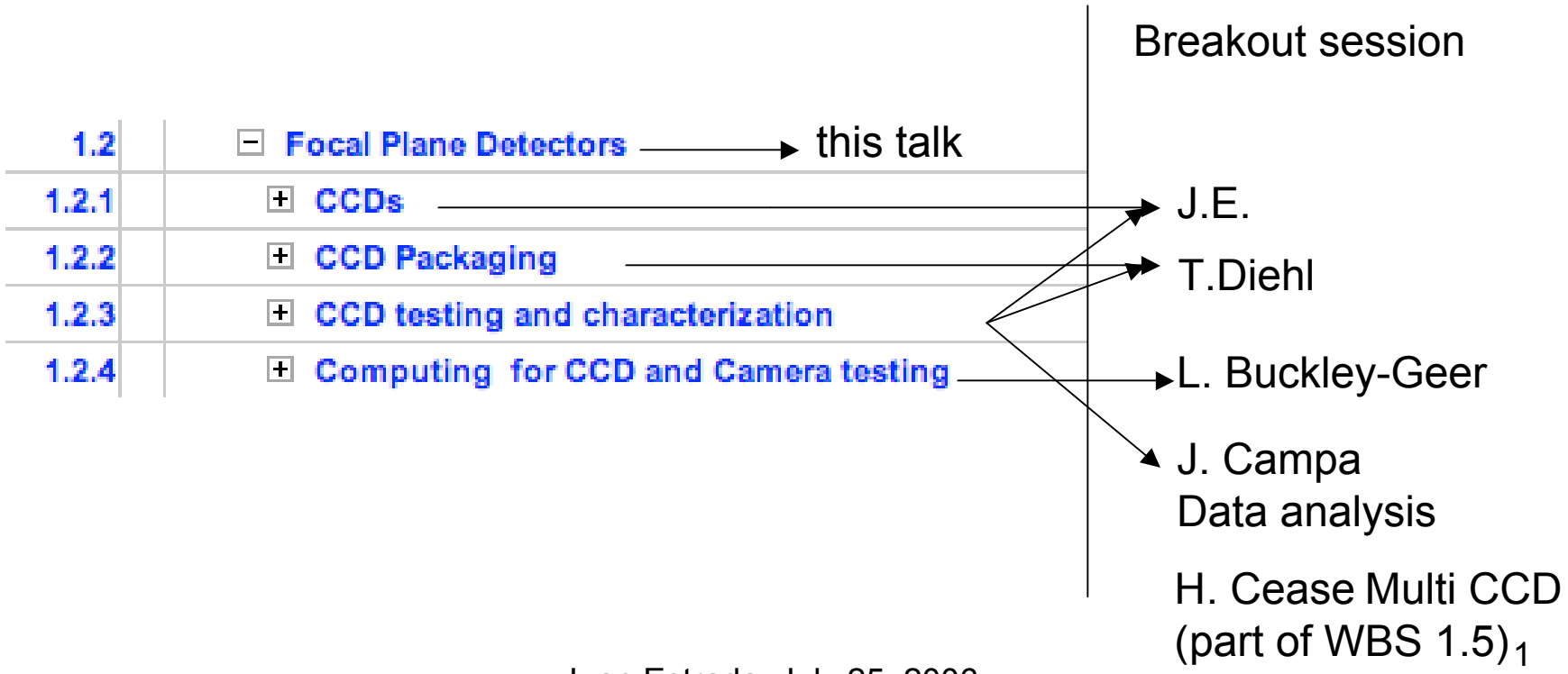
DARK ENERGY SURVEY

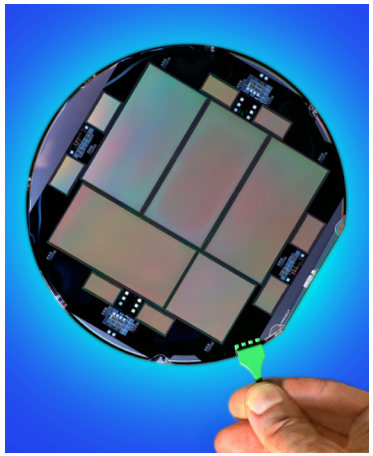
Focal Plane Detectors
WBS 1.2



CCDs (WBS 1.2.1)

DARK ENERGY SURVEY

The CCD design was developed by LBNL and follows the fabrication business model developed for SNAP. The DES design has already been proven and used on telescopes./\ Main feature is a high QE in the near IR.The die arrive from LBNL with cold probe data for the 2kx4 devices. Manufacturer requires 3 test wafers per lot, those do not get thinned to 250μm and stay at 650μm.



- 71 Lot 1A engineering grade CCDs (including 3 thick wafers):
  - 32 1k x 512
  - 7 2k x 2k
  - 32 2k x 4k

- 69 Lot 1B engineering grade CCDs (including 3 thick wafers)
  - 24 1k x 512
  - 9 2k x 2k
  - 36 2k x 4k

Expecting 2A in November

DARK ENERGY SURVEY

Focal Plane detectors at FNAL

CCDs arrive at Fermilab diced and ready for **packaging at the Silicon Detector Facility (SiDet) (WBS 1.2.2)** . Device level tracking and bookkeeping for this task is described in talk by T.Diehl in breakout session.

Every device to be installed in the DES focal plane will be characterized in the FNAL testing lab. **Testing will compare the CCD performance with the DES science requirements and select the best devices for the focal plane (WBS 1.2.3).** Analysis is done with outside collaborators.

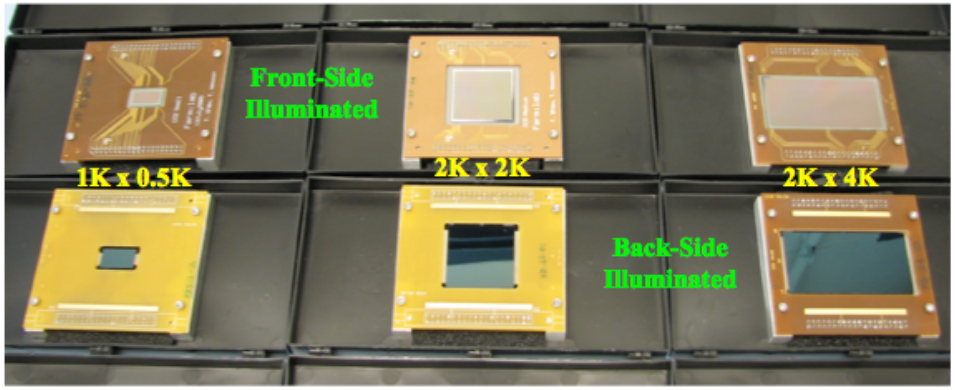
During production we will test up to 20 devices per month, with some capacity to absorb bursts of higher delivery rates. Infrastructure to achieve this testing rate is described in talk by T.Diehl in breakout session. Testing will be done with the "same" electronics that we plan to use in the instrument. **Software for automated testing and storage of data is developed at FNAL (WBS 1.2.4)**

CCD Packaging (WBS 1.2.2)

DARK ENERGY SURVEY

- Packaging is done at FNAL in Silicon Detector Lab (SiDet). Details about this will be discussed by T.Diehl in the breakout session.

Picture Frame (WBS 1.2.2.2)

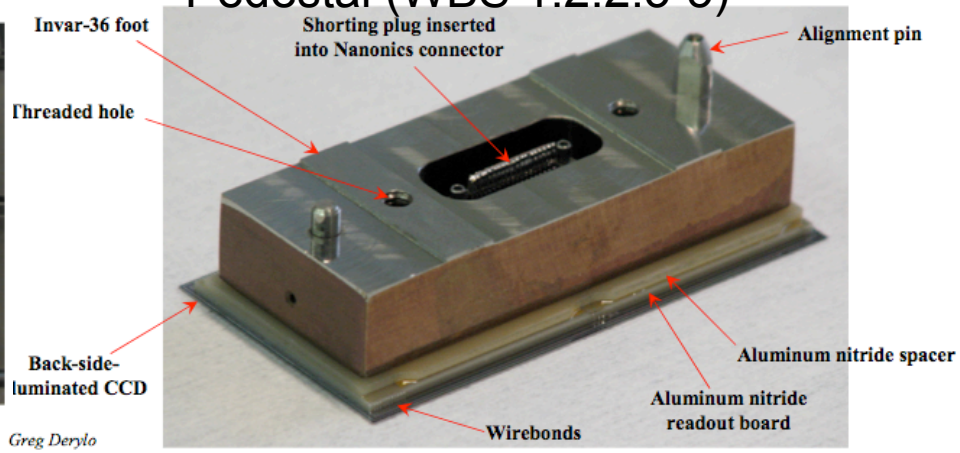


For CCD characterization only.

