Sensors and Raft Tower Modules

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BROOKHAVEN NATIONAL LABORATORY

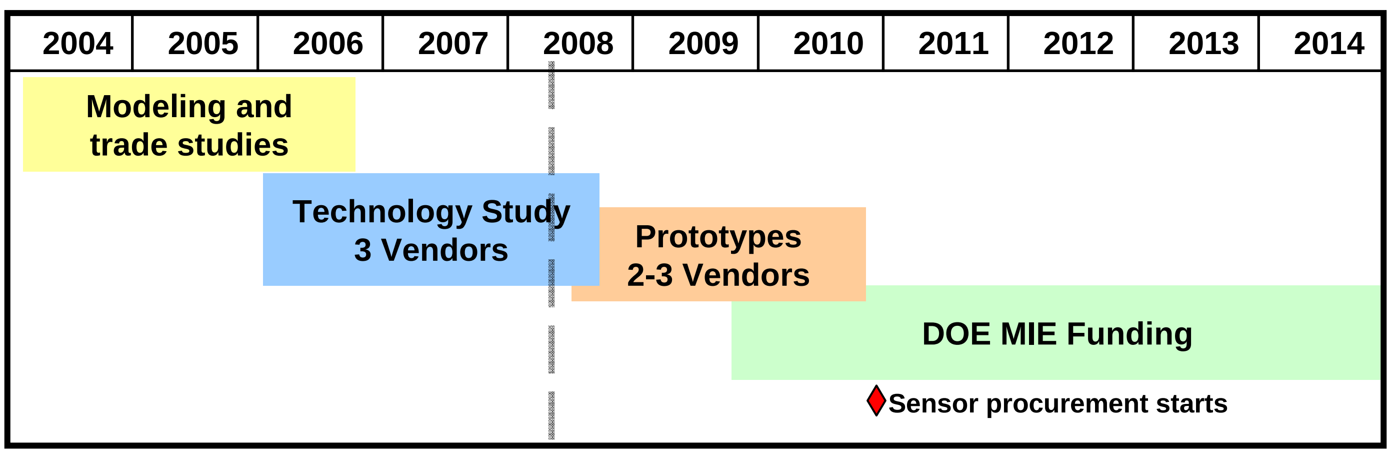
- * *IAA-CSIC Granada*
- ** *Charles Univ. Prague*

Outline

- **Sensor Prototype contracts**
  - *Scope, deliverables, and schedule*
- **Sensors experimental program**
  - *BNL test facilities*
  - *Results on study contract devices*
  - *Development of CCD Qualification Test*
  - *R&D Plans*
- **Raft Tower Module (RTM)**
  - *Design changes since CoDR*
  - *Metrology studies*
  - *R&D Plans*
- **Integration and Test**
  - *R&D Plans*
- **Timelines**
  - *R&D*
  - *Production*

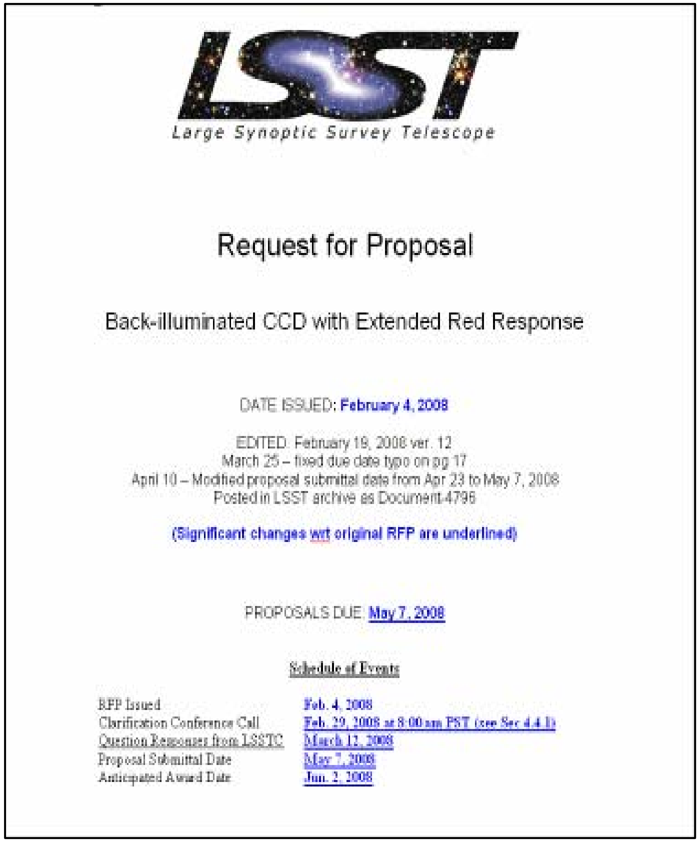
Sensor development plan

- **Technology study**
  - *understand and model device characteristics*
  - *engage qualified vendors*
  - *address the most pressing technical challenges early*
  - *establish test lab at BNL*
- **Prototype**
  - *multivendor competition*
  - *fabricate sensor meeting all LSST specifications*
  - *demonstrate yield and quality control*
  - *ramp up test capability within LSST collaborating institutions*
- **Production**
  - *manufacture, test, and deliver 200+ science-grade sensors*
  - *24-month production period*
  - *single- or dual-source*



Prototype Sensor Development Plan

- **Sensor prototype development funded by private donations through LSSTC**
- **Requested 2-year proposals for full-spec LSST sensors:**
  - all optical, electrical, mechanical requirements met
  - at least 2 operable samples delivered
  - production plan
  - manufacturability demonstration
  - optional deliverables:
    - proposal to deliver fully-assembled production rafts
    - wavefront sensor design report
- **Two of four bidders awarded for a total of $2.4M:**
  - e2V
  - Univ. of Arizona ITL
  - (both participated in sensor study contract phase)
- **Supplemental funding being sought to complete both vendors' proposed scope (and add a third qualified vendor?)**


Large Synoptic Survey Telescope

Request for Proposal

Back-illuminated CCD with Extended Red Response

DATE ISSUED: **February 4, 2008**

EDITED: February 19, 2008 ver. 12
March 25 – fixed due date typo on pg 17
April 10 – Modified proposal submittal date from Apr 23 to May 7, 2008
Posted in LSST archive as Document-4796

(Significant changes wrt original RFP are underlined)

PROPOSALS DUE: May 7, 2008

Schedule of Events

RFP Issued	Feb. 4, 2008
Clarification Conference Call	Feb. 29, 2008 at 8:00am PST (see Sec 4.4.1)
Question Responses from LSSTC	March 12, 2008
Proposal Submittal Date	May 7, 2008
Anticipated Award Date	Jun. 2, 2008

RFP for prototypes

- **Provided LSST project background, emphasizing focal plane concept.**
- **Presented sensor reference design and requirements table.**
- **Named organizational contacts:**
  - *LSSTC Project Manager and sensor contracts coordinator (D. Sweeney)*
  - *LSSTC Contracts Officer (D. Calabrese)*
  - *Sensor working group technical leads (V. Radeka, P. O'Connor)*
  - *LSST Project Director (T. Tyson)*
- **Requested 7 required deliverables:**
  1. *CCD design report*
  2. *Package design report*
  3. *Mechanical package model*
  4. *First operable lot prototypes & test reports*
  5. *Interim Review*
  6. *Yield & reproducibility demonstration (2 additional lots)*
  7. *Final review including production plan*
- **Two optional deliverables:**
  1. *Assembled raft baseplate design and production plan*
  2. *Curvature wavefront sensor design*
- **Suggested schedule of deliverables**
- **Eligibility and award selection criteria**

RFP evaluation and award procedure

- **Evaluation team selected by Don Sweeney:**
  - *J. Geary*
  - *K. Gilmore*
  - *P. O'Connor, chair*
  - *V. Radeka*
  - *T. Tyson*
  - *V. Krabbendam, D. Sweeney* (ex officio)
- **RFP issued Feb. 4, 2008**
- **Clarification telecon w/vendors Feb. 29**
- **Proposals received by May 7**
- **Evaluation committee met June 9-10 and issued recommendation memo to LSSTC**
- **Revised proposals received from awardees**
- **Formal contracts drafted**
- **Contracts signed Oct. ??**

Scope of work

- **e2v**
  - *all seven required deliverables*
  - *reduce quantity of mechanical samples*
  - *omit commissioning some production equipment*
  - *scale back manufacturability demo to one lot (require more contingency in production contract)*
  - *supplemental funding of $0.4M needed to recover full scope by 2010*
- **ITL**
  - *package development is emphasized (ITL has already delivered working 4K x 4K devices in study phase)*
  - *deliver packaged samples of study contract devices only (won't meet LSST specs in several areas).*
  - *no CCD redesign and no manufacturability demonstration*
  - *performance period reduced to 1 year*
  - *recovery of full scope needs additional $1.1M*

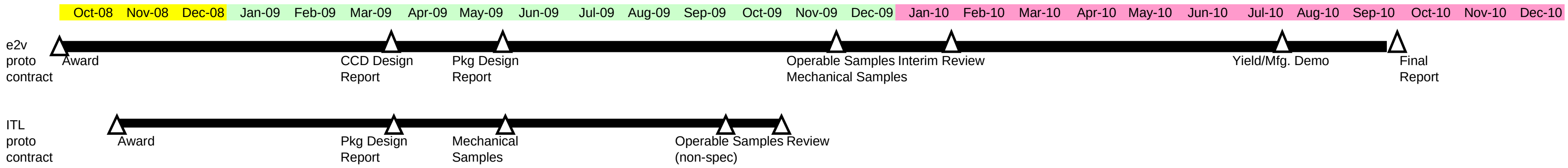
- **Wavefront sensor development remains unfunded**

