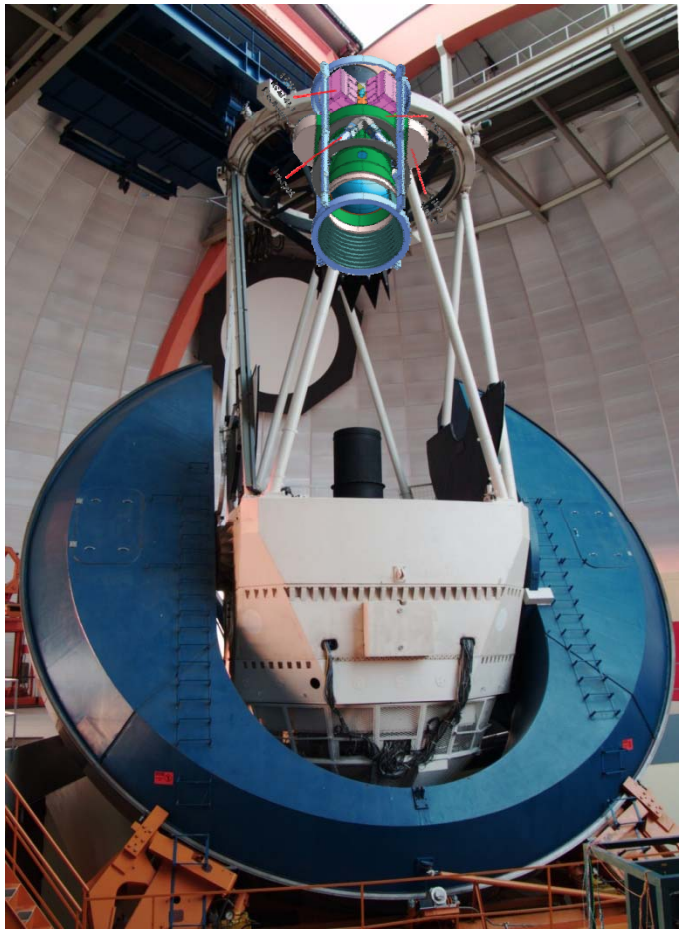
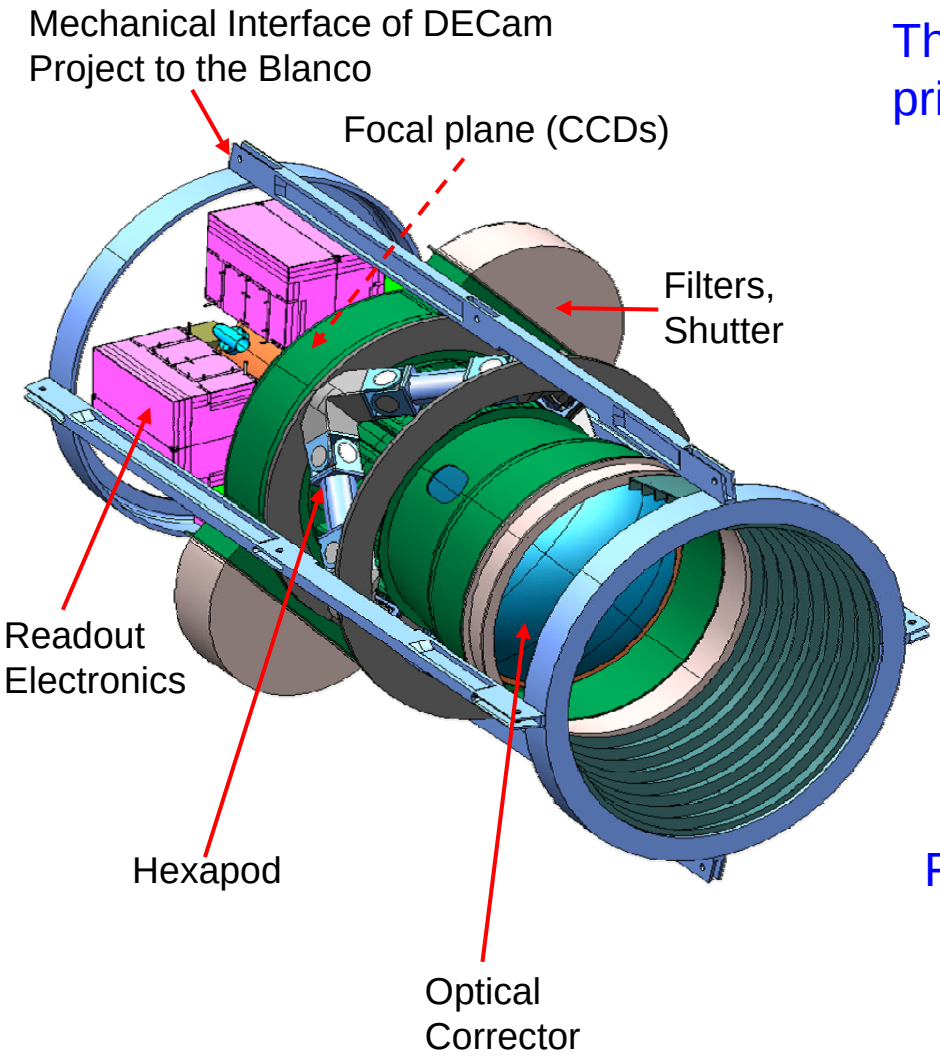
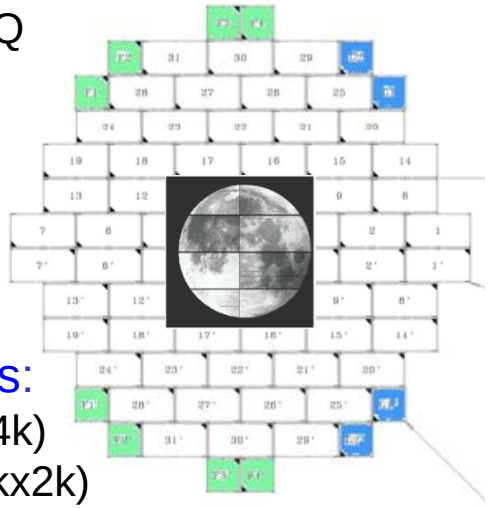


The DECam Instrument



The DECam instrument will replace the entire prime focus cage of the Blanco.

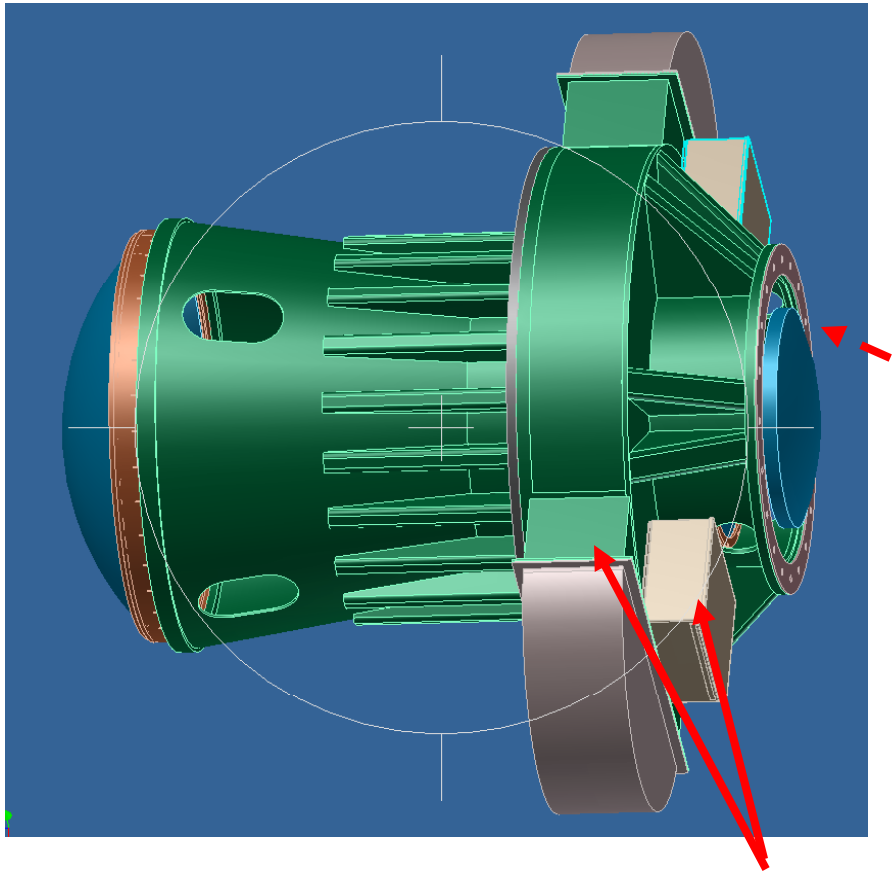
- 520 megapixel CCD camera
  (QE > 65% for 800<λ<1000)
- Low noise electronics (< 15 e- noise)
- Combination shutter-filter system
- Wide field optical corrector (2.2 deg. FOV)
- Hexapod to provide adjustability
- High performance DAQ