Large flexibility for readout adaptors. (lot of space for connections)

The best performances in terms of noise have been achieved using this type of packages.

Pedestal (WBS 1.2.2.3-5)



Package to be used in the focal plane.

V0 Prototype currently being tested.

CCD testing and characterization (WBS 1.2.3)

DARK ENERGY SURVEY

Individual CCD testing: Comparison of science requirements with performance

	LBNL CCD performance	DES requirements	
Pixel array	2048 × 4096 pixels	2048 × 4096 pixels	
Pixel size	15 μm × 15 μm	15 μm × 15 μm	
<QE (400-700 nm)>	~70%	>60%	
<QE (700-900 nm)>	~90%	>80%	✓ Relative QE
<QE (900-1000 nm)>	~60%	>50% at 1000 nm	
Full well capacity	170,000 e^-	>130,000 e^-	✓
Dark current	2 e^-/hr/pixel at –150°C	<~25 e^-/hr/pixel	✓
Persistence	Erase mechanism	Erase mechanism	✓
Read noise	7 e^- @ 250 kpix/s	< 10 e^- @ 250 kpix/sec	→ achieve 77%
Charge Transfer Inefficiency	< 10^{-6}	<10^{-5}	✓
Charge diffusion	6 μm	< 7 μm (*)	✓
Linearity	Better than 1%	1%	✓

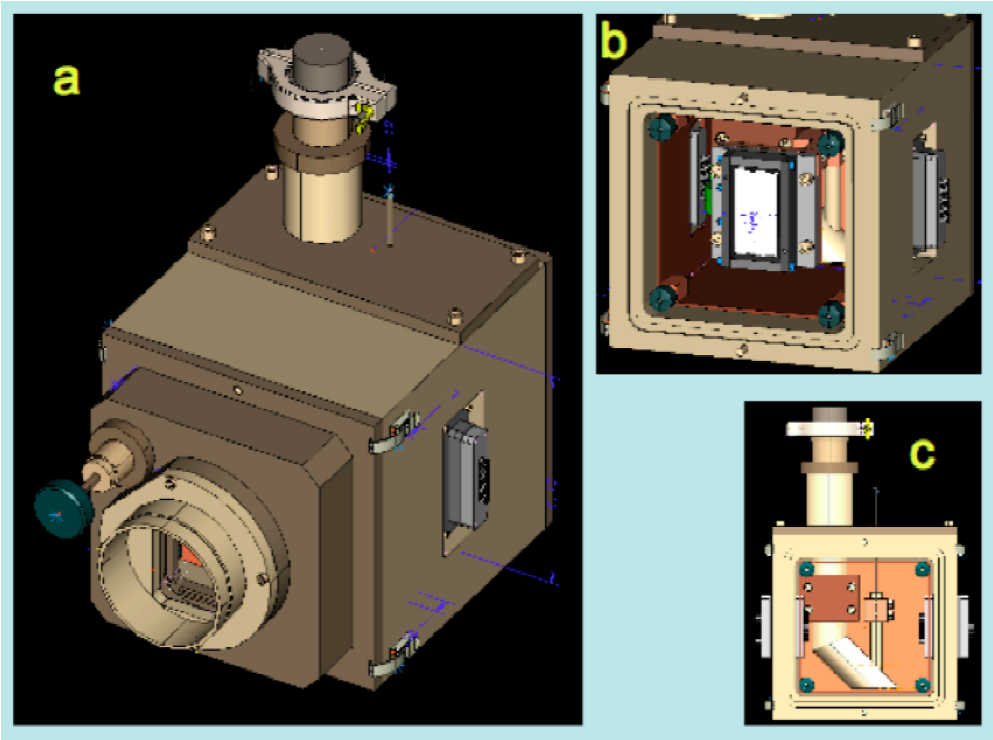
More in breakout session (talk by J.E.)

✓ achieved at FNAL

A full size camera prototype is under construction (vessel exists) see H. Cease in breakout session. MultiCCD testing is also part of this task (WBS1.2.3.4).

Testing Facility

DARK ENERGY SURVEY



Dewars cooled with LN2

Easy access, short warm-up (6hrs) and cool-down (2hrs) time.

Automated system for LN2 supply is in place and being commissioned.

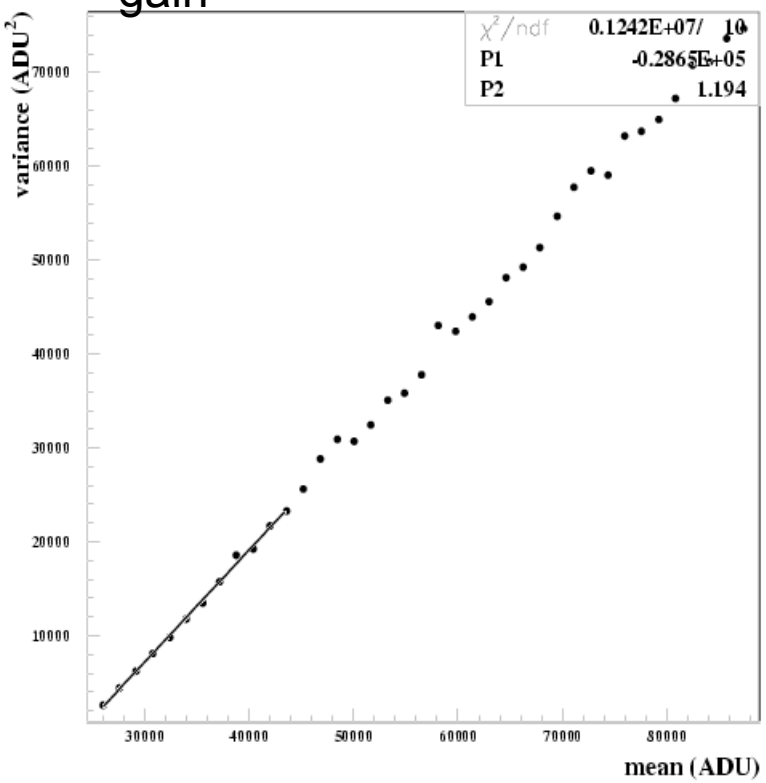
Currently:
- **three testing stations**
- **2 Monsoon controllers**
- 1 Leach controller
- Optical instruments

In the next few slides I will show you that now we are starting to understand the operation of these devices and their performance.

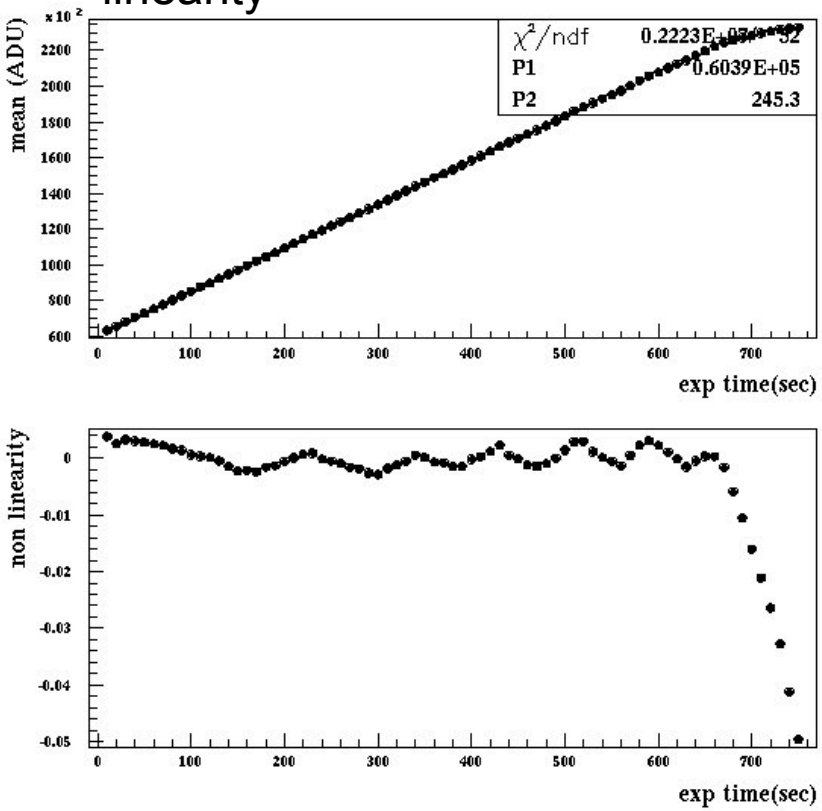
CCD performance (gain-linearity)