Package concepts from prototype vendors

Chart removed for public distribution

sensitive – not to be distributed outside collaboration

Timeline – prototype contracts

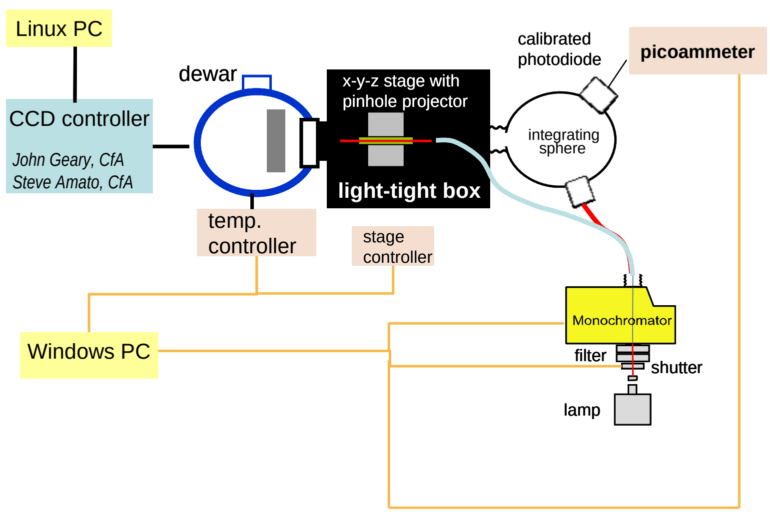


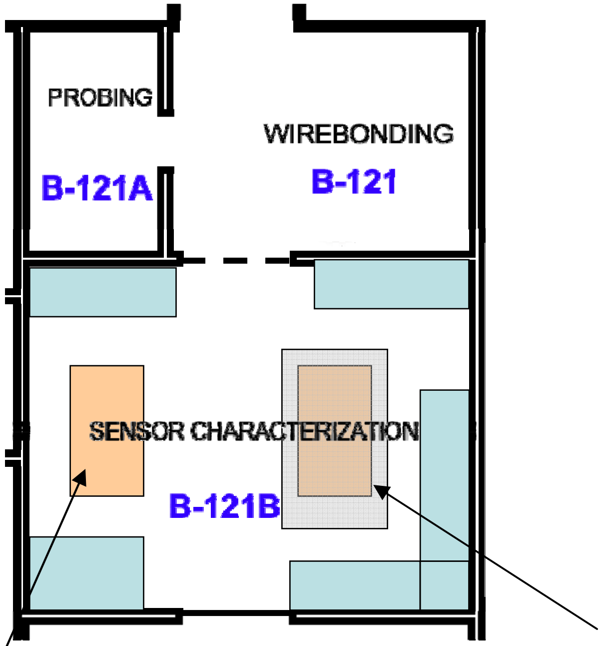
Sensors Experimental Program at BNL

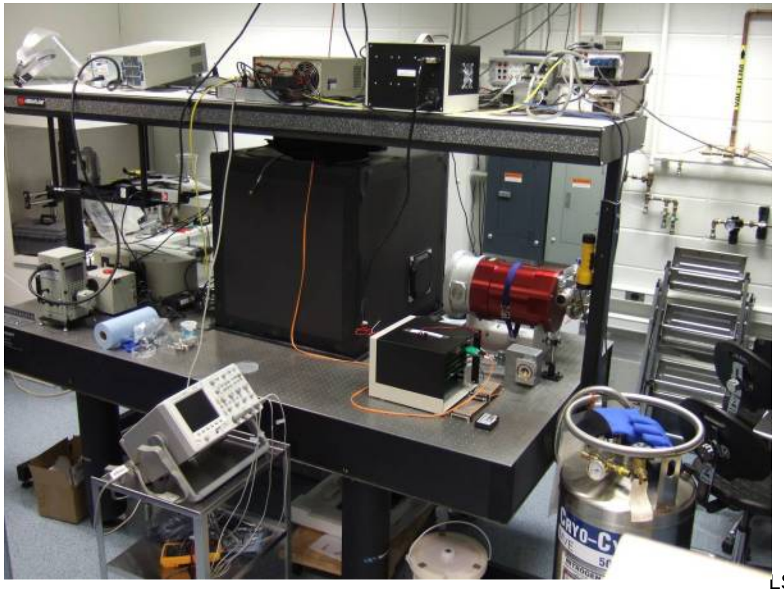
Goals

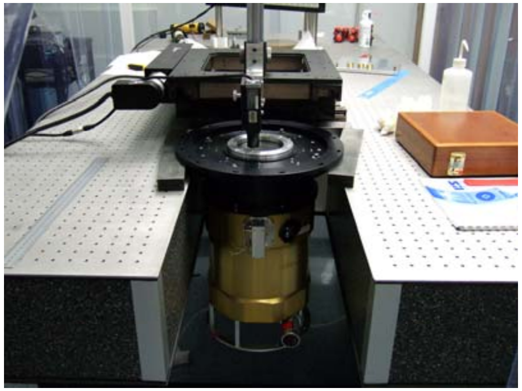
- **Understand behavior of thick fully depleted CCDs**
- **Study sources of intra- and inter-chip variability**
- **Develop qualification test for production sensors:**
  - *instrumentation and data collection*
  - *calibration*
  - *algorithms*
  - *database*

BNL Test Facilities – Bldg. 535



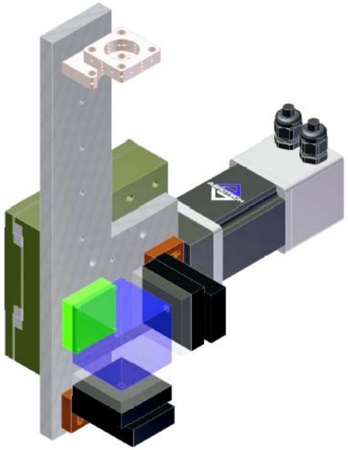


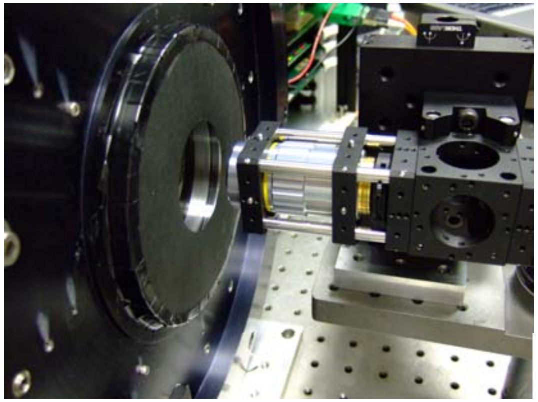


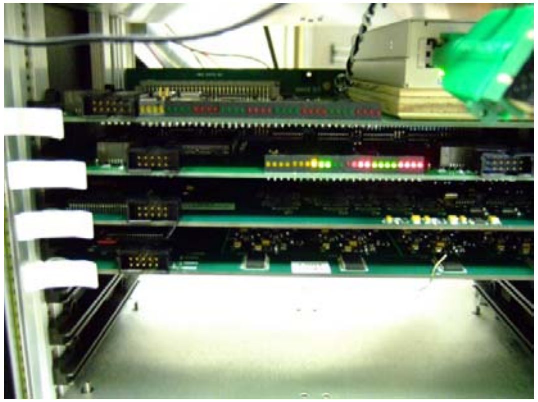


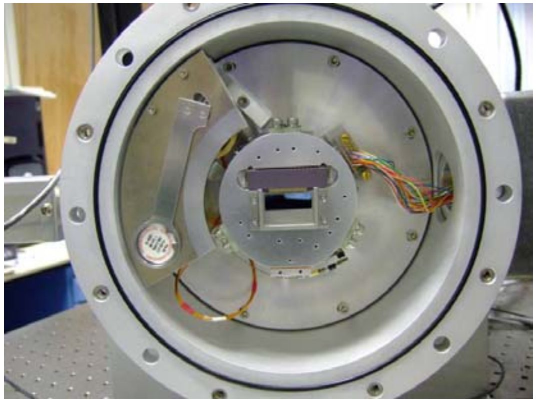
Purpose-built test equipment

- CCD controller
- Point projector
- Fringe projector
- In-cryostat xray source swing arm
- LN2 autofill







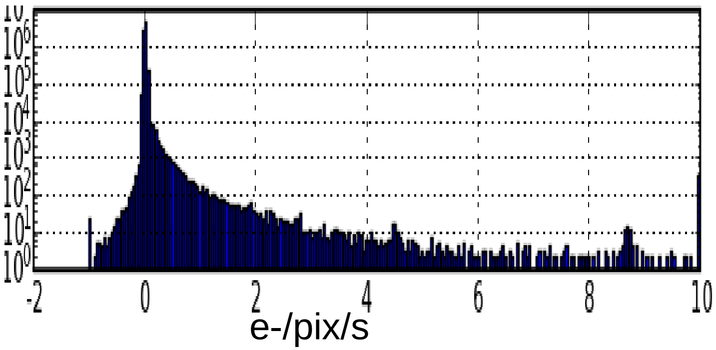


Results on e2v study contract CCDs

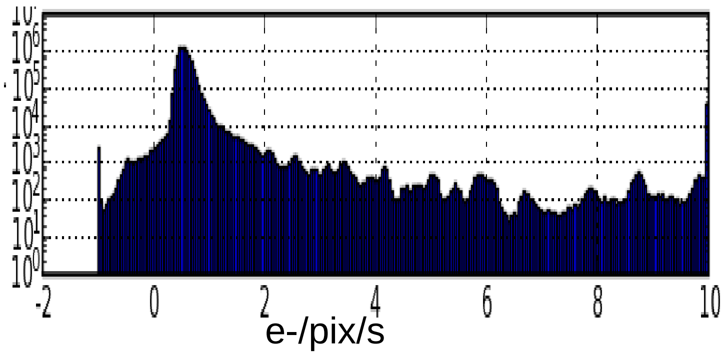
- **Five operable devices delivered**
- **Two mechanical samples**
- **100, 150μm thick**
- **single, two-stage amplifiers**
- **Format: 2K x 0.5K, 2K x 4.5K (col. x row)**
- **13.5μm pixels**
- **“first-generation” high-rho CCDs:**
  - *backside illuminated*
  - *biased, conductive window*
  - *no separate frontside substrate contact → high noise*
- **Results have been presented at 5/08 AHM, SPIE 6/08 meeting**