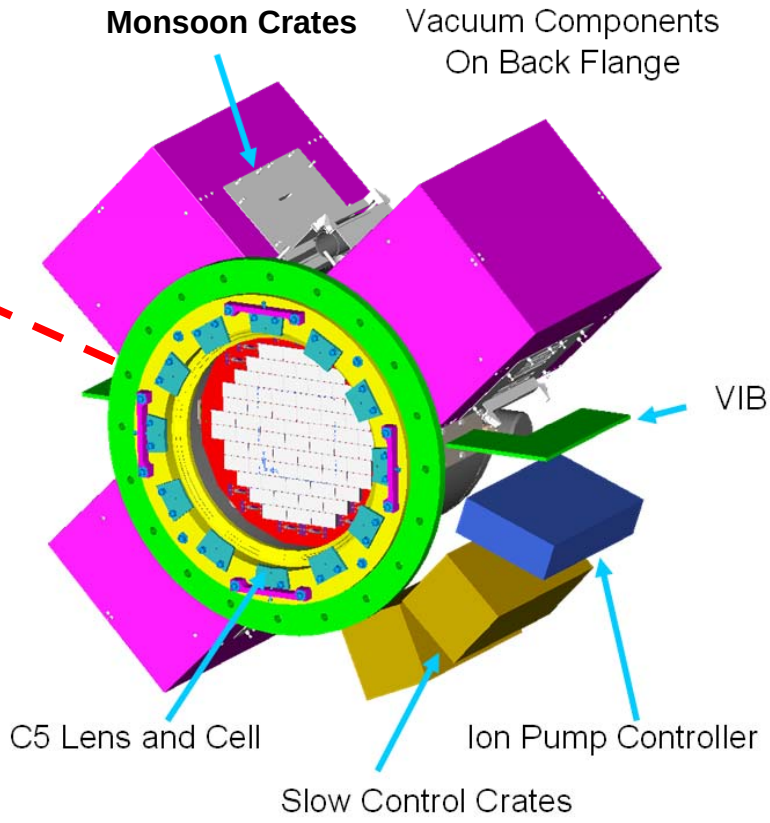


Focal plane parameters:

- 62 Image CCD (2kx4k)
- 4 Guide, 8 Focus (2kx2k)
- Pixel size 0.27” /15μm
- Readout speed 250 kpix/s

Instrument Close Up





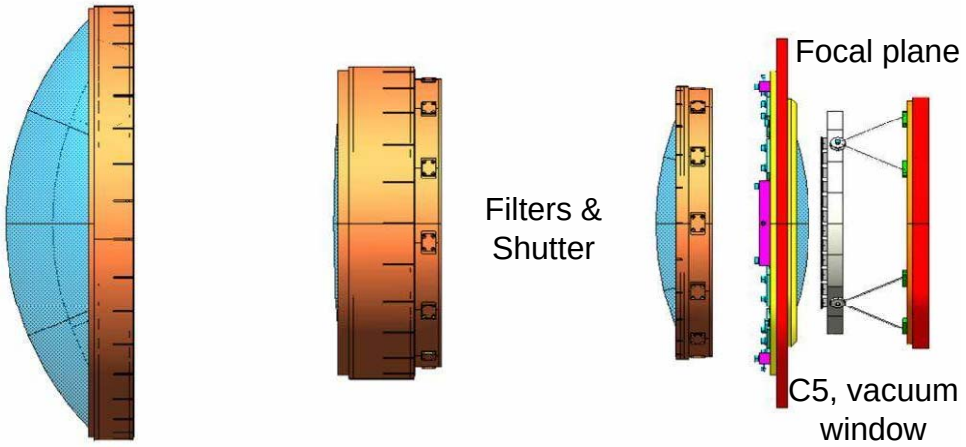
Filter Changer and Shutter

The Optical Corrector

5 fused silica lenses produce a 2.2º image area. C1 has a diameter of 930 mm.

The space between C3 and C4 accommodates the shutter and filter mechanism.

- Filter: 57 cm diameter, 2 cm thick
- Shutter: University of Bonn design



C5 is the window on the CCD vacuum vessel.

C1 C2 C3 C4 C5

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C5 is the window on the CCD vacuum vessel.

C1

The blanks were completed in Jan. 2008 and the polishing contract was awarded April 2008
20 months quoted delivery

Filter and Shutter

Filter changer with 8 ‘cartridges’

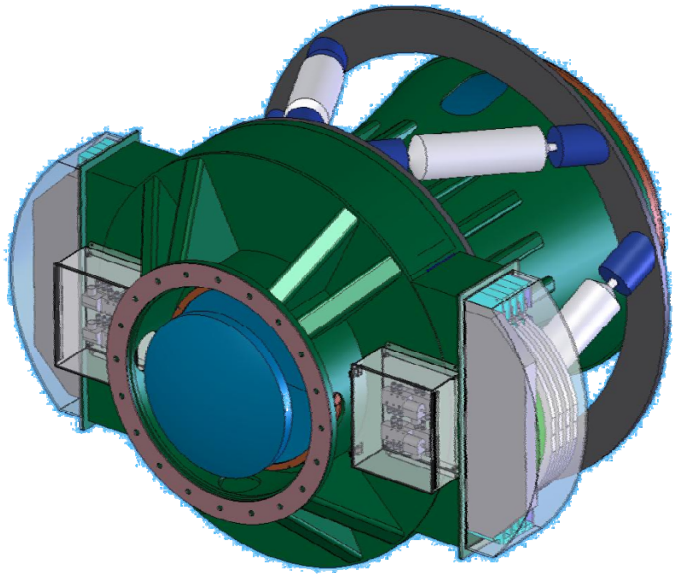
- 5 are used for DES: SDSS *griz* and the Y band
- Photometric redshifts

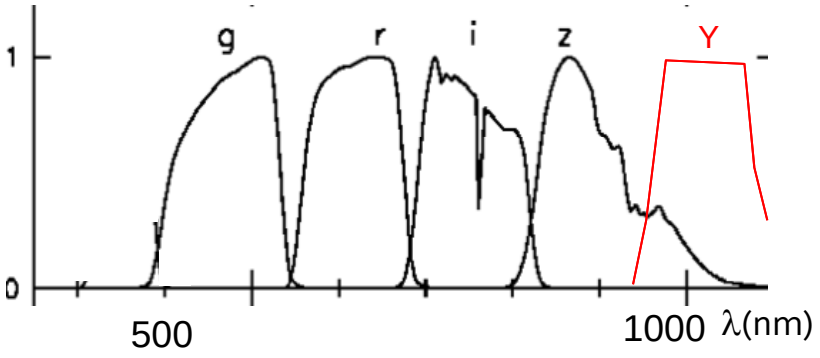
Filters are ~580 mm in diameter and ~15 mm thick

- Tight requirements on uniformity and light throughput

U. of Michigan builds the filter changer.

Shutter system is being built by Bonn University. Schedule delivery March 2010





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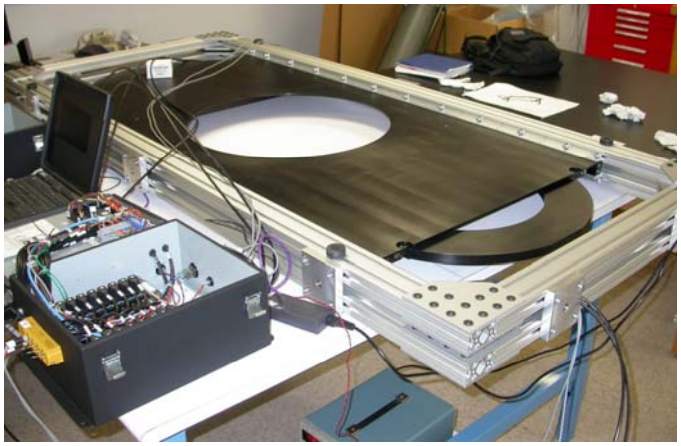
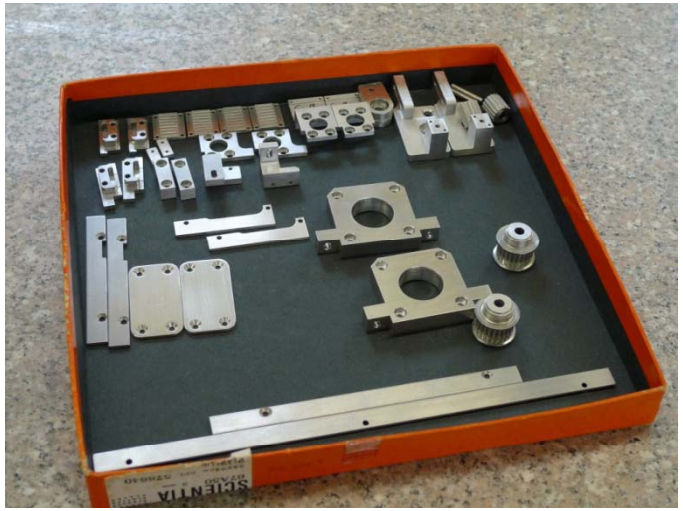
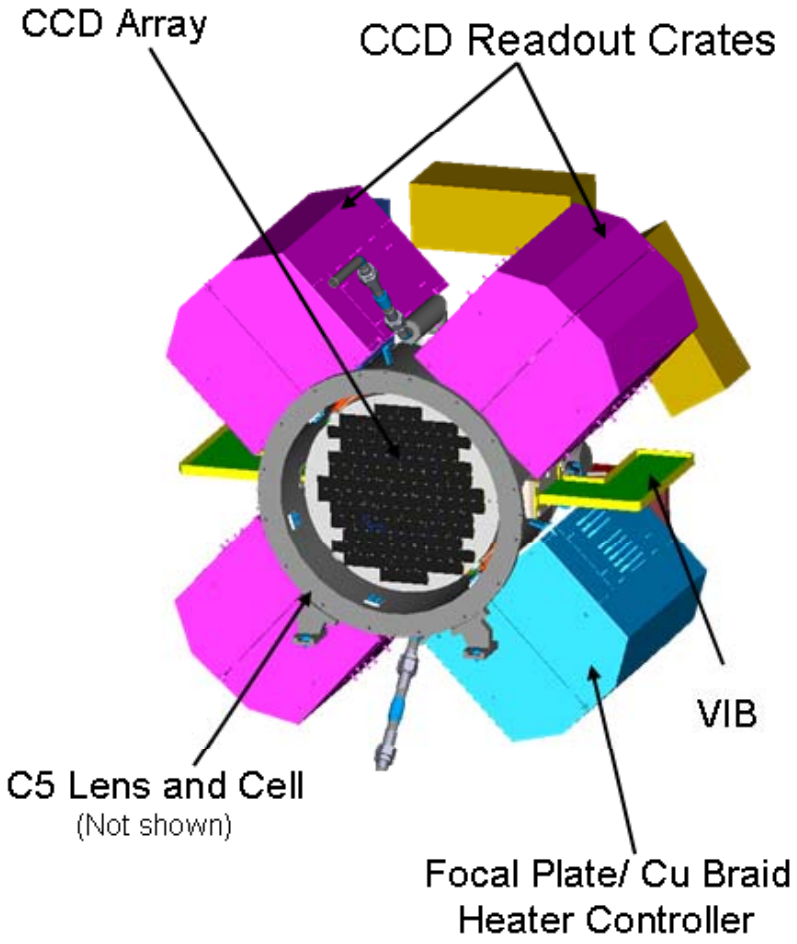




Camera Vessel



Cooling:

Detectors must be cooled to temperatures O(173K) to minimize dark current. Temperature must be stable throughout the focal plane and in time to ensure uniform performance.