DARK ENERGY SURVEY

gain



linearity

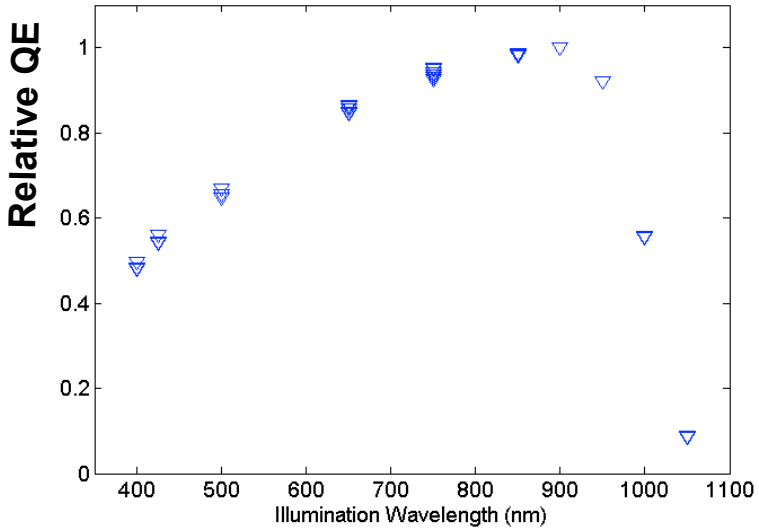


Gain is measured with photon transfer curve, and in some cases with Fe55 (not shown here).

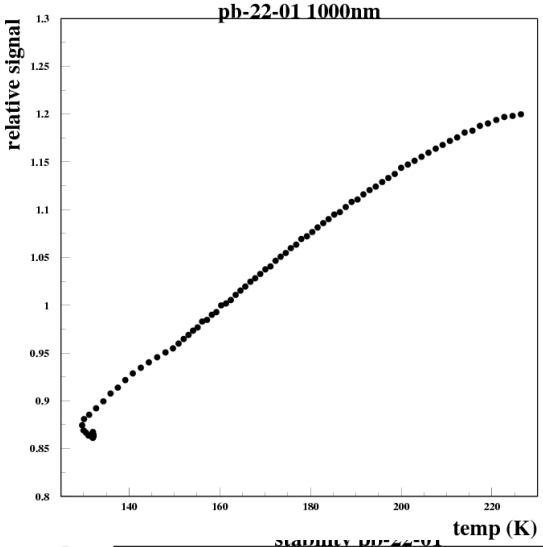
Non linearity better than 1% up up 160000e (as required)

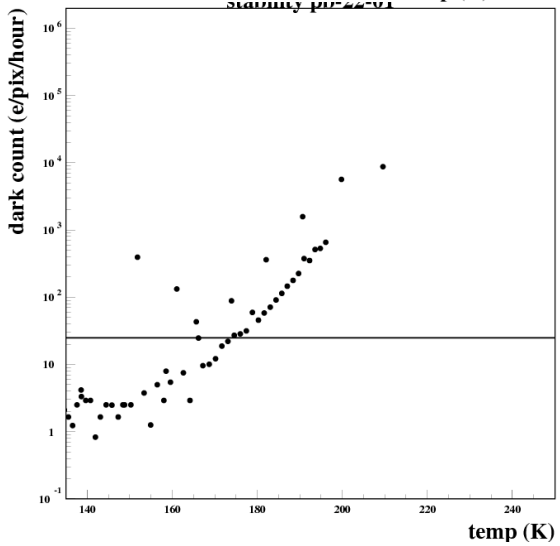
QE & Dark Current

DARK ENERGY SURVEY



QE in the red and dark current studies done as a function of temp. We satisfy the requirements at 173K (for our best devices, see defects discussion later)

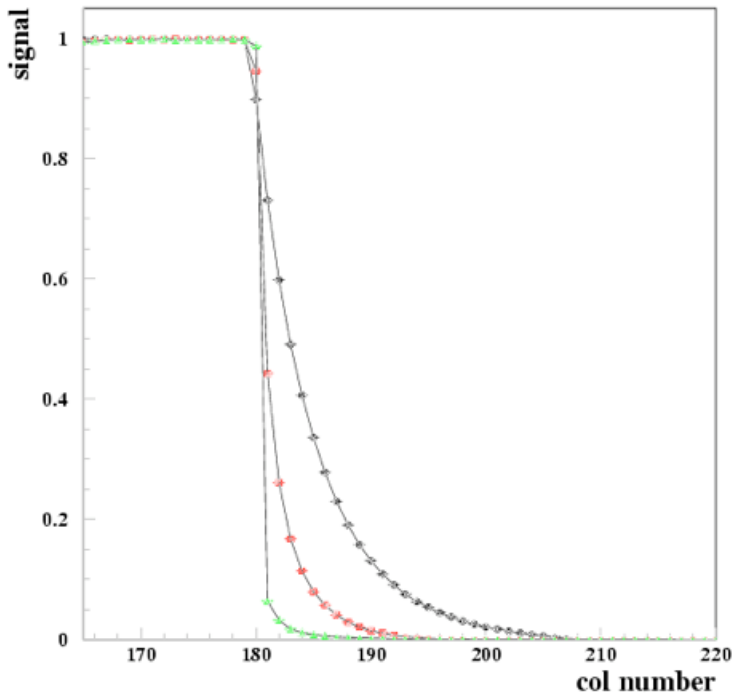


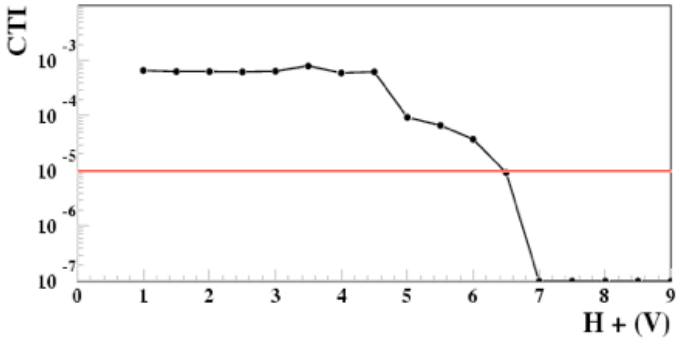


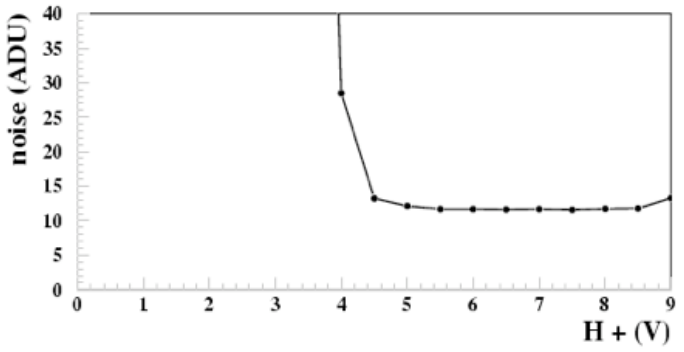
Relative QE measurements done at FNAL, results obtained consistent with expectations (absolute calibration is going on now).

Voltage optimization

DARK ENERGY SURVEY







Voltage is optimized to obtain the CTE in our requirements (>0.99999).
In general this is not a problem for the DES CCDs.

The experience so far indicates that it will be possible to group devices by 3 for sharing clock settings.