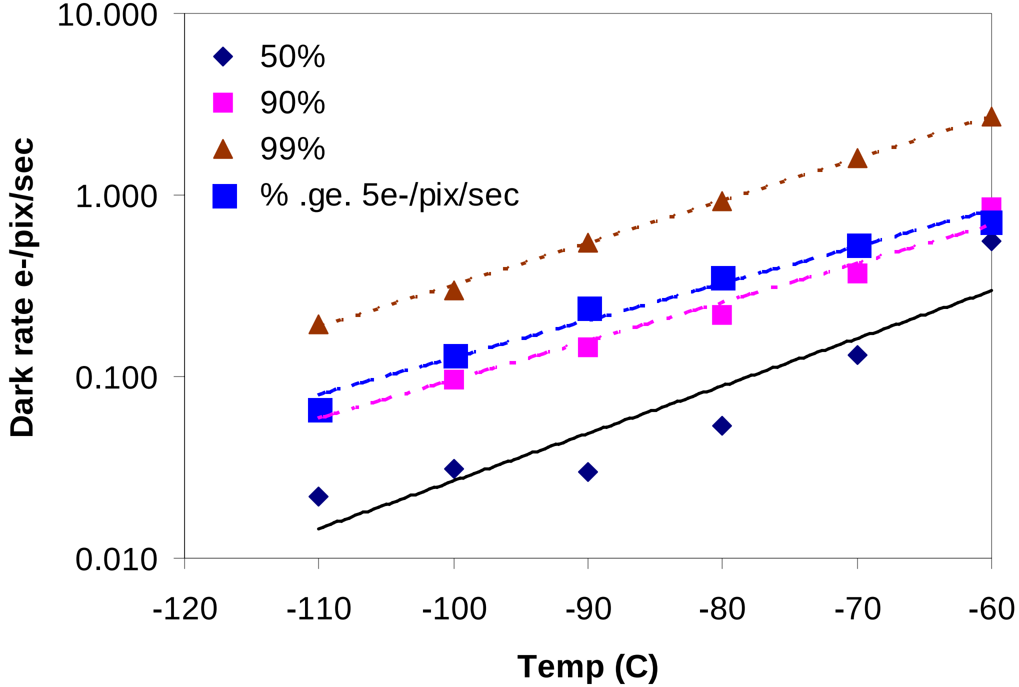
Dark current and defects

dark frame -110C



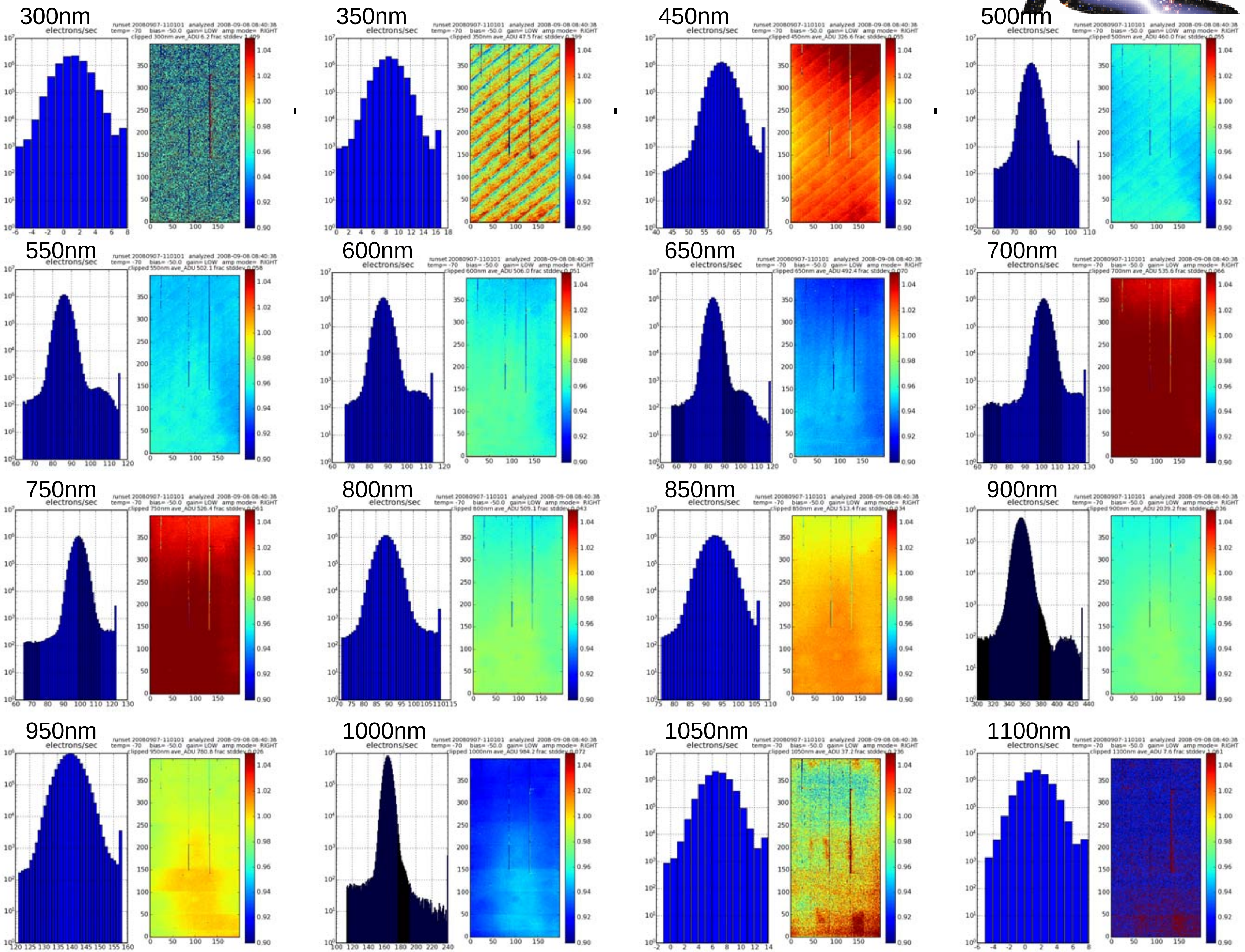
dark frame -60C



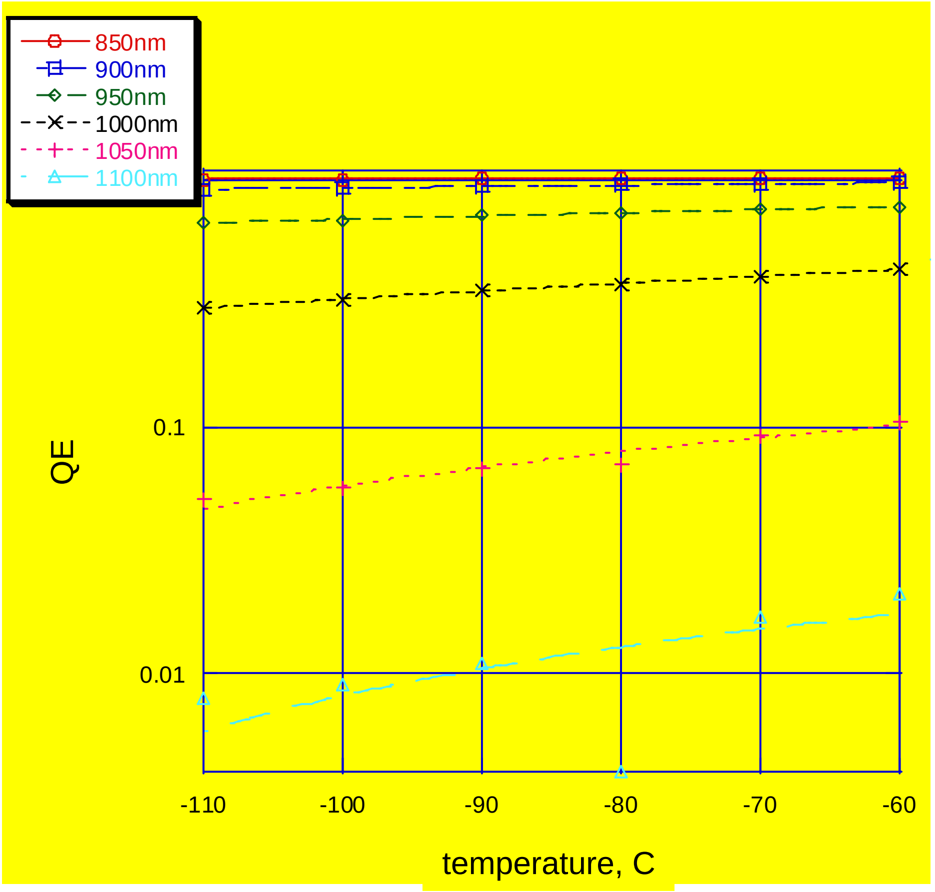


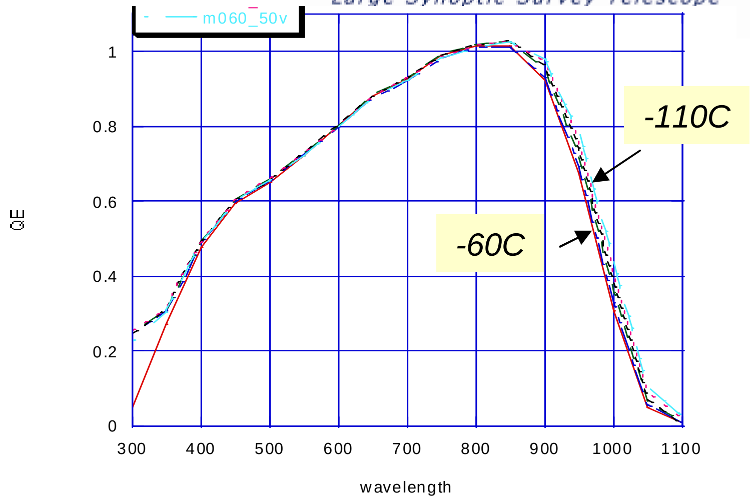
doubles every 12 - 17°C

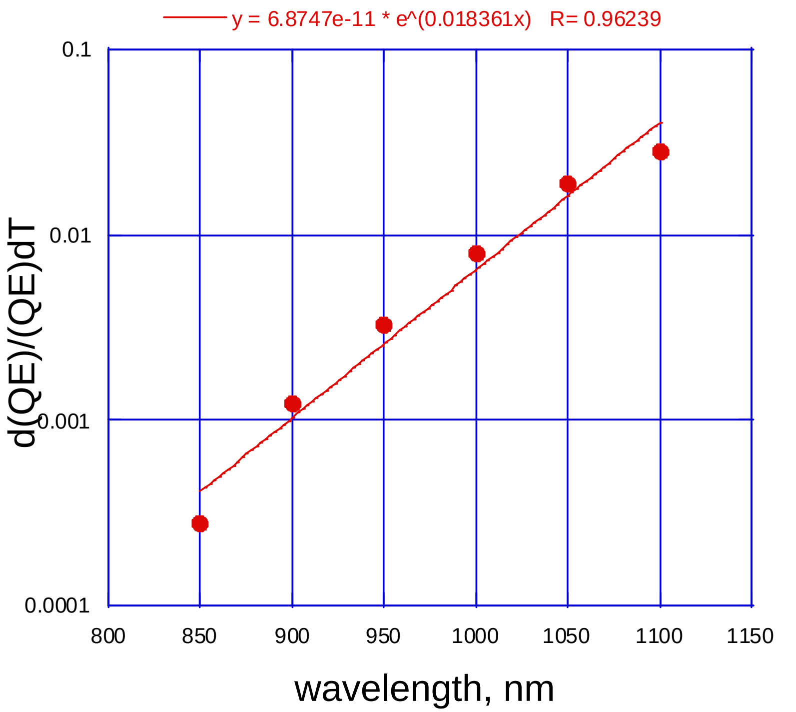
Normalized flatfield response vs. wavelength



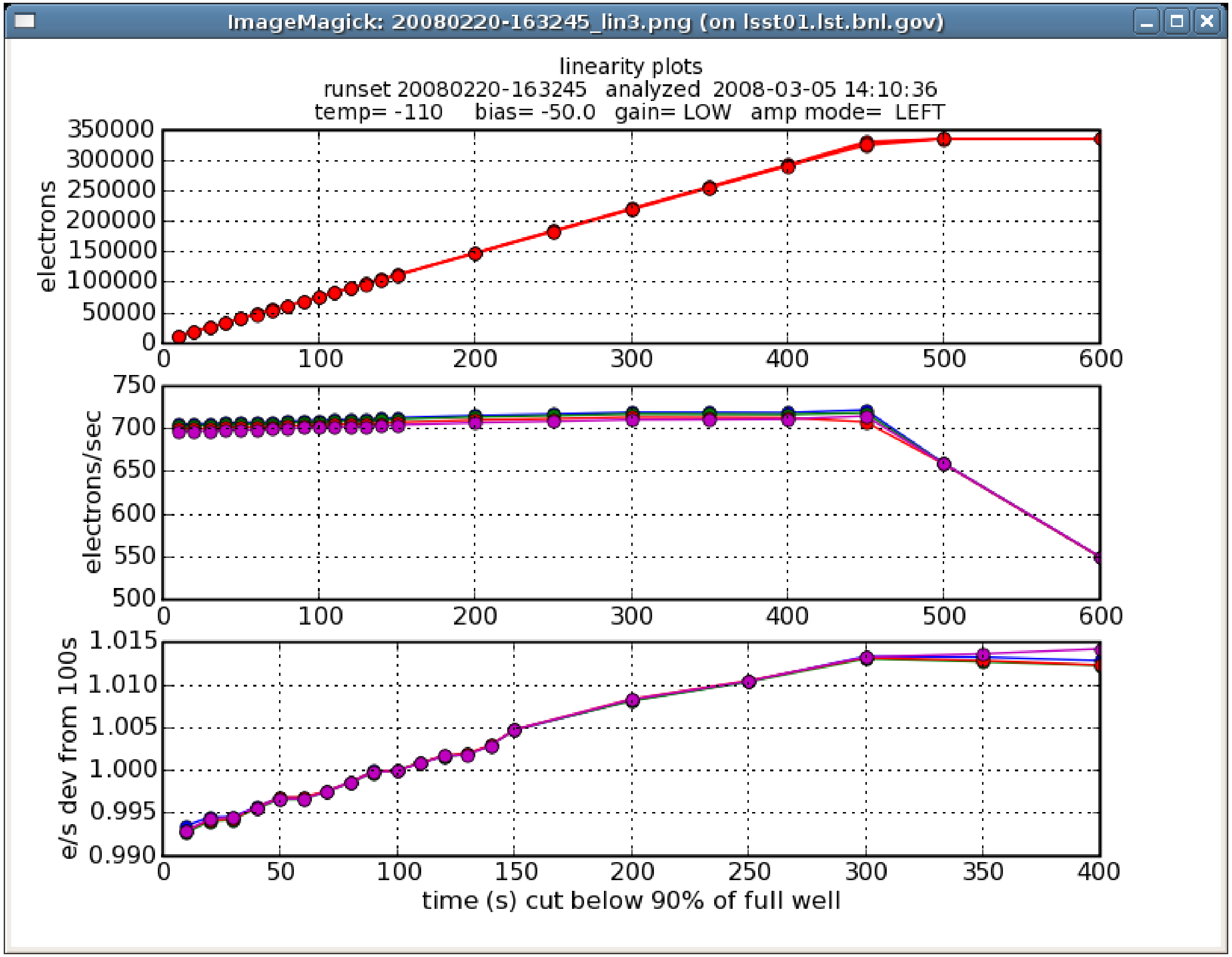
Quantum efficiency vs. temperature







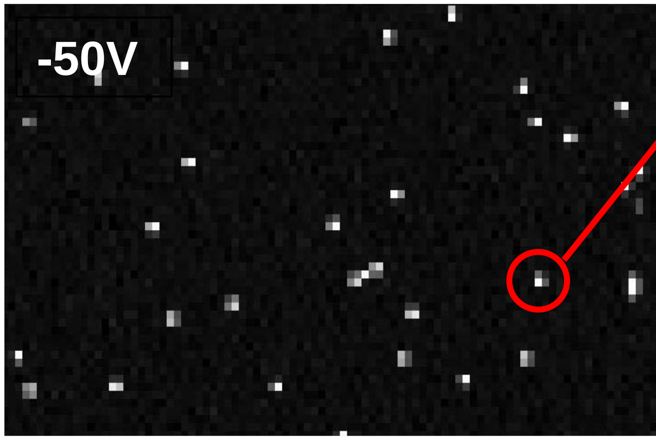
Linearity



ImageMagick: 20080220-163245_lin3.png (on lsst01.lst.bnl.gov)