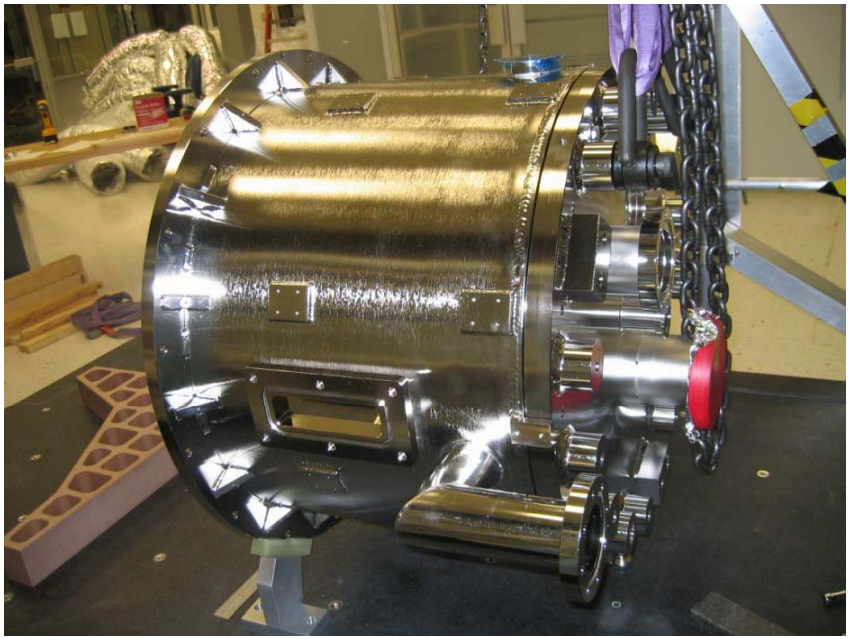
Vacuum:

A vacuum of O(10^{-5} torr) is needed to avoid contaminant and water deposition on the CCD surface.

Control:

These conditions must be kept autonomously during the night and for extended (months) periods.

Camera Vessel



Final DECam Vessel

Cooling:

Detectors must be cooled to temperatures O(173K) to minimize dark current. Temperature must be stable throughout the focal plane and in time to ensure uniform performance.

Vacuum:

A vacuum of O(10^{-5} torr) is needed to avoid contaminant and water deposition on the CCD surface.

Control:

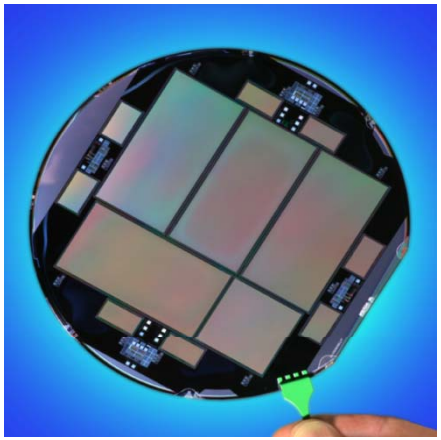
These conditions must be kept autonomously during the night and for extended (months) periods.

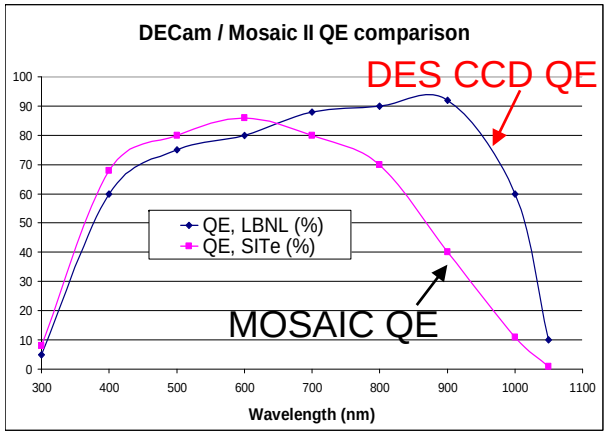
Infrastructure in operation at Fermilab

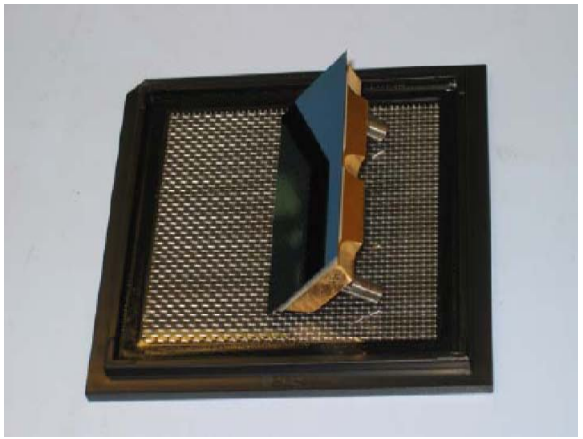
The CCDs

Fully depleted, high resisitivity, 250 micron thick CCDs

- Developed by LBNL
- High Quantum efficiency; QE > 50% at λ=1000nm.
- Readout rate of 250 kpix/s with a read noise of ~7 e-
- 2kx4k, 15 μm pixels
- Flatness of the CCD module < 10 microns.
- Four-side buttable, mounted on AlN boards with an Invar foot developed at FNAL.



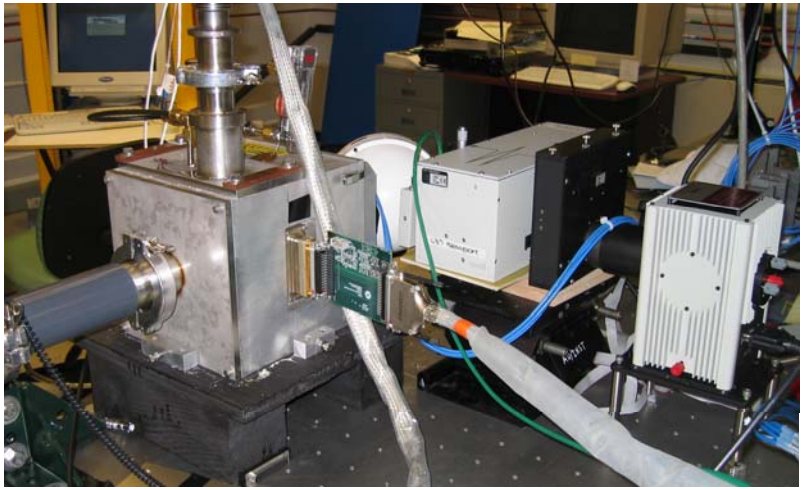




CCD Characterization

We designed and operate several Test stations (dewars) at Fermilab

- Quantum Efficiency
- Full Well
- Linearity
- Flatness
- Noise, Readout Speed
- Persistance
- Charge Transfer Efficiency
- Cross Talk



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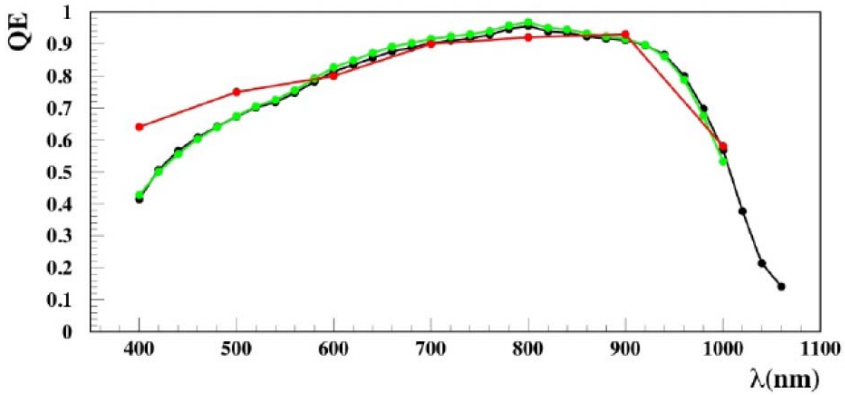

Measured QE for 3 DES CCDs vs. wavelength at a temperature of -100 C.
3% uncertainty on absolute QE,
Negligible uncertainty on relative QE