DARK ENERGY SURVEY

Readout noise/speed

Sci. Requirement: Read Noise < 10e- @ 250 kpix/sec

Best performance achieved so far:
10e @ 192 kpix/sec (pixel time of 5.2 usec)

most testing has been done @ 6.5 usec/pix

This was achieved using an amplifier on the outside of the testing dewar.
Readout time of 21sec per image, instead of the 17sec required.
Reducing the pixel time from 5.5usec to 5.2usec increased the noise from 6e to 10e.

This is a conern. The plan is to install the preamp closer to the device and continue readout time reduction studies with that hardware.

Erase mechanism speed is being studied (contributes to time between exposures)

DARK ENERGY SURVEY

Full testing for a device

- LBNL Cold probing (determines packaging priority)
- **FNAL-1 (one day)**
  - Photon transfer curve
  - Scan rails for the horizontal clocks
  - Scan rails for the vertical clocks
  - Output gate transfer curve
  - Dark current measurements
  - QE at 6 wavelengths
  - Defect counts at operating temp

  ⇒ report is produced after step 1 (see talk by J. Campa)

  (7 Terabytes)

Overnight automated data taking ~600 images (22Gb)

Automated report

- **FNAL-2 (3 days) for devices passing FNAL-1**
  - Detailed QE measurement
  - Detailed Temp studies
  - Keep cold and running to see if any problem develops
  - Package flatness

Packages built so far (75)

DARK ENERGY SURVEY

- **37 2k x 4k**:
  - 33 picture frames
    - 23 front illuminated (PF) :
      - 9 Lot 1A thick (9 pack Ok *)
      - 14 Lot 1B (12 pack Ok, 10 pass)
        - » 10 thick
        - » 4 thinned (defect studies)
    - 10 back illuminated (PB):
      - 7 Lot 1A (5 pack Ok, 3 noisy, 2 pass)
      - 3 Lot 1B (0 pack Ok)
  - 4 pedestal packages (V0)
    - S0-01: 1/2 works (14e noise due to early Kapton cable)
    - S0-02: no v-clocks, repair attempted
    - S0-03: accident during assembly, no video output
    - S0-04: works (32e noise not in cable, probably CCD)

For the moment we have been packaging everything that does not look good according to the cold probe data. Keep the good stuff for pedestal packages.

- **4 2k x 2k:** (all picture frame)
  - 3 front illuminated
  - 1 back illuminated
- **34 1k x 512:** (all picture frame)

* Not fully tested.Operated before completion of testing software. Plan to go back.

DARK ENERGY SURVEY

Yield at FNAL

- Fraction of devices passing all the tests after successful packaging:

performance yield = 12/17 = 70%

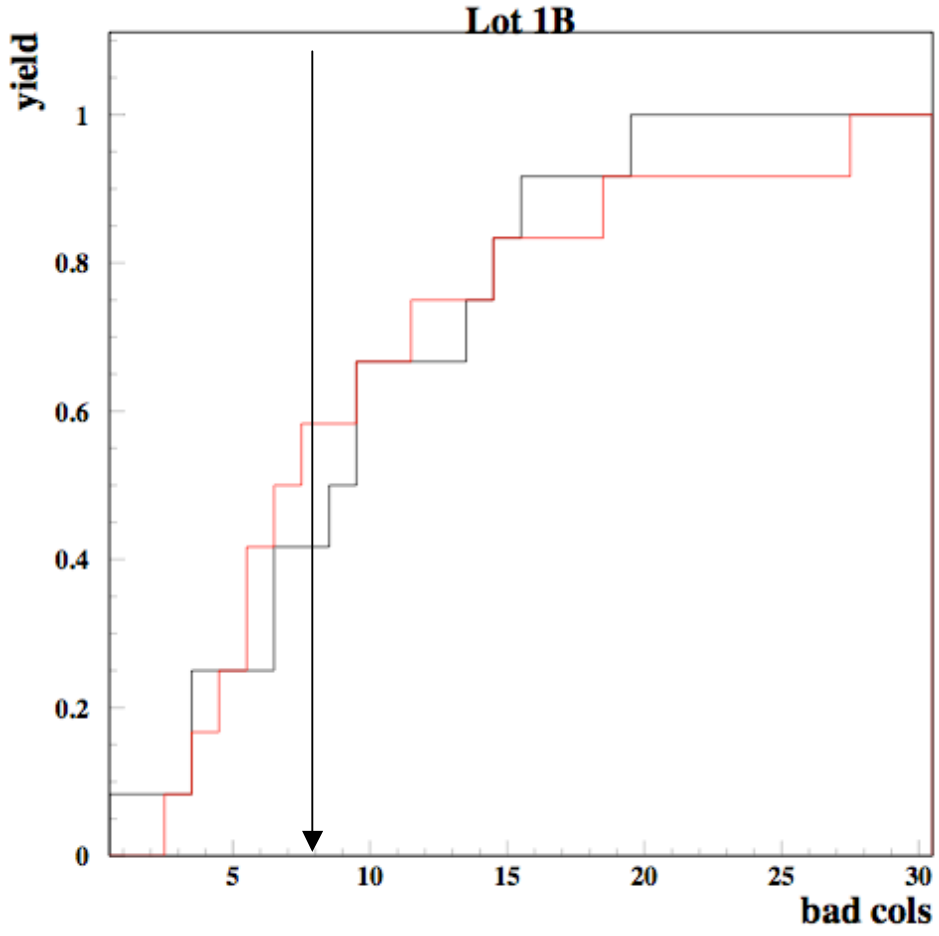
- Successful readout (2 channel) after packaging:

  - Front illuminated: **PF-packaging yield 11/13 = 85%**
  - Back illuminated: **PB-packaging yield 5/10 = 50%**
  - Low efficiency here was traced to electro-static discharge (ESD) damage and prompted a halt to the packaging of the large devices. The handling procedure were changed and tested with small devices. The new procedure was proven to work on 7/3/06 and since then we successfully packaged our first pedestal package.

    this yield does not include the cosmetic defects on the devices (next slide)

DARK ENERGY SURVEY

Cosmetics



Yield as a function of bad columns for (thick and thinned devices). Our requirement is less than or equal to 8 bad columns.

Cosmetics yield ~ 50%

Note that the curve is very sharp. There is room for increasing the yield by accepting a somewhat larger number of bad cols. For the moment we are sticking to the original specs.

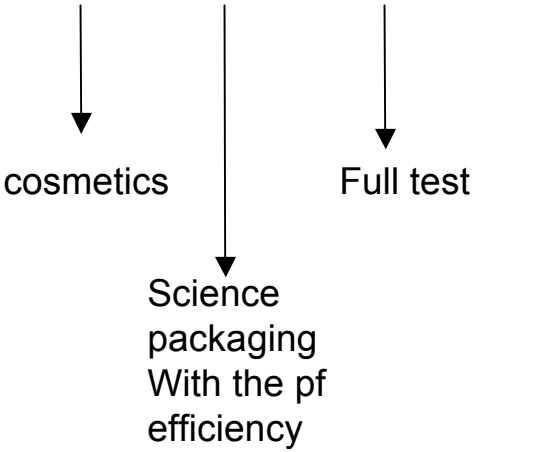
Light bulbs problems solved as discussed by Brenna.

Yield estimation

DARK ENERGY SURVEY

Expected yield:

0.5 x 0.85 x 0.7 = 0.3



Assumes:
- packaging of science modules as good as PF
- maintain the achieve rate for passing the full test

Concerns:
- packaging yield (not much experience with pedestal modules yet

We have a total of **32 unpackaged 2k x 4k**:

- 14 with no light bulbs from Lot1A and Lot1B.1
- 8 with no light bulbs from Lot1B.2

Computing for CCD and camera testing (1.2.4)

DARK ENERGY SURVEY

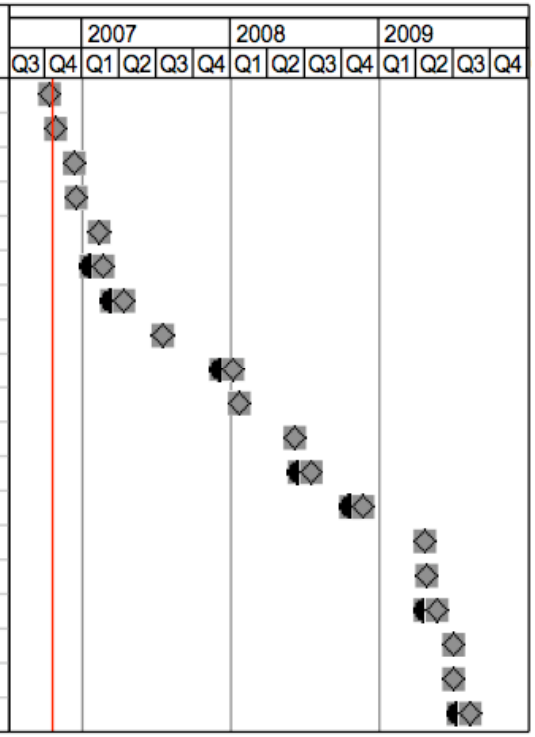
Details on this will be covered by L. Buckley-Geer in the breakout session. This task includes:

- **Graphical User Interface (GUI) for controlling the Monsoon hardware and the optical instruments**:
  - Have currently something working for the individual testing stations
  - Work is being done to polish the interface and accommodate multiCCD test vessel
- **Development of a CCD testing database and data storage system** with easy access to collaborators from outside FNAL (including a electronic logbook):
  - First implementation in place
- **Monsoon Alarm system.** Prototype in place, for the moment attached to the Monsoon testing GUI.