linearity plots
runset 20080220-163245 analyzed 2008-03-05 14:10:36
temp= -110 bias= -50.0 gain= LOW amp mode= LEFT
electrons
electrons/sec
e/s dev from 100s
time (s) cut below 90% of full well

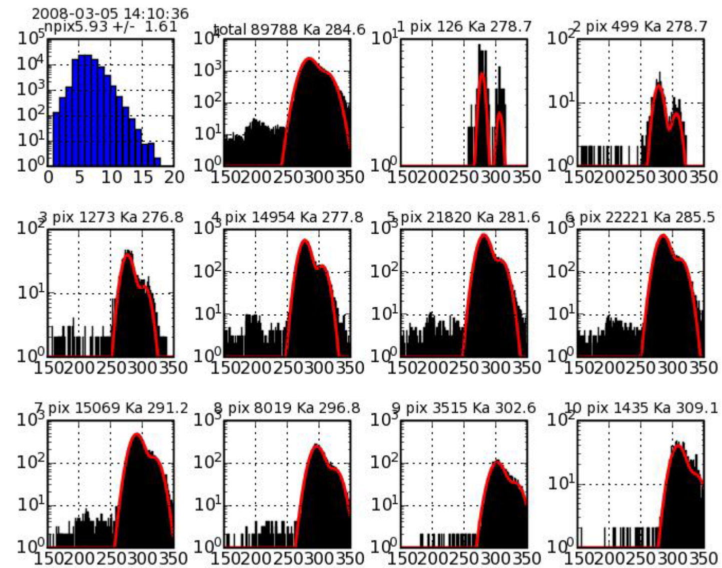
Two methods of Xray cluster analysis

small section of xray image

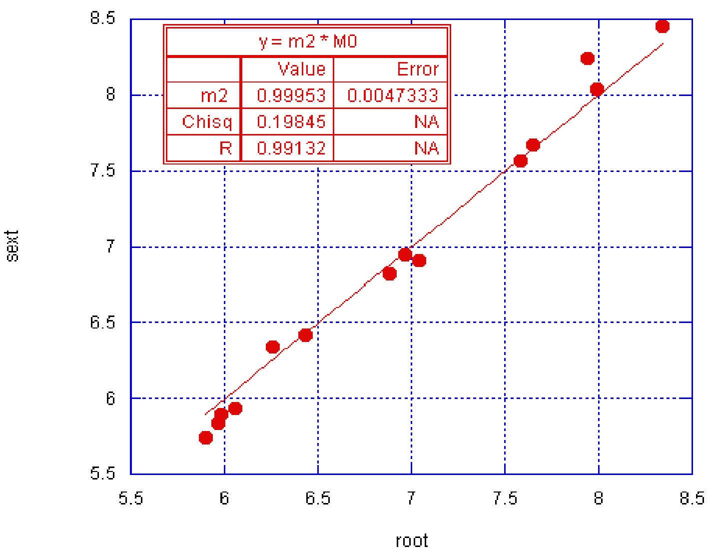


- *subtract bias frame*
- *identify clusters*
- *sum flux in cluster*
- *find conversion gain from known charge generated by ^{55}Fe $K\alpha$, $K\beta$ photons*