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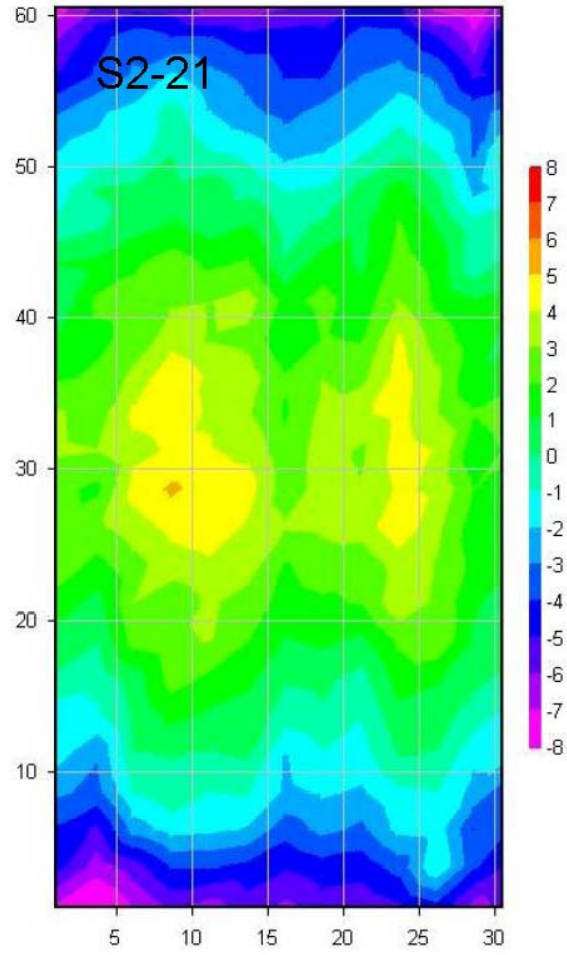

RMS < 3 μm within a cm^2
Adjacent 1 cm squares within 10 μm

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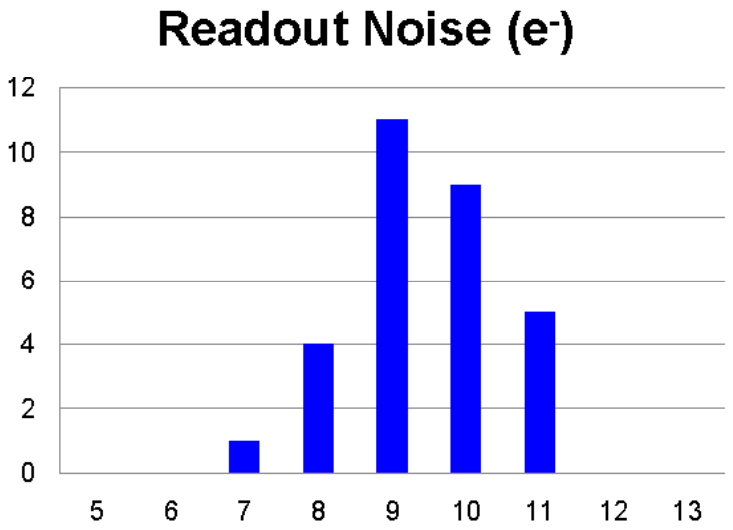
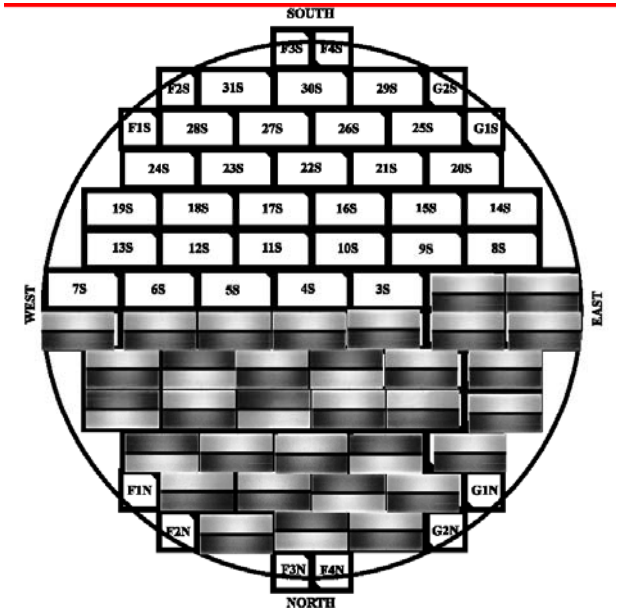
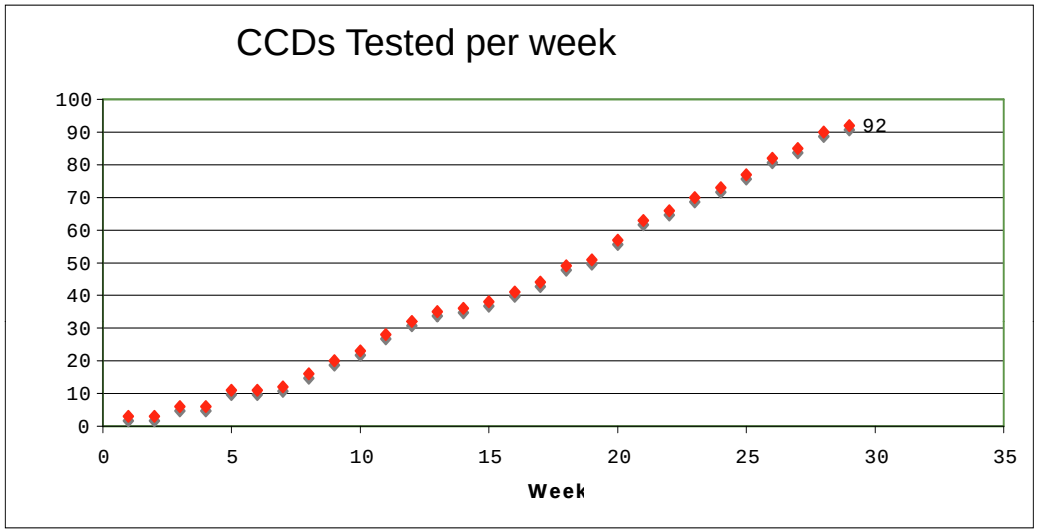
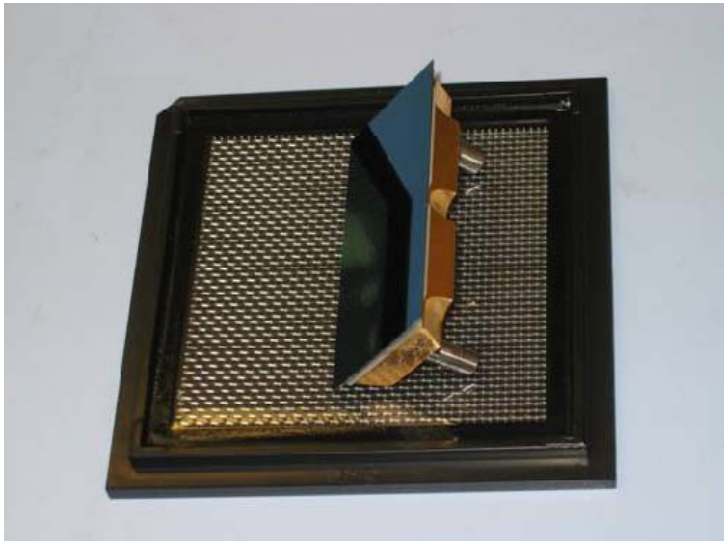


Spec: < 15 e^- @ 250 kpix/s
Measured mean: 8.9 e^-

CCD Production







On schedule

Test and production facility at Fermilab

92 CCDs packaged and tested (started with lower quality devices to test the process)

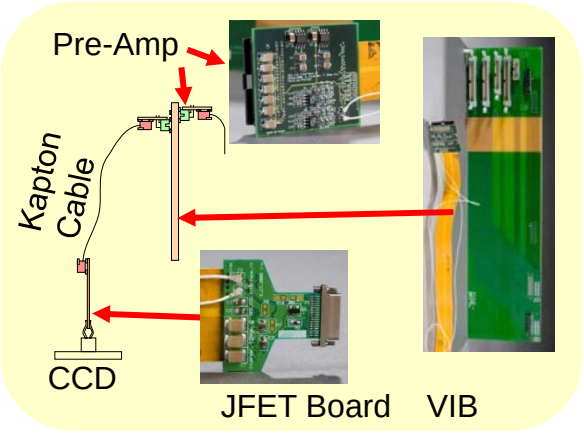
33 are Science Grade and ready for the focal plane! (need 72 including spares)

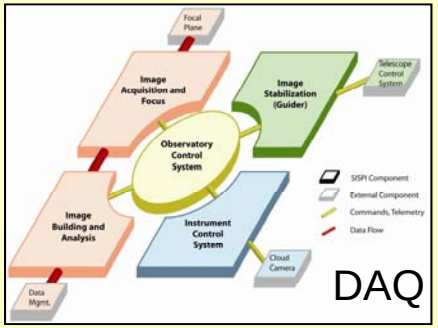
The Front-End Electronics and DAQ

The CCD read-out electronics is based on Monsoon developed by NOAO. Several boards have been redesigned to meet DES specifications.