Schedule Summary

DARK ENERGY SURVEY

WBS-Level 3	Name	Forecast Start	Baseline Start	Variance
1.2.4	L4 - Release first version of data access tools to users	7/13/2006	7/13/2006	0 wks
1.2.3	L4 - First Pedestal Package Tested	7/27/2006	7/27/2006	0 wks
1.2.3	L4 - Autofill For 3 Cubes Operational	9/11/2006	9/11/2006	0 wks
1.2.4	L4 - Release v2 of data access tools to users	9/18/2006	9/18/2006	0 wks
1.2.3	L4 - Lot 2A testing started	11/13/2006	11/13/2006	0 wks
1.2.3	L3 - Design review of testing plans complete	10/23/2006	11/22/2006	-4.4 wks
1.2.5	L3 - CCD Processing and Packaging (v1) Review Complete	12/13/2006	1/12/2007	-2.4 wks
1.2.1	L4 - Cold probe yield known for Lots 2A and 2B	4/18/2007	4/18/2007	0 wks
1.2.5	L3 - CCD Processing and Packaging (v2) Review Complete	9/5/2007	10/5/2007	-4.4 wks
1.2.1	L4 - Cold probe yield known for Lots 2C and 2D	10/24/2007	10/24/2007	0 wks
1.2.4	L4 - Release v3 of data access tools to users	3/7/2008	3/7/2008	0 wks
1.2.5	L3 - 1st prod. CCD ready for testing	3/18/2008	4/17/2008	-4.4 wks
1.2.1	L3 - 30 production wafers delivered to FNAL	7/22/2008	8/21/2008	-4.4 wks
1.2.1	L4 - Final CCDs at FNAL	1/19/2009	1/19/2009	0 wks
1.2.2	L4 - v2 Guide & Focus Packaging Complete	1/27/2009	1/27/2009	0 wks
1.2.1	L3 - Final CCDs at FNAL	1/19/2009	2/18/2009	-4.4 wks
1.2.2	L4 - CCD Packaging Complete	4/2/2009	4/2/2009	0 wks
1.2.3	L4 - CCDs Ready for mounting on focal plane	4/2/2009	4/2/2009	0 wks
1.2.5	L3 - Production CCD testing complete	4/9/2009	5/9/2009	-4.2 wks



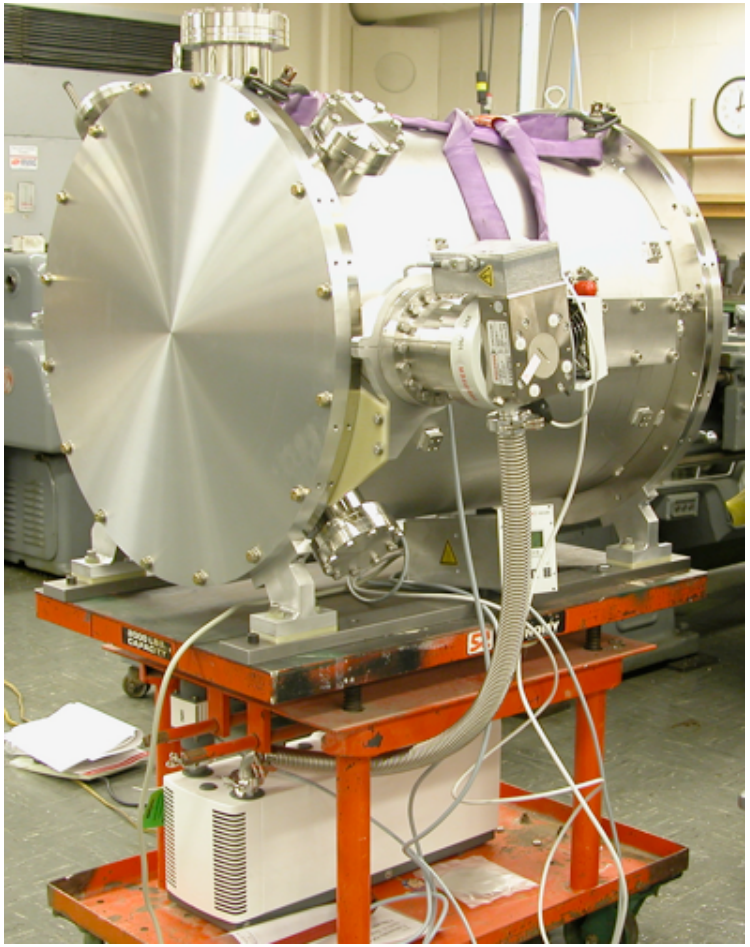
DARK ENERGY SURVEY

Cost at Level 3

WBS	Task	M&S ($M)	Labor ($M)	In-Kind	Total ($M)
1.2	**Focal Plane Detectors**	**2.52**	**1.44**	**0.03**	**3.99**
1.2.1	CCDs	1.75	0.12	0.00	1.86
1.2.2	CCD Packaging	0.44	0.60	0.02	1.06
1.2.3	CCD testing and characterization	0.33	0.58	0.02	0.93
1.2.4	Computing for CCD and Camera testing	0.00	0.14	0.00	0.14

Numbers and unburdened and unescalated

New Toy



Currently at FNAL, the full size camera prototype built at U.of Chicago will allow us to operate multiple CCDs (changes needed in software, electronics and controls).

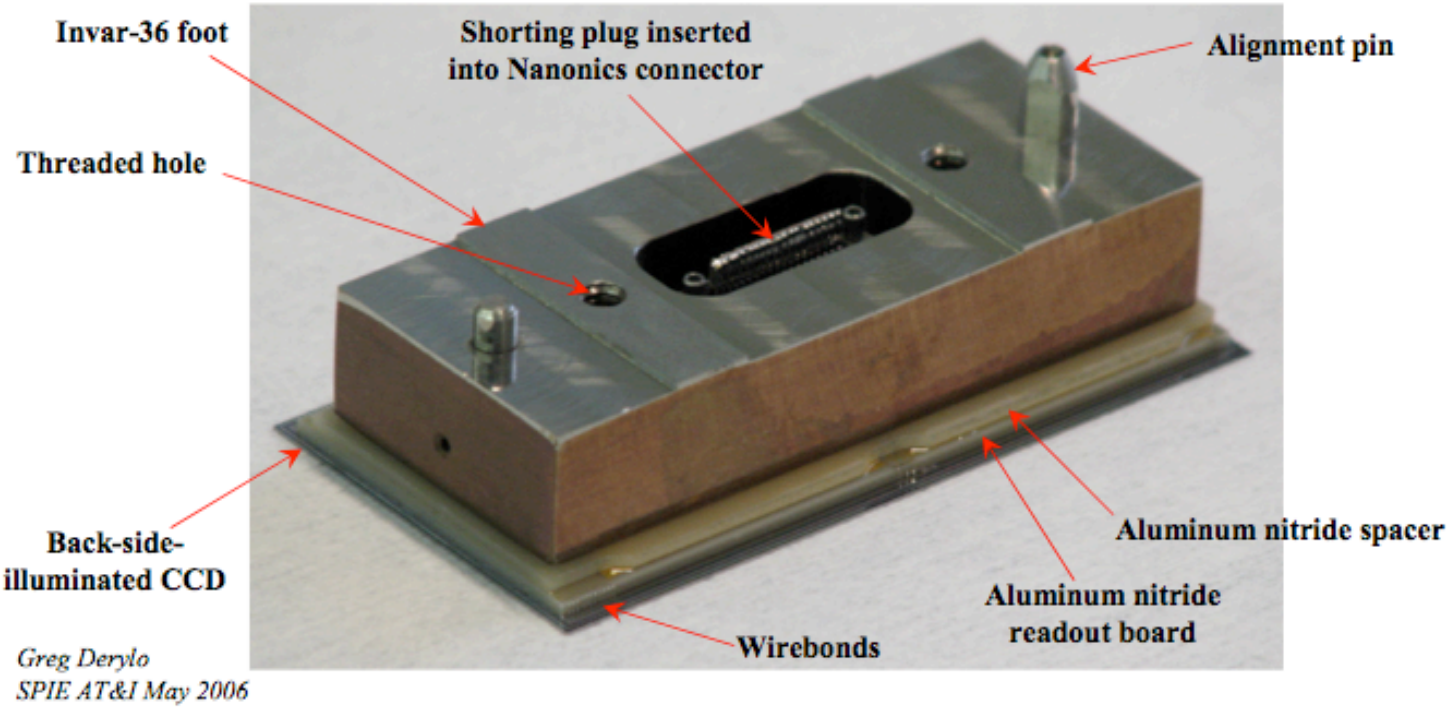
We expect to be operating this camera in the fall.