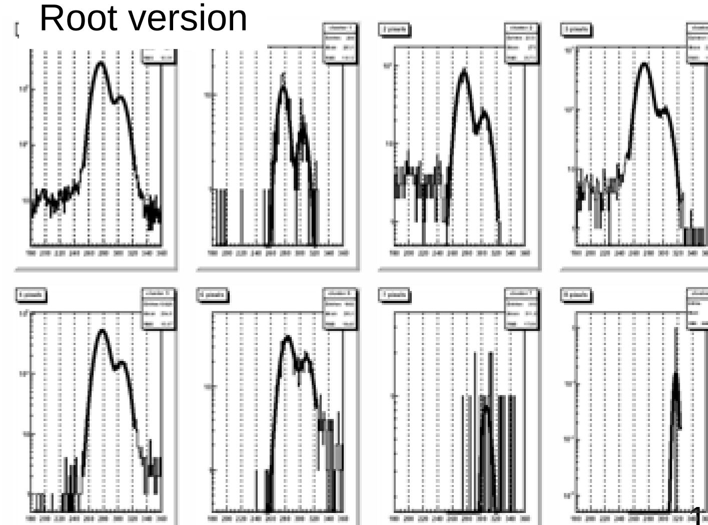
Sextractor version



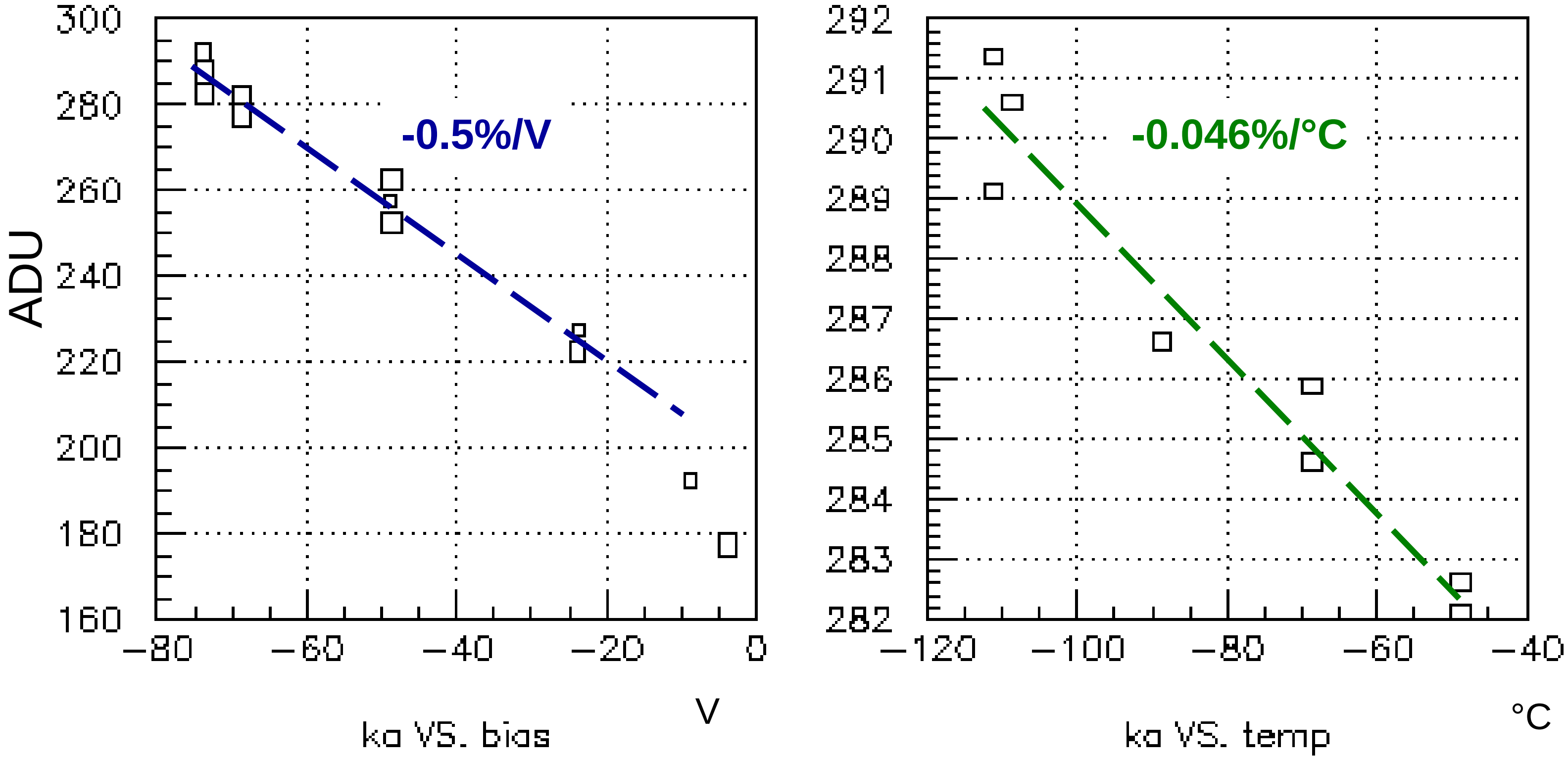
gain from 'sextractor' vs gain from 'root'



Root version



Conversion gain vs. substrate bias and temperature

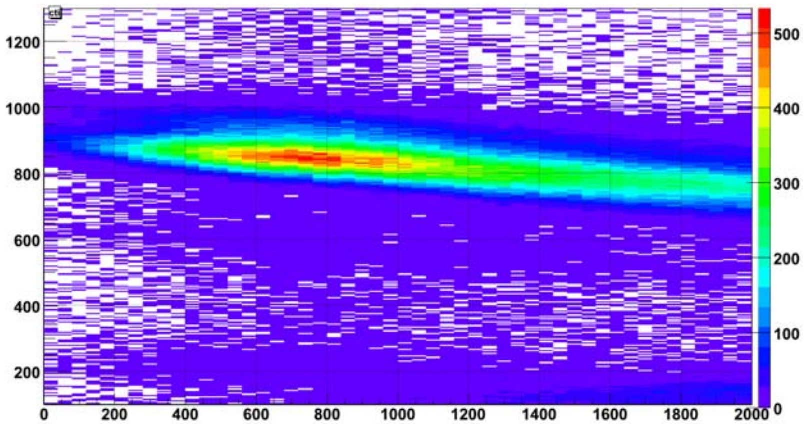


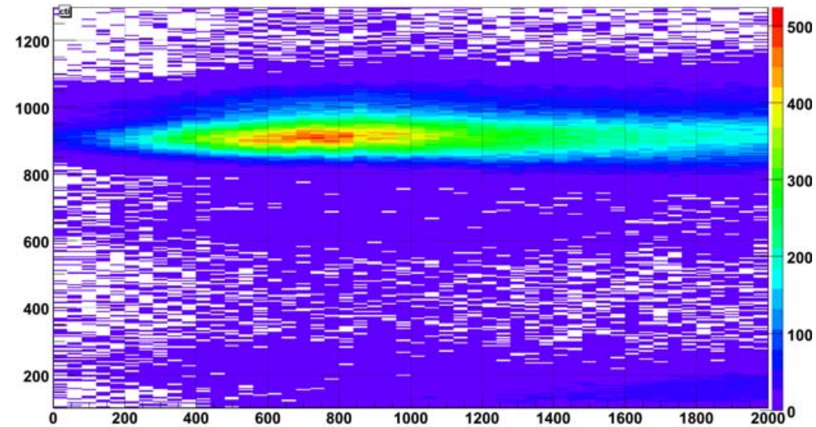
CTE: 200808 data set, device 106-07, T=-140C