- 12 channel acquisition module
- Clock/Bias board
- New controller with an S-Link based interface

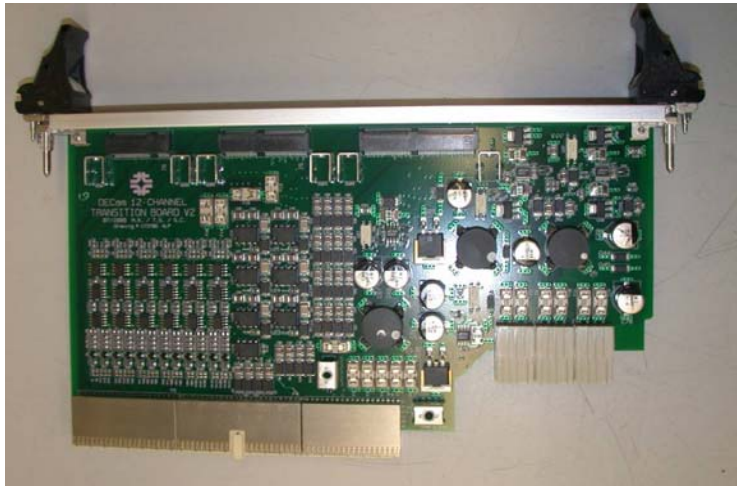
A modern data acquisition system and observation control system is being designed.





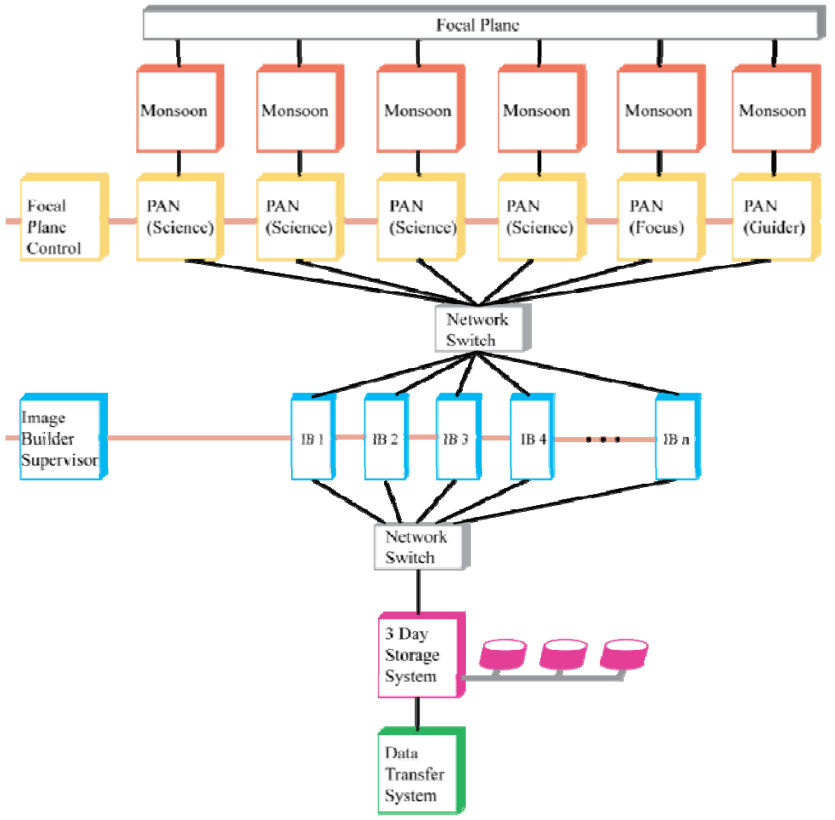
Electronics and DAQ Status

Pre-Production Version of all Modules



Pre-Production Electronics Crate

Prototype DAQ System Operational



Multi-CCD Test Vessel

- First integration platform at Fermilab
- Electrically and Mechanically very similar to final imager
- Number of CCDs and systems to integrate is increasing

- 33/62 2kx4k CCDs installed
  - 15 are live and proved that low noise multi-crate readout works!
  - Other 18 are mechanical (don't readout) detectors – used for thermal and flatness measurements

Multi-CCD Test Vessel

- First integration platform at Fermilab
- Electrically and Mechanically very similar to final imager
- Number of CCDs and systems to integrate is increasing

- Pinhole camera
  Image taken with11 engineering grade CCDs read out with DES electronics and SISPI data acquisition code
- Noise = 10 electrons, Spec. = <15e

On-Sky Integration Platform

- DECam runs on the 1m at CTIO provide calibration information and a test bed for DECam hardware
- October 2008
  - 1 DECam CCD (2kx2k)
  - with Monsoon electronics
  - in a small test dewar
  - on the CTIO 1m (next to the Blanco)
  - VRI filters
- June 09:
  - Guiding successfully demonstrated
  - “Real” learning experience for CCD/electronics debugging
- Next observing run in August 09

DECam Telescope Simulator

Provides platform for testing all components of DECam in all orientations
also tests installation

Filter changer/shutter

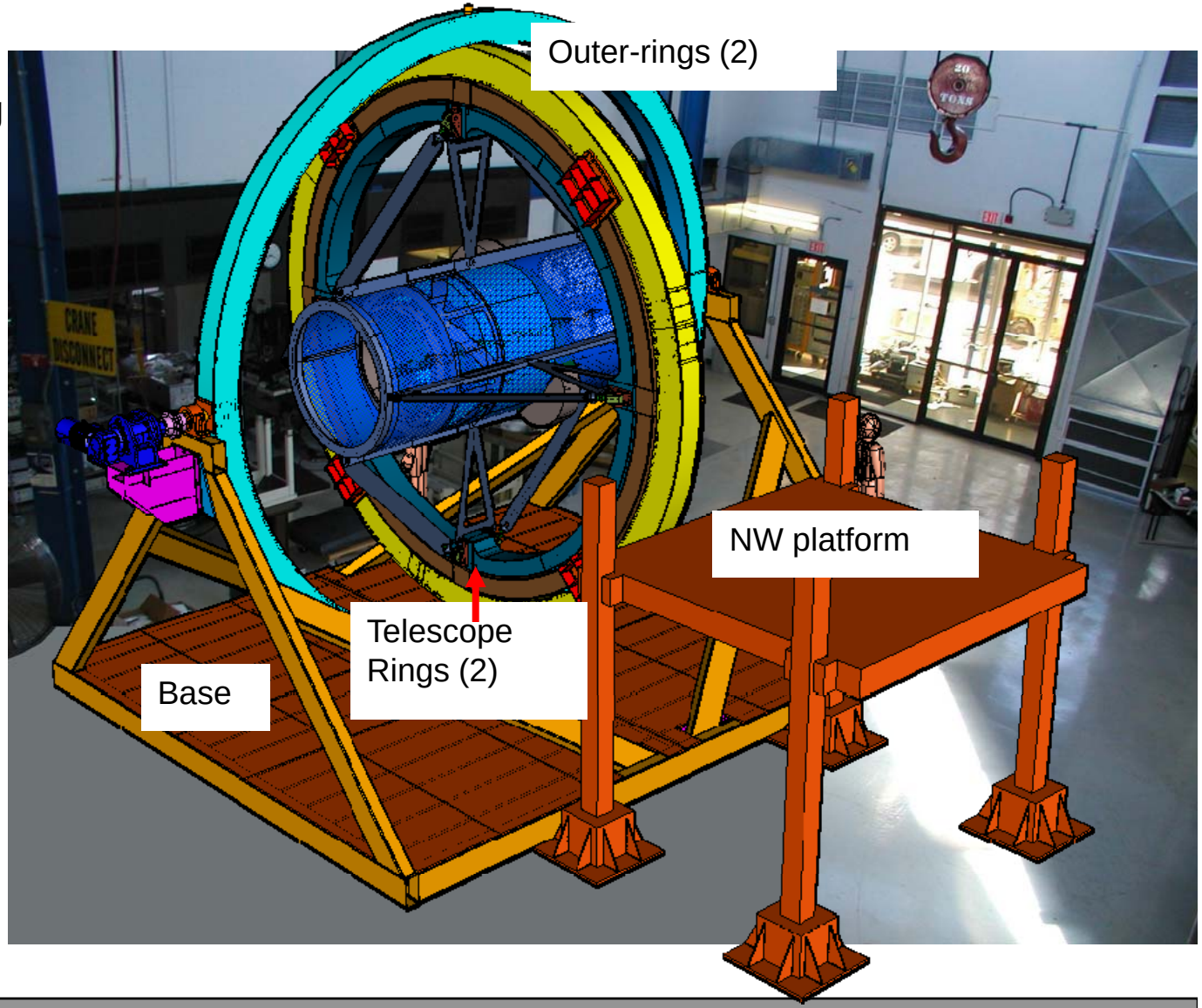
Imager into the cage at the service platform

F/8 handling

Cage onto the telescope spiders

Control System

Data Acquisition Software



Status and Summary

The Dark Energy Survey is an approved and funded project.

Construction of the DECam instrument is on schedule

- CCD and optics fabrication well underway.
- Barrel and lenses finished by the end of the year.
- CCD test and production facility operational.
  About 40% of science-grade CCDs have been selected.
- Front-end electronics and crates in production.
- Opto-mechanics
  - Hexapod — Ordered, under construction (Italy)
  - Filter Changer — Almost complete (Michigan)
  - Shutter — Early 2010 (Bonn)
- Integration platforms
  - Multi-CCD Test Vessel — Now
  - Full size telescope simulator — 2010
- Pre-production version of SISPI ('mountain-top software') ready and being used on-site (CTIO and Fermilab).