DARK ENERGY
SURVEY

BACKUP SLIDES

Pedestal package for Focal Plane

DARK ENERGY SURVEY

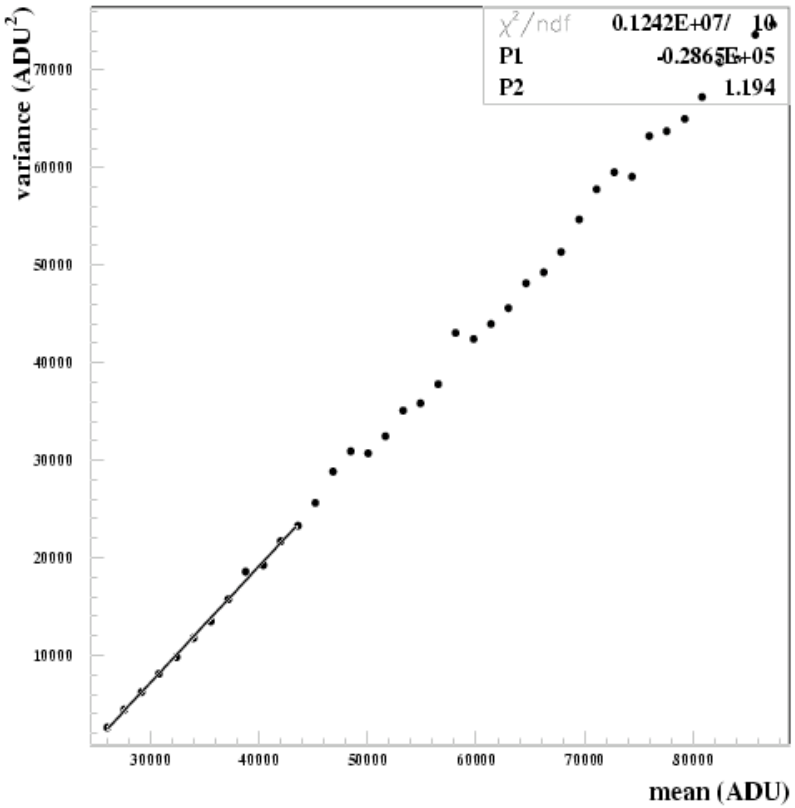


Now we have the Nanonics and that is the way we talk to the CCD. See talk by T.Shaw for details on the hardware used. Cable for the readout of this package has been tested and gives good performance on PF.

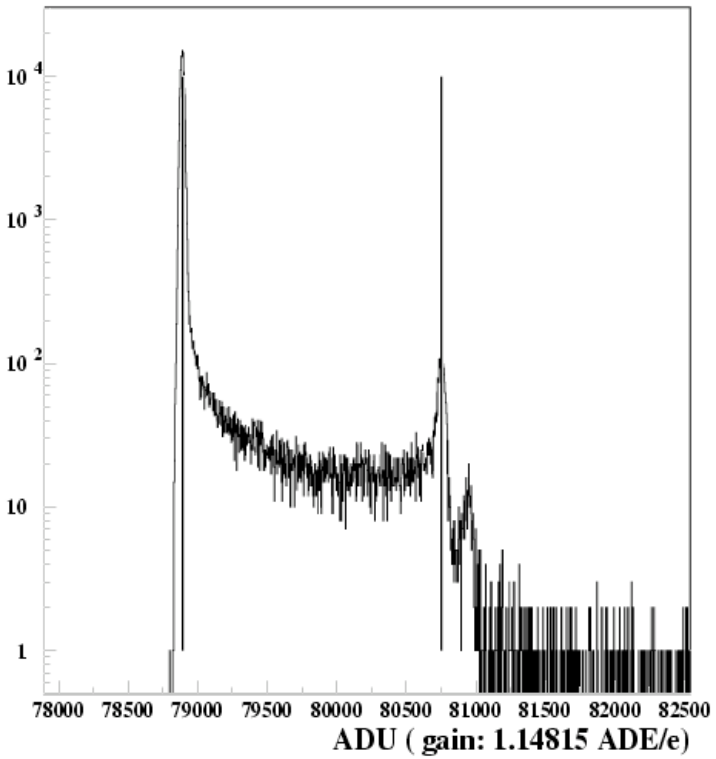
Gain determination

DARK ENERGY SURVEY

Conversion gain is needed to obtain the performance parameters in terms of electrons.

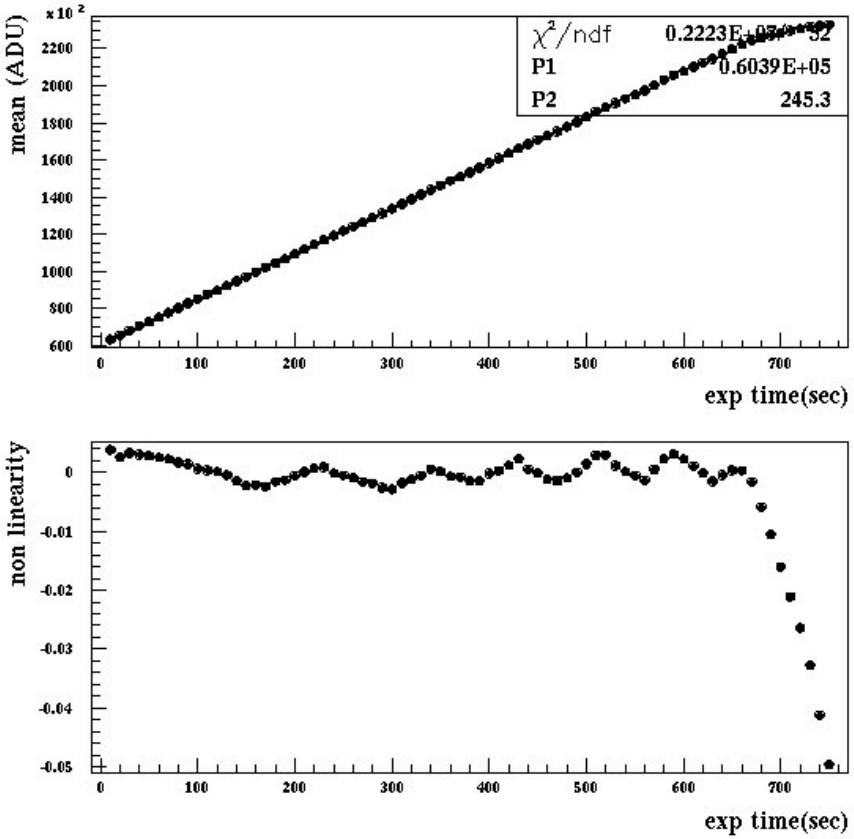


Assuming Poisson statistics the relation between the mean and the variance is used to determine the gain. The gain is also verified (for some devices) with Fe55 X-ray source.