initial distribution

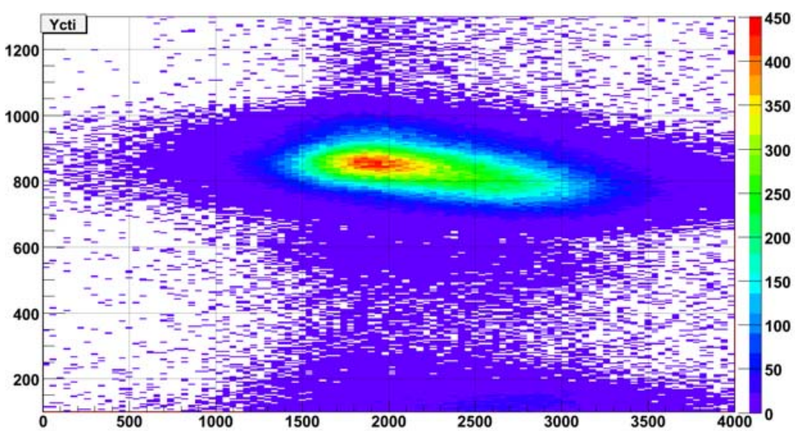
after correction

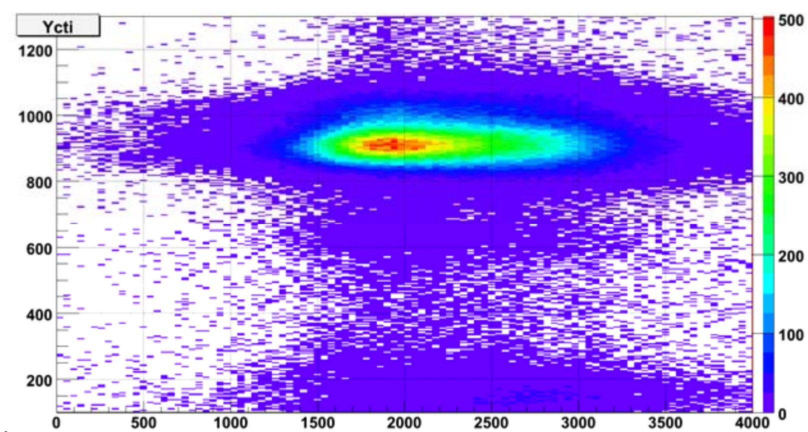
X direction, serial transfer CTE=0.999911





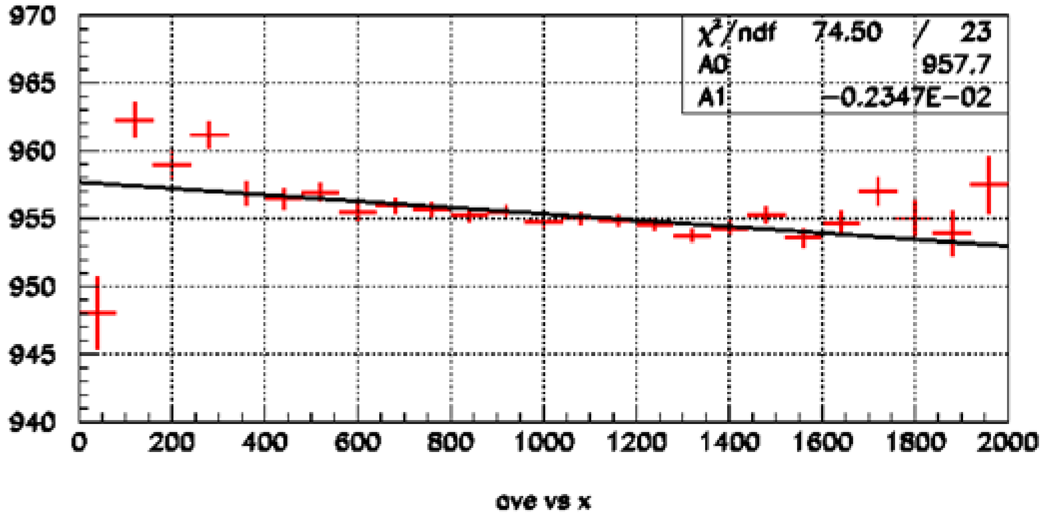
Y direction, parallel transfer CTE=0.999996





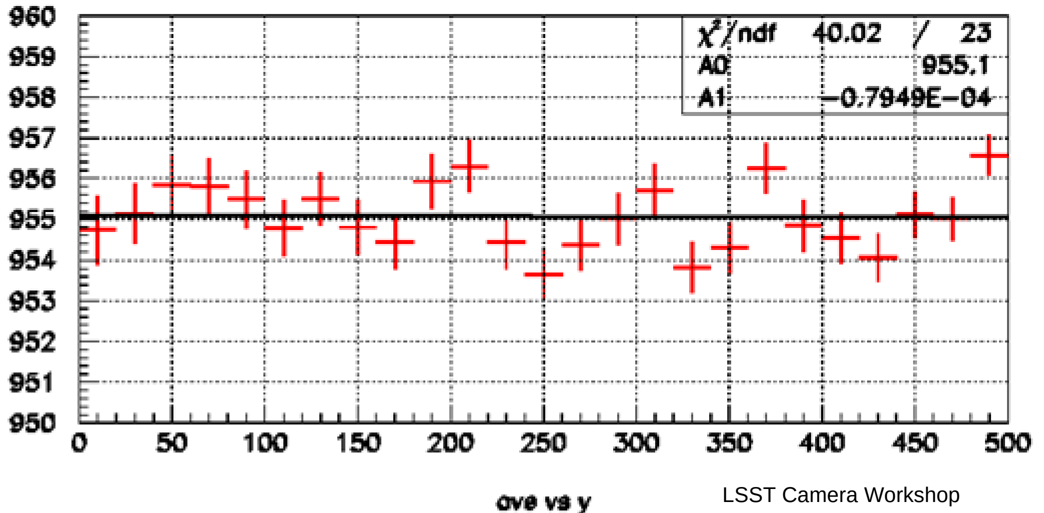
Charge Transfer Efficiency (Inefficiency)

CTE from slope of ^{55}Fe peak vs. no. pixels shifted



CTE_{ser} = .9999975

(CTI_{ser} = 2.45e-6)

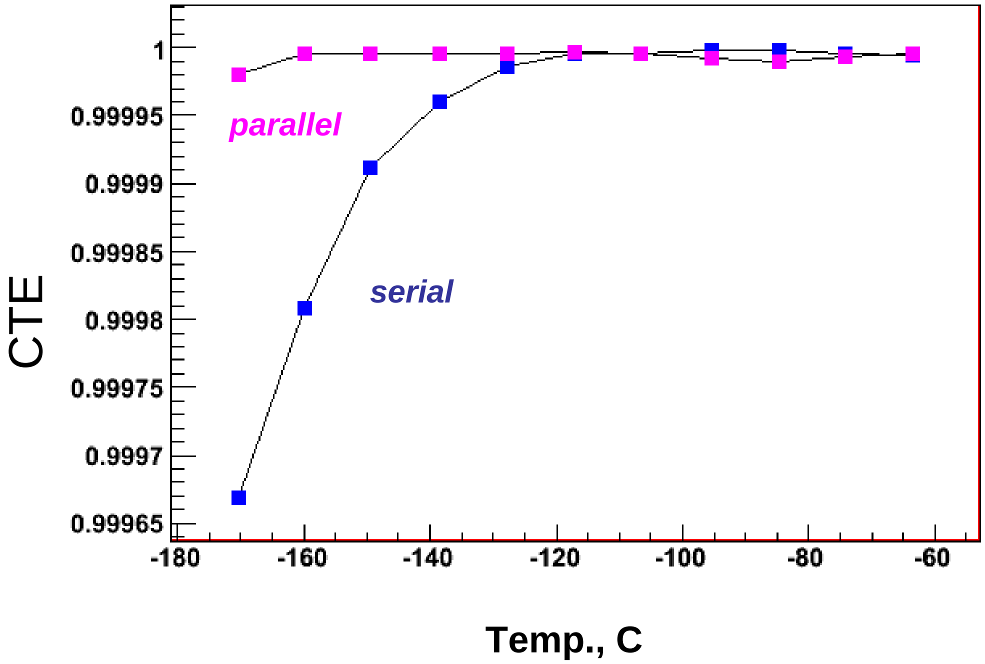


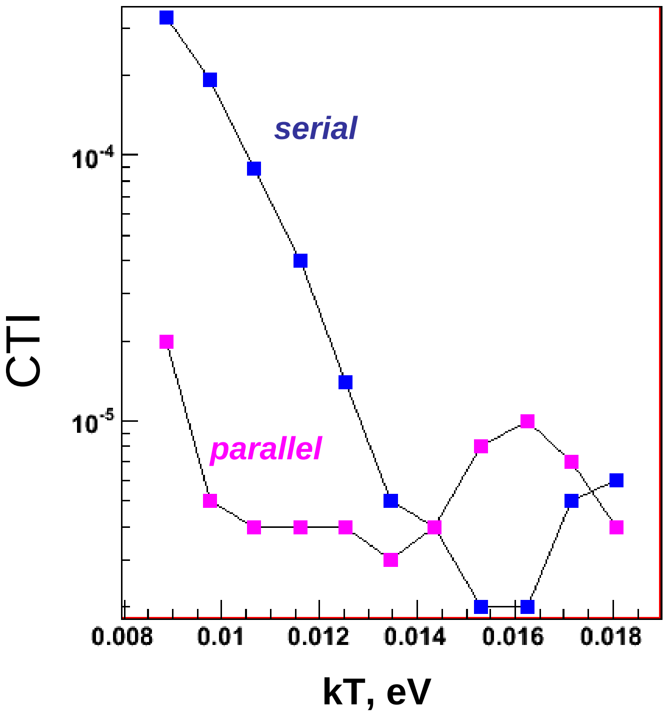
CTE_{par} = .99999992

(CTI_{par} = 8.3e-8)

512 x 2008 pixel device
166kpix/s, -110C

Charge transfer efficiency vs. temperature





Model

- **High field effects important at our electric field**
- **Drift time increase due to velocity saturation**
  - *substantially increases diffusion*
  - *effects hole transport differently than electrons*
- **Possible suppression of transverse diffusion coefficient at high fields**
  - *reduces diffusion, countering velocity saturation effect*
- **Possible non-uniform doping of high-rho silicon near entrance window**
  - *would leave thin undepleted, field-free region, leading to high diffusion*
- **Not easy to distinguish experimentally**