DES Timeline

Now	Finalize design; select and test CCDs
	Complete Blanco Telescope Upgrades
During 2010	All camera elements (except optics) will be integrated and tested at Fermilab with a full-size telescope simulator.
Early 2011	Camera arrives at CTIO
	Installation
Summer 2011	Commissioning
Fall 2011	First Light
	Survey begins

Summary

Additional Transparencies

Acknowledgements

Funding for the DES Projects has been provided by

The U.S. Department of Energy, the U.S. National Science Foundation, the Ministry of Science and Education of Spain, the Science and Technology Facilities Council of the United Kingdom, the Higher Education Funding Council for England, the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign, the Kavli Institute of Cosmological Physics at the University of Chicago, Financiadora de Estudos e Projetos, Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro , Conselho Nacional de Desenvolvimento Científico e Tecnológico and the Ministério da Ciência e Tecnologia and the Collaborating Institutions in the Dark Energy Survey

The Collaborating Institutions in the Dark Energy Survey:

Argonne National Laboratories, University of Cambridge, Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas-Madrid, University of Chicago, University College London, DES-Brazil, Fermilab, University of Edinburgh, University of Illinois at Urbana-Champaign, Institut de Ciencies de l'Espai (IEEC/CSIC), Institut de Fisica d'Altes Energies, Lawrence Berkeley National Laboratory, University of Michigan, National Optical Astronomy Observatory, The Ohio State University, University of Pennsylvania, University of Portsmouth, University of Sussex, South-Bay Consortium (SLAC, Stanford, UCSC), Nottingham University.

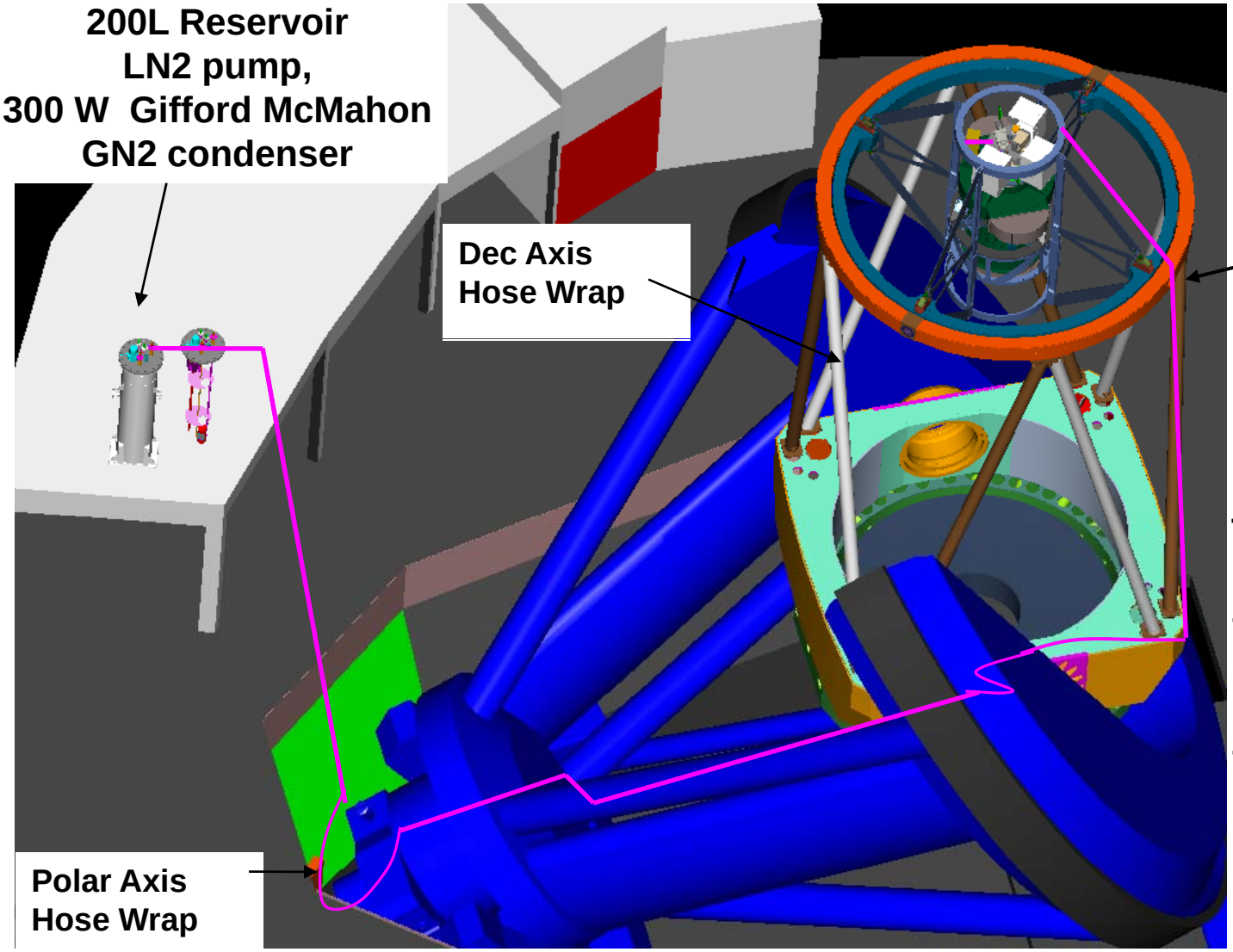
Expected DECam Performance

Blanco Effective Aperture/ f number @ prime focus	4 m/ 2.7
Blanco Primary Mirror - 80% encircled energy	0.25 arcsec
Optical Corrector Field of View	2.2 deg.
Corrector Wavelength Sensitivity	<350-1050 nm
Filters	SDSS g, r, i, z, Y (400-1050 nm)
Effective Area of CCD Focal Plane	3.0 sq. deg.
Image CCD pixel format/ total # pixels	2K X 4K/ 520 Mpix
Guide, Focus & Alignment Sensor CCD pixel format	2K X 2K
Pixel Size	0.27 arcsec/ 15 μm
Readout Speed/Noise requirement	250 kpix/sec/ 10 e
Survey Area SPT overlap SDSS stripe 82 Connection region	5,000 sq. deg. total RA -60 to 105, DEC -30 to -65 RA -75 to -60 , DEC -45 to -65 RA -50 to 50, Dec -1 to 1 RA 20 to 50, Dec -30 to -1
Survey Time/Duration	525/5 (nights/years)
Median Site Seeing Sept. – Feb.	0.65 arcsec
Median Delivered Seeing with Mosaic II on the Blanco	0.9-1.0 arcsec (V band)
Limiting Magnitude: 10σ in 1.6” aperture assuming 0.9” seeing, AB system	g=24.7, r=24.2, i=24.4, z=23.9
Limiting Magnitude: 5σ for point sources assuming 0.9” seeing , AB system	g=26.1,r=25.6, i=25.8, z=25.3

Testing CCD Characteristics for DECam

	Typical LBNL CCD Performance	DECam Requirements
Pixel array	2048 x 4096 pixels	2048 x 4096 pixels
Pixel size	15 μm x 15 μm	15 μm x 15 μm
# Outputs	2	2
QE(g,r,i,z)	70%, 90%, 90%, 75%	60%, 75%, 60%, 65%
QE Instability	Stable	<0.3% in 12-18 hrs
QE Uniformity in focal plane	uniform	<5% in 12-18 hrs
Full well capacity	170,000 e^-	>130,000 e^-
Dark current	2 e^-/hr/pixel at 120°K	<~25 e^-/hr/pixel
Persistence	Erase mechanism	Erase mechanism
Read noise	7 e^- @ 250 kpixel/s	< 15 e^- @ 250kpix/s
Charge Transfer Inefficiency	$< 10^{-6}$	$<10^{-5}$
Charge diffusion	6-7 μm	1D σ < 7.5 μm
Cosmetic Requirements		<# Bad pixels> <0.5%
Linearity	Better than 1%	1%
Package Flatness	< 10 μm	Two specs.