Linearity better than 1%
Full well > 130000 e

DARK ENERGY SURVEY



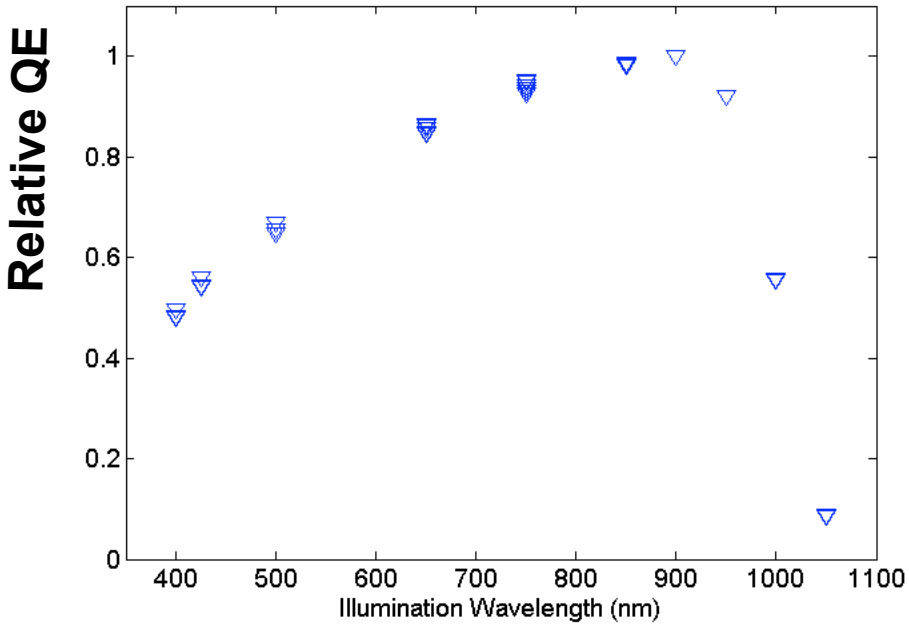
The photon transfer curve data is used to determine the linearity and full well.

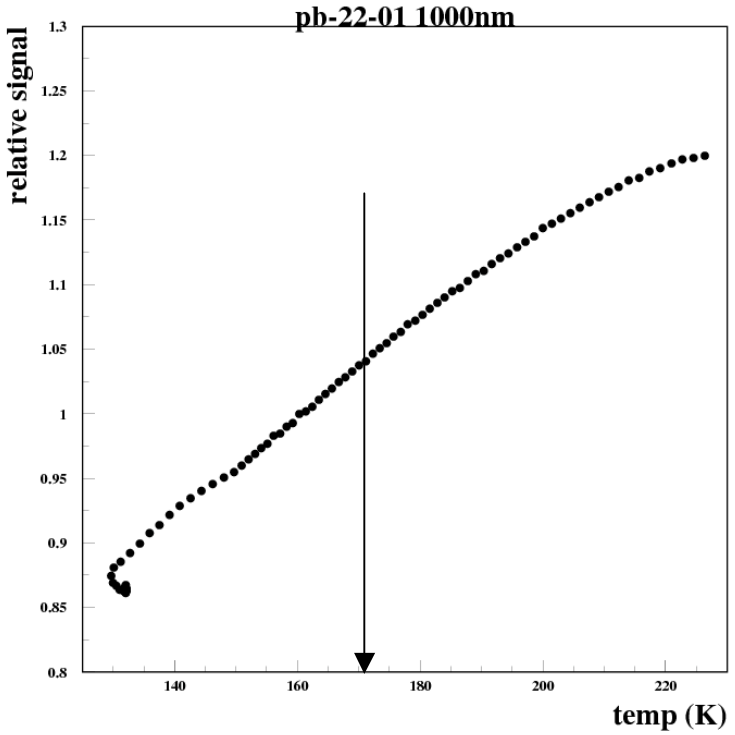
In this case linearity is better than 1% up to 150000e.

requirement satisfied √

QE better >50% at 1000nm

DARK ENERGY SURVEY





Relative QE measurements at FNAL.

Absolute QE measurement setup will be ready by the end of the summer. We are getting the expected performance.

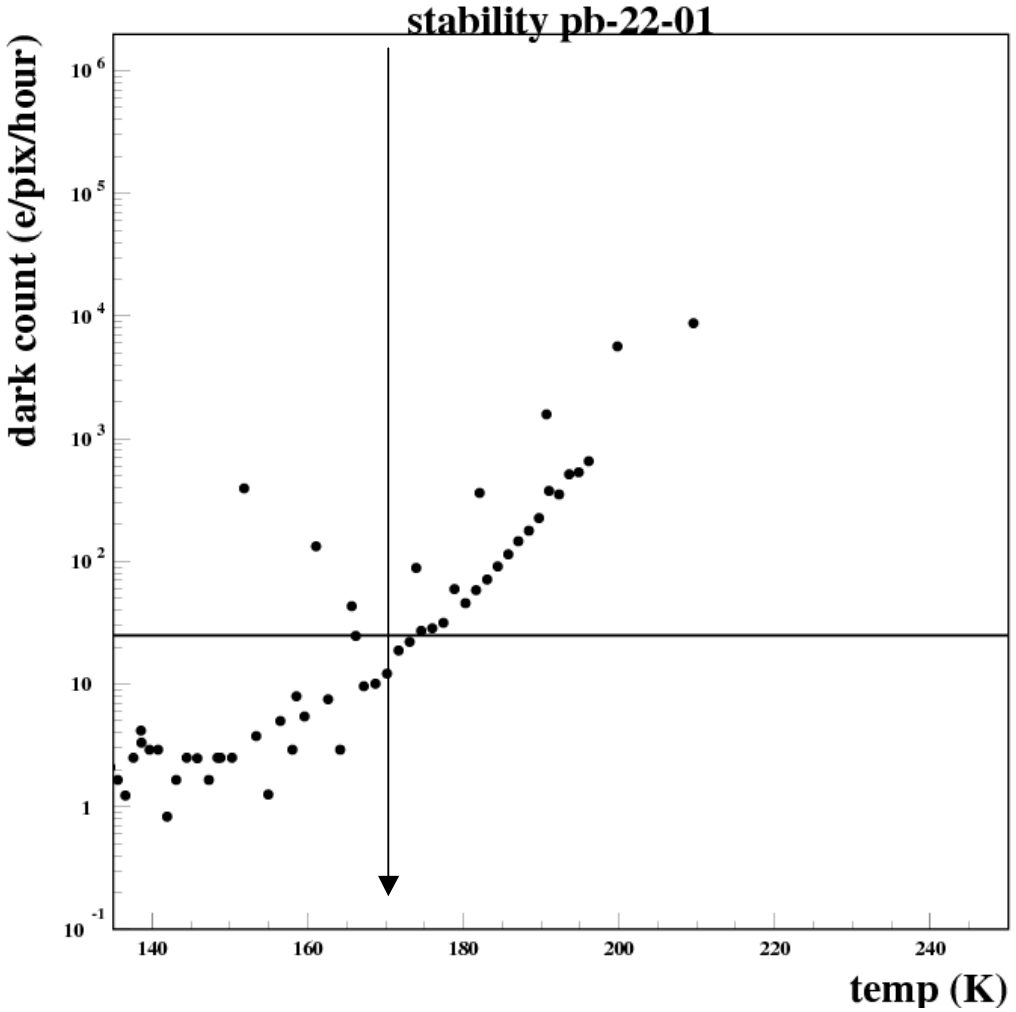
Temp dependence for the QE in the near IR has also been studied. Operating temp T=173K.

DARK ENERGY SURVEY

Dark current < 25 e/pix/hour

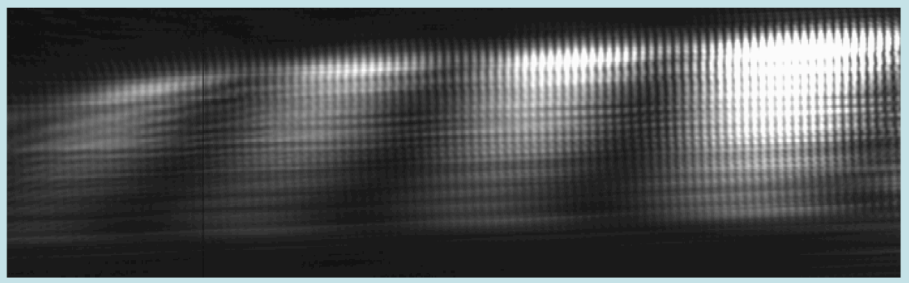
We can reach our dark current spec with the devices that have low number of defects (see later).