Measurement

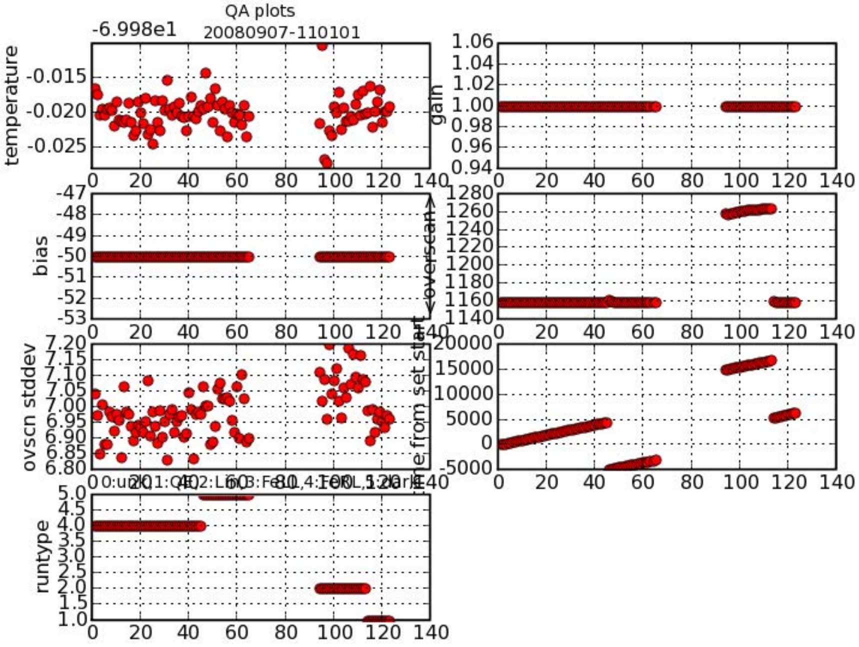
- **Virtual Knife Edge method**
  - *project small spot on detector, scan spot, calculate flux in virtual box*
  - *differentiate to get PSF*
- **Modulation transfer function method**
  - *project sinewave pattern on detector, measure contrast vs. spatial frequency*
- **Xray method**
  - *analyze distribution of xray cluster size, fit to PSF model*
- **Cosmic ray method**
  - *oblique-incident cosmic muons leave long track*
  - *track width on detector is indication of diffusion as function of depth*
  - *estimate diffusion vs. depth from track width (compare simulation)*

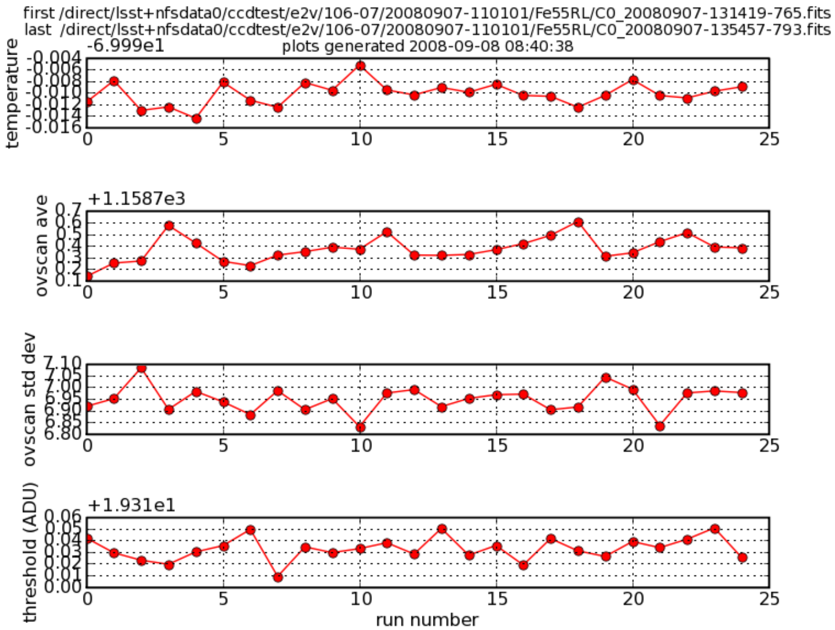
Diffusion calculation and measurement

Thk	100				75	45	193	280	um
Rho	3000				3000		3800	12800	Ohm-cm
Bias	-70				-50		133	80	V
Temp	163		203		200		140	140	K
	e-	h	e-	h	e	e	h	h	
No HFE	2	2	2.2	2.2	2.1	1.7	2.6	4.9	um
VS only	4.3	3.3	4	3.2	3.5	2.7	4.7	6.8	um
VS + DT-s	2.3	2.8	1.7	2.9	2.4	2	3.7	6.4	um
Meas.	5				3.1	1.9	3.9	6.3	um
Ref.	BNL				Tonry	Tonry	Karcher	Holland	

Camera requirement: 0.”25 FWHM = 5.30μm

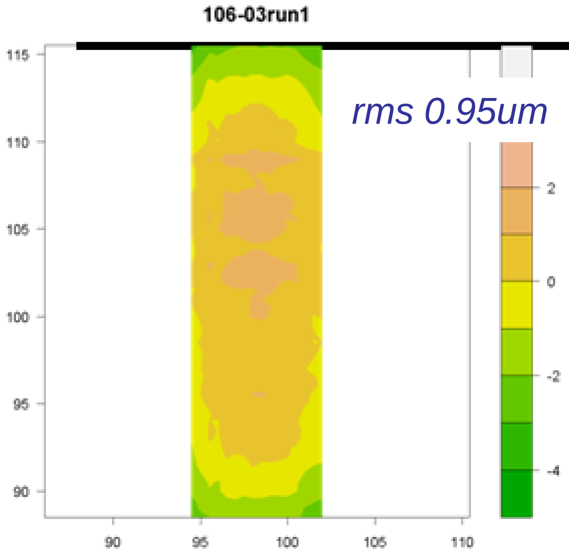
Data QA plots





monitor track of temperature, noise and offset in overscan image region during overnight data taking runs

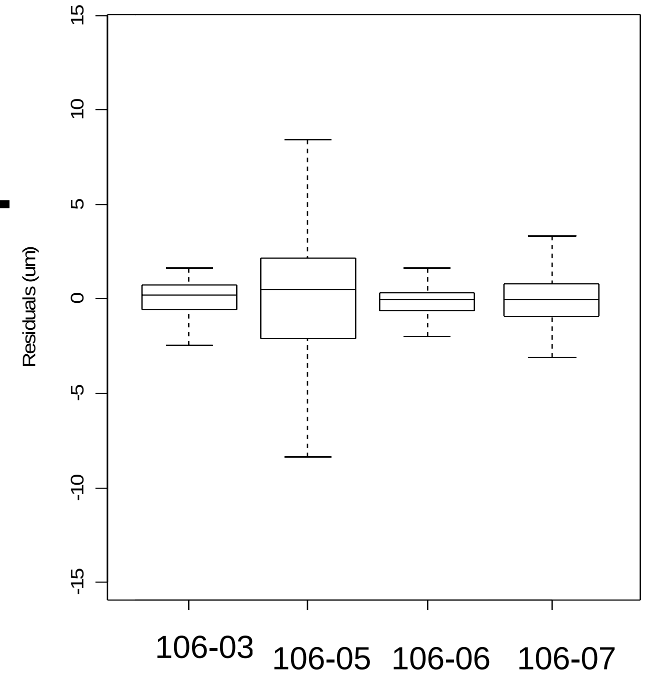
Flatness: e2v study contract devices

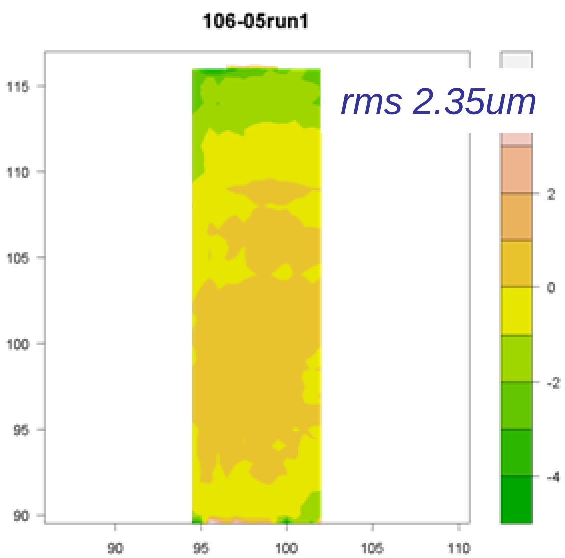


rms 0.95um

x,y: mm

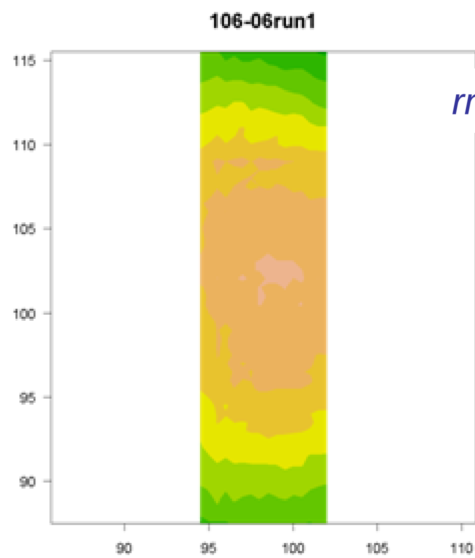
z: micron





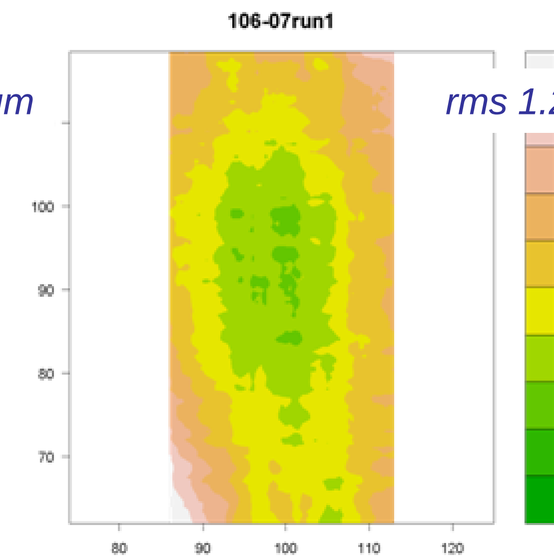
rms 2.35um

study deliverable, 2K x 512, backside



rms 1.54um

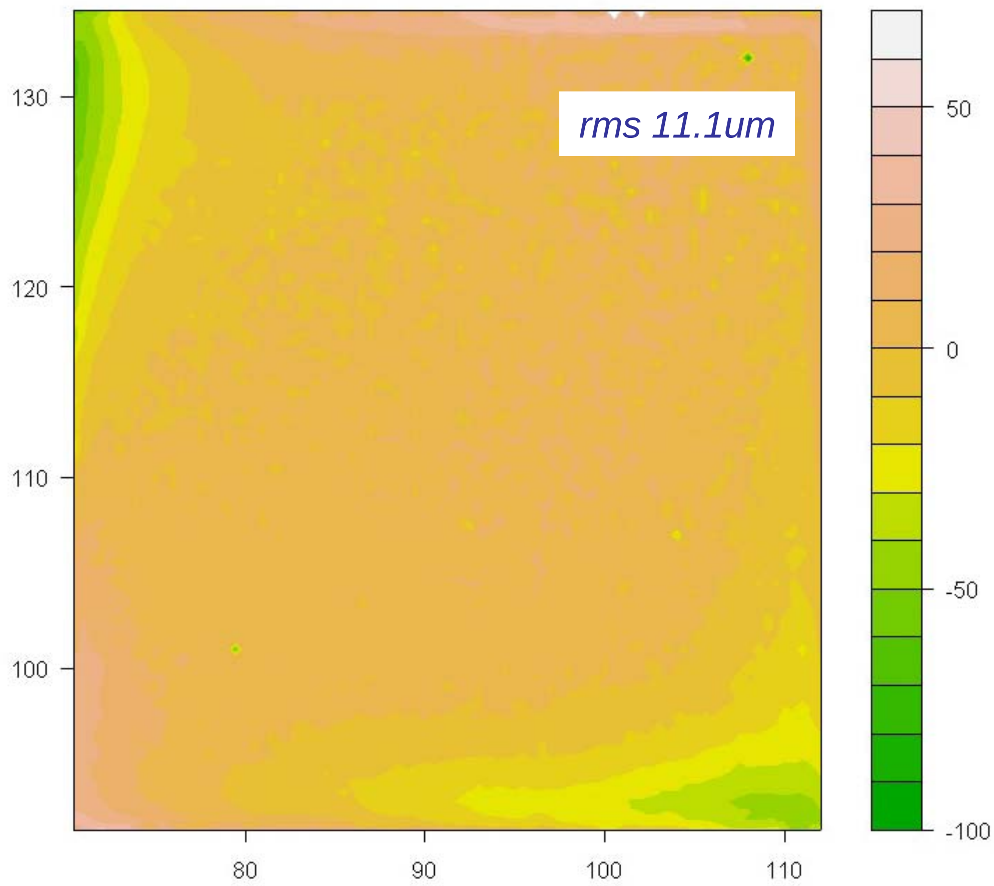
study deliverable, 2K x 512, backside



rms 1.27um

study deliverable, 2K x 4K, backside

Flatness: STA/ITL 4K x 4K study contract device



x,y: mm

z: micron

Standard test procedure – CCDs (preliminary)

- **Log device in**
- **Transfer CCD from storage container to test cryostat**
- **Vacuum**
- **Apply bias and clocks observing required sequence**
- **Cool down to operating temperature (don't exceed maximum dT/dt)**
- **Start automated data taking script**
  - *zero exposures* — *bias subtraction, read noise*
  - *dark frames to 500s* — *dark rate*
  - *^{55}Fe exposures* — *conversion gain, CTE, PSF(?)*
  - *monochromatic flat fields* — *QE, linearity, full well*
- **Run data QA check**
  - *reject compromised data sets*
- **Warm up Dewar, break vacuum, transfer CCD to clean storage**
- **Transfer fits files to cluster for analysis**
- **Extract fits headers for image database**
- **Run analysis scripts**
  - *image processing pipeline to extract standard report, check vs. requirements*
- **Enter results in test database**

Standard test report (preliminary)

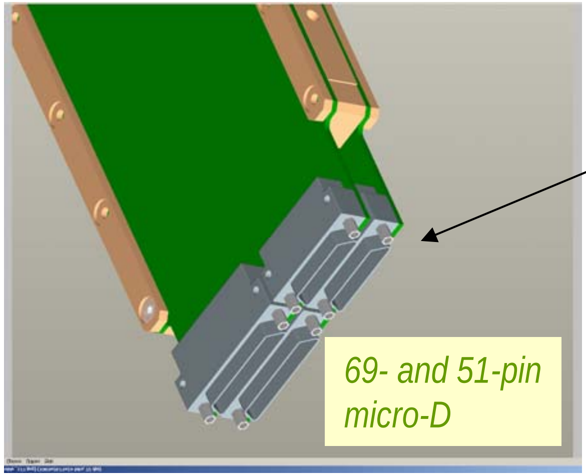
Device	106-05	106-06	106-07	107-01	
columns x rows	2000 x 500	2000 x 500	2000 x 4000	2000 x 500	pixels
Thickness	100	100	100	150	microns
amplifier	1	2	2	2	stage
Temperature	-110	-110	-100	-110	deg C
QE400	43	46	49	39	%
QE600	76	79	80	81	%
QE800	93	100	101	98	%
QE900	83	92	93	96	%
QE1000	28	32	33	47	%
ReadNoise	16.8	14.9	21.7	16.6	%
Full Well	-	310k	180k*	350k	e
Conversion gain	1.68	5.89	3.53	6.40	e/ADU
Linearity (~100e to 90%FW)	-	-4; +1	+/-0.4*	-0.7;+1.4	%
xray <npix>	3.49	3.86	3.73	5.12	pixels
Darkrate 50%	0.058	0.029	0.031	0.025	e/pix/sec
Darkrate 95%	0.083	0.054	0.097	0.055	e/pix/sec
Darkrate 99%	0.128	0.07	0.3	0.081	e/pix/sec
Defects	0.0273	0.0027	0.132	0.0036	%
Flatness (95th %ile p-v)	4	5.5	4.4	-	microns

Sensors R&D Activity 2008 – 2010

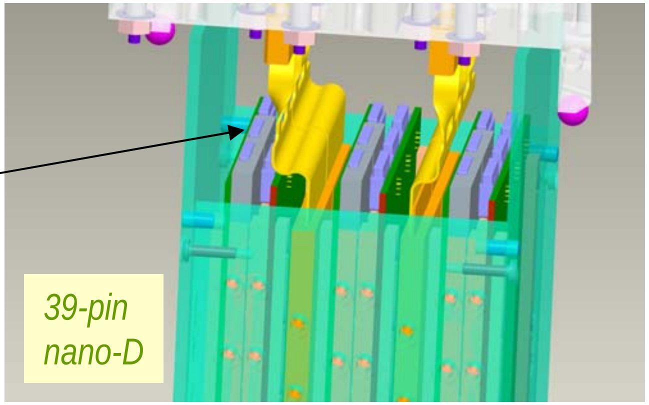
- **Verify diffusion model and measurement**
- **Evaluate STA/ITL study contract devices**
- **Evaluate prototype devices**
- **Complete 2nd generation test stand: new Dewar, controller, PSF point projector, MTF fringe projector → evolve to production test stand**
- **Design and procure production test hardware, facilities**
- **Develop production test procedure, software, and database**
- **Technical liason with vendors**
  - *Electrical interface to FEE (w/UPenn)*
  - *Mechanical/thermal interface to raft (w/SLAC, Purdue)*
  - *WFS (pending availability of funding)*

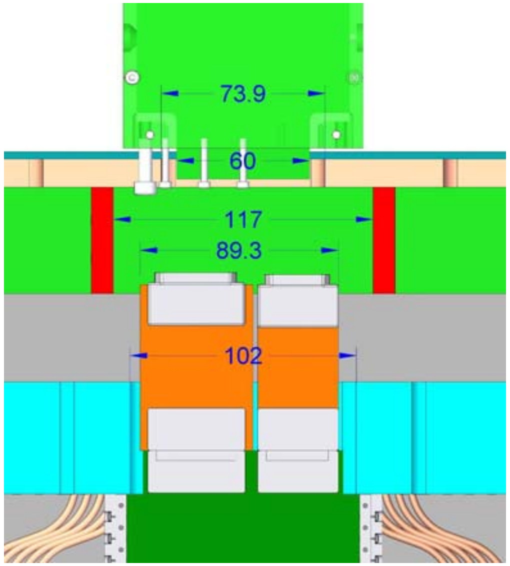
Raft Tower Module (RTM) Design Modifications

Raft-tower design changes