Schematic LN2 Supply System at CTIO



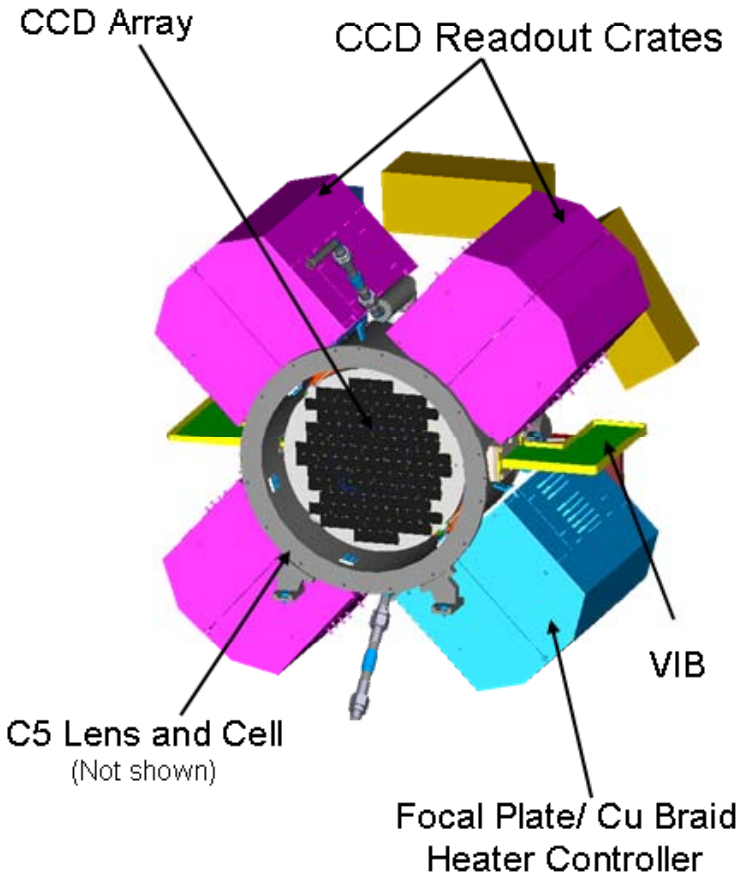
Bypass valve to Pre-cool transfer lines

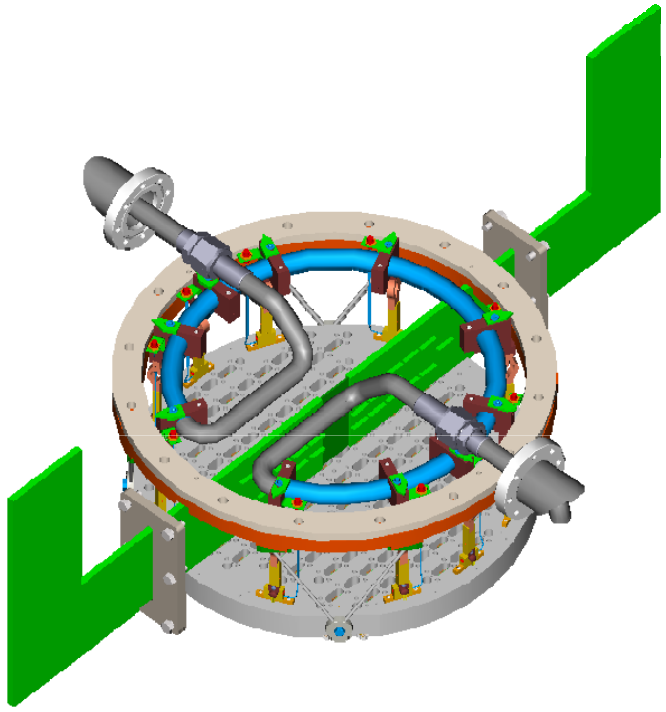
Transfer Line Length

~31 meters
Pump to Polar axis

~34 meters
Polar axis to Imager

Imager Vessel and Heat Exchanger

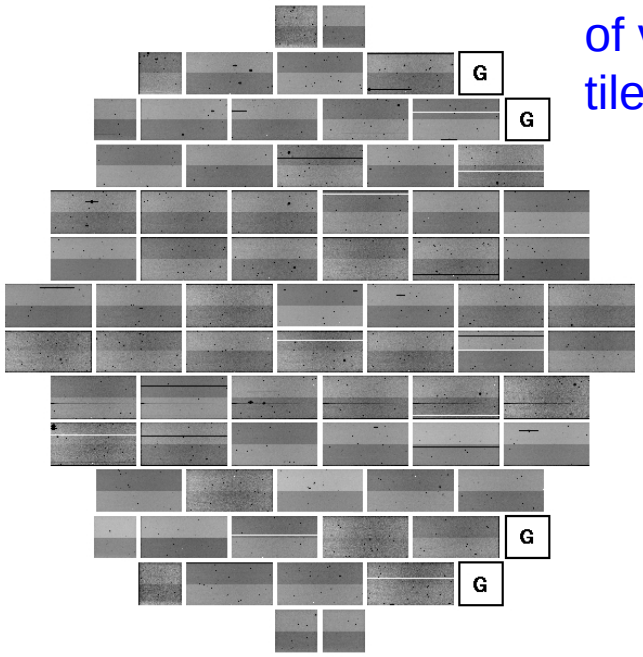




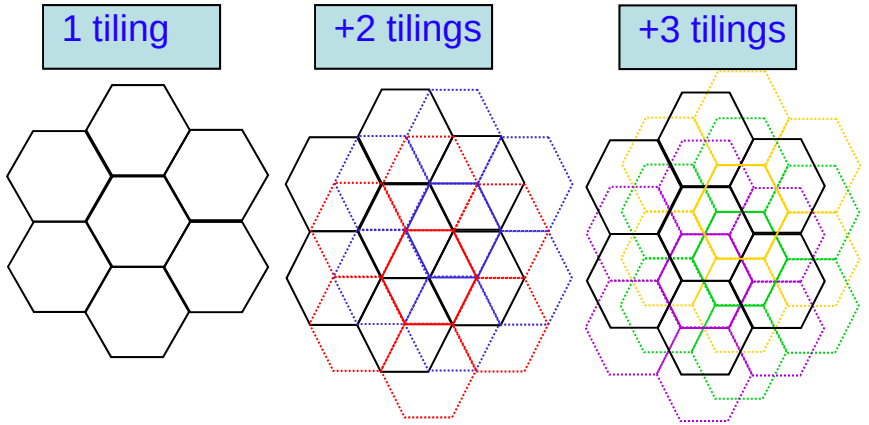
Simple Tube Heat Exchanger
Copper braids attach to focal plate
Copper braids contain temperature feed back and trim heaters

Survey Planning

- Determination (simulation) of an efficient observing strategy
  - Optimize for excellent photometric calibrations
- Simulation of mock raw DECam survey images, including galaxies and stars, and instrumental effect
- Status: On schedule



DECam 3 deg^2 field of view (= 1 hex = 1 tile = 1.1 GB)



- DES “tiles” 5000 deg^2 of sky at a rate of 2 times per year in each of 4 filters, constraints on DE possible after two years

DECam Telescope Simulator

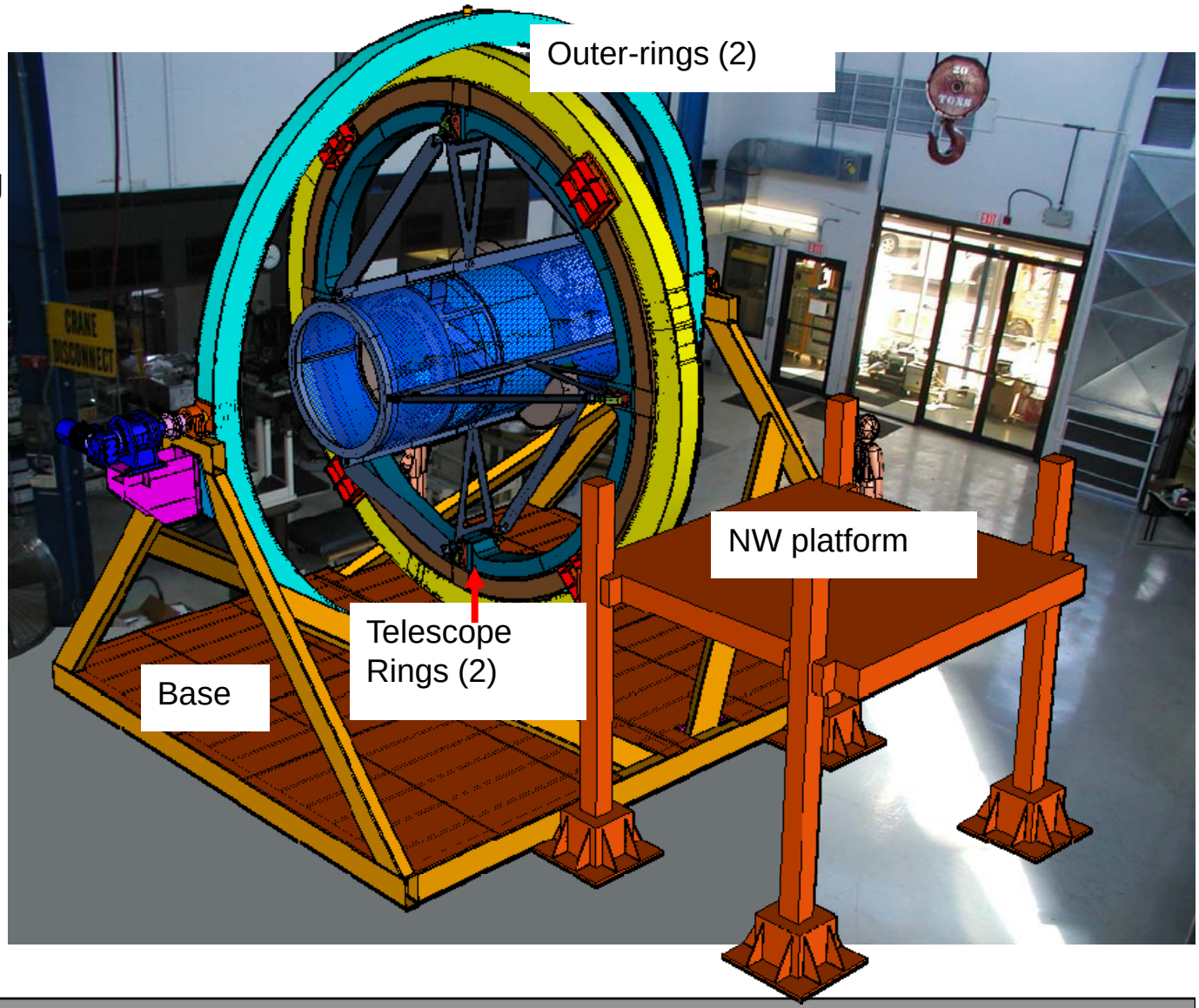
Provides platform for testing all components of DECam in all orientations
also tests installation

Filter changer/shutter

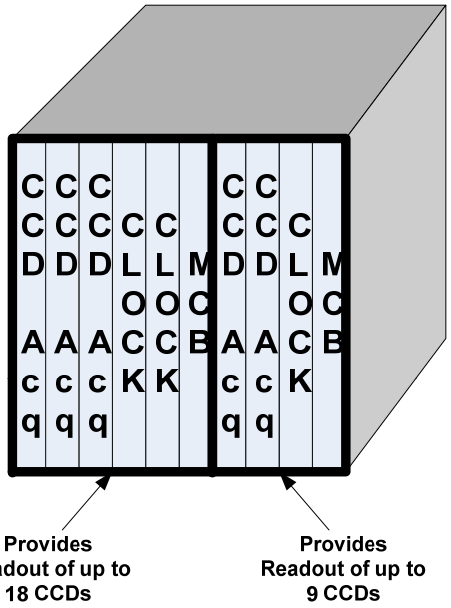
Imager into the cage at the service platform