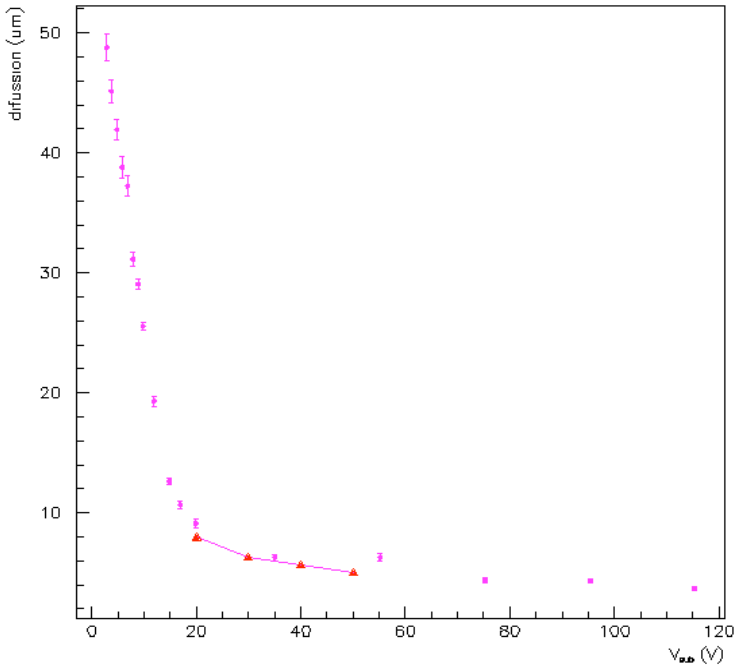
requirement satisfied √



Difussion < 7 μm

DARK ENERGY SURVEY





Using a diffraction pattern we have done measurements of diffusion that agree with our requirements, and the LBNL specs. We also expect to use the equipment at University of Michigan to confirm this measurements.

requirement satisfied √

DARK ENERGY SURVEY

Persistence

Persistence can also be considered part of the readout time problem. After the device is saturated, charge gets trapped in the back surface, the trapped charge will produce extra dark current.

A way to eliminate this dark current is by driving the CCD into inversion, we can not operate in inversion mode because we have 40V in the substrate voltage (Vsub).

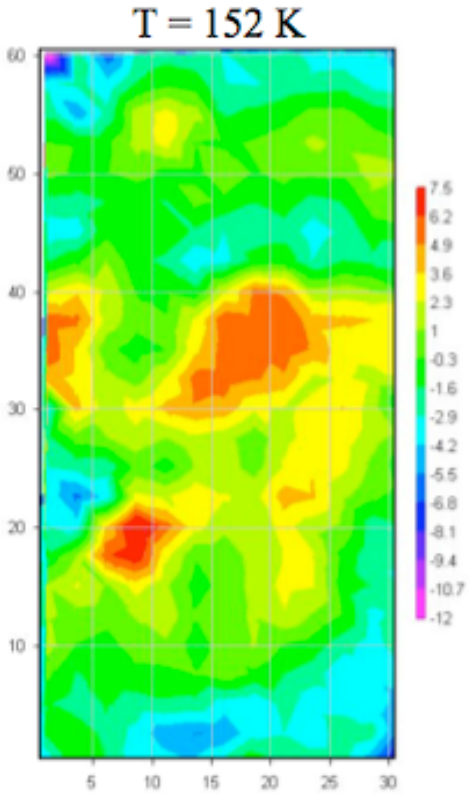
The idea is then to reduce the Vsub, go to inversion (V clocks high) and back to operating voltages. How fast can we do this?

We know we can do this in 10 sec or less, the question is how much less. The other question is how often we need to do this.

We now have automated the ERASE mechanism in our Monsoon system (because of the 40V needed some additional hardware to do this). Soon we will know how much we can reduce this time.

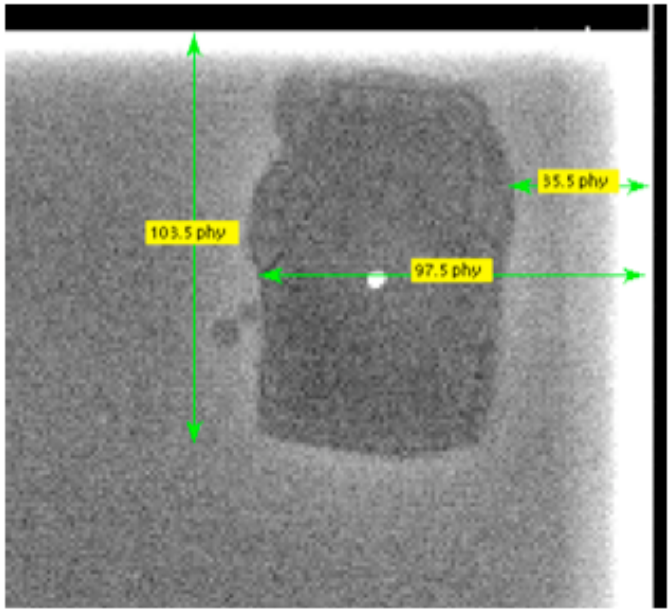
Package performance

DARK ENERGY SURVEY



The mechanical performance of the package is also studied at SiDet. Flatness testing station in place.

We also have been studying the edge effects. This has all been done in prototype versions of the pedestal package (before V1 in WBS 1.2.2.3).



Light bulbs

DARK ENERGY SURVEY

The light bulbs

Lot 1A:

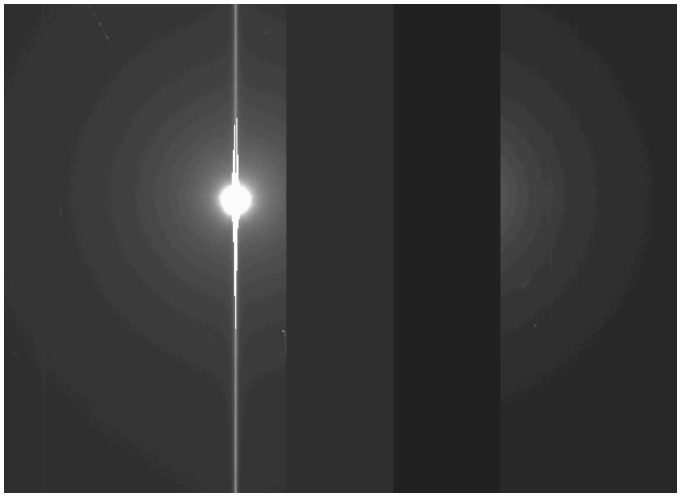
- thick = 0.6 lb/CCD
- thinned = 1.5 lb/CCD

•Lot 1B:

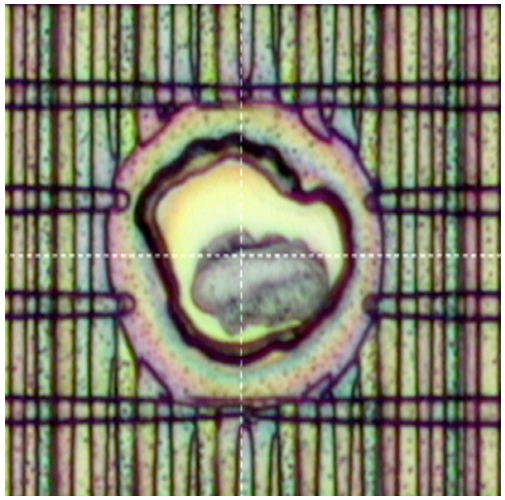
- thick = 0.09 lb/CCD
- **thinned 1B.1: 0.4 lb/CCD**
- **thinned 1B.2: 0/8 = 0 lb/CCD (*)**

(*) LBNL process parameters optimized. Information from cold probe data (no FNAL data yet).

Two possible solutions as discussed by Brenna.



This makes a CCD unusable.



More details in breakout session by J.E.