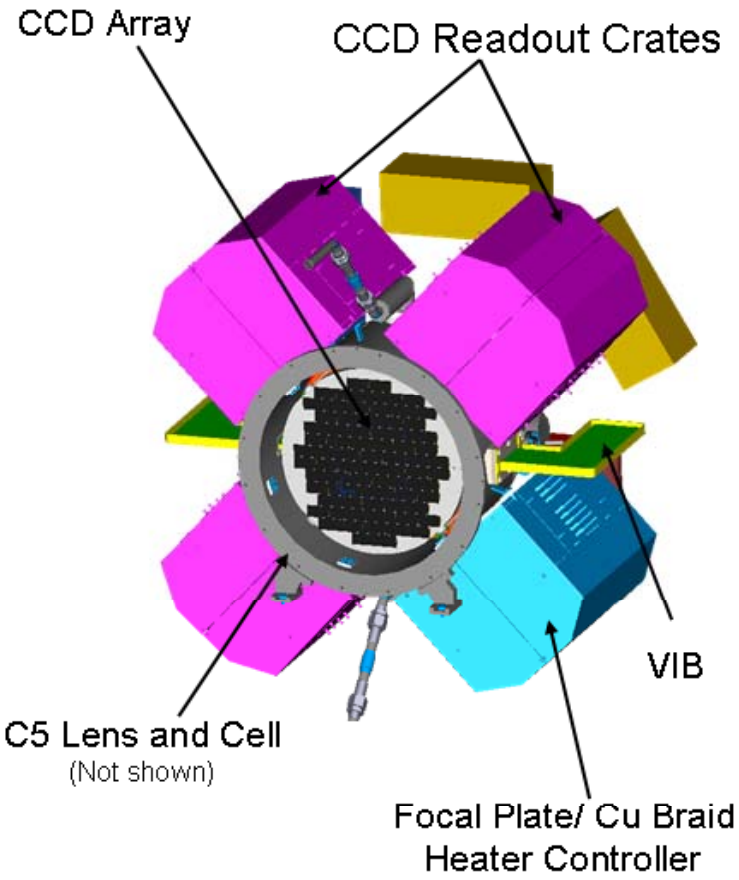
F/8 handling

Cage onto the telescope spiders



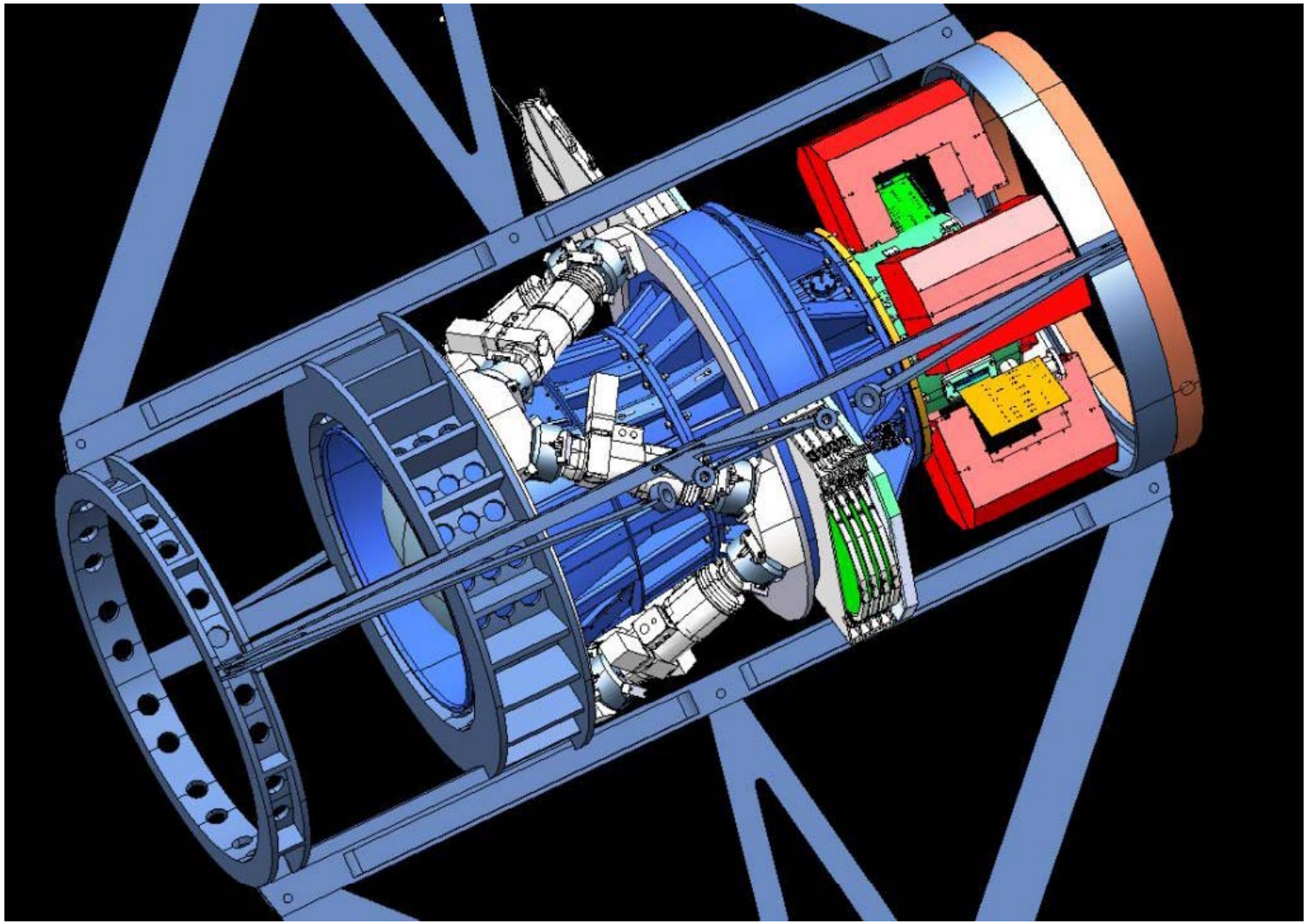
FE Electronics Packaging



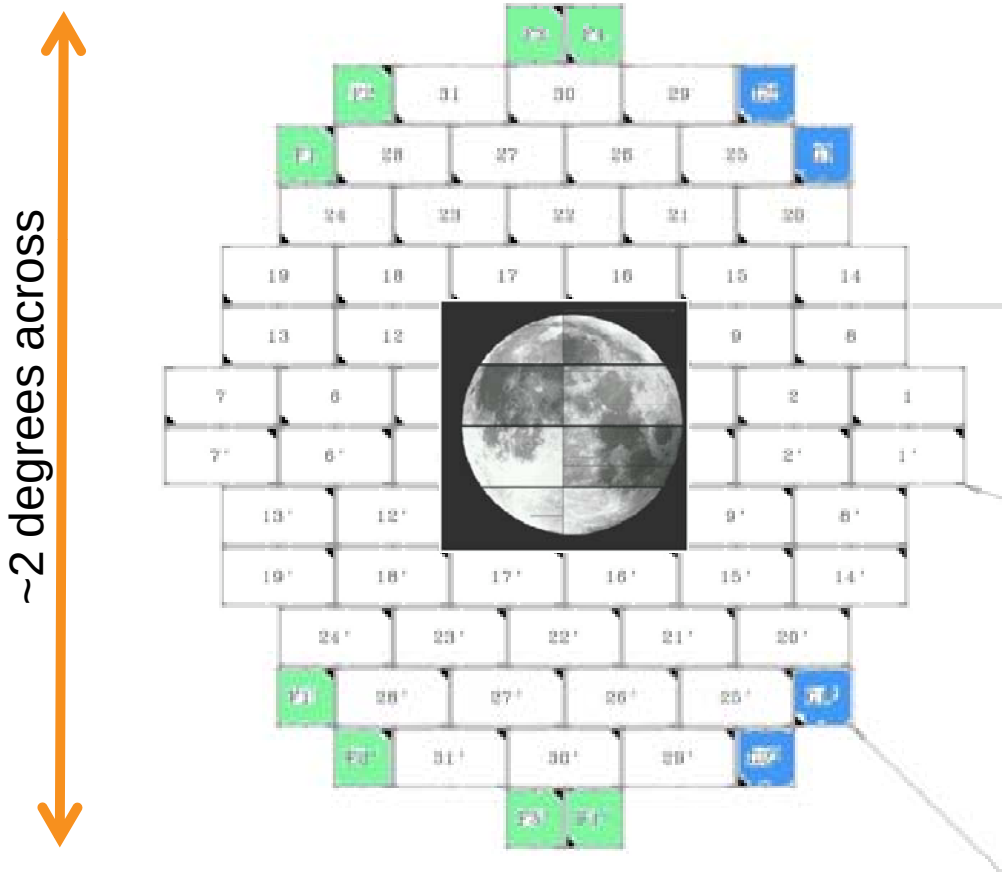


- Each crate will contain two backplanes; on slots.
- A single 4-slot section would provide for readout the 4 guide CCDs
- The remaining backplane sections will provide readout of up to 72 science and alignment CCDs.
- Active cooling will hold electronics temperature stable to within +/-2°C. Crate is designed to radiate less than 20Watts.

DECam solid model: the cage is full



Detector Requirements



Many requirements to meet DES science objectives:

- Linearity (<1%), high dynamic range (1e4-1e5).
- Low dark current, low read noise (<15 e-/pixel).
- CTI < 1e-5
- QE ~0.7
- Charge diffusion & flatness.
- Cosmetic defects (<0.5%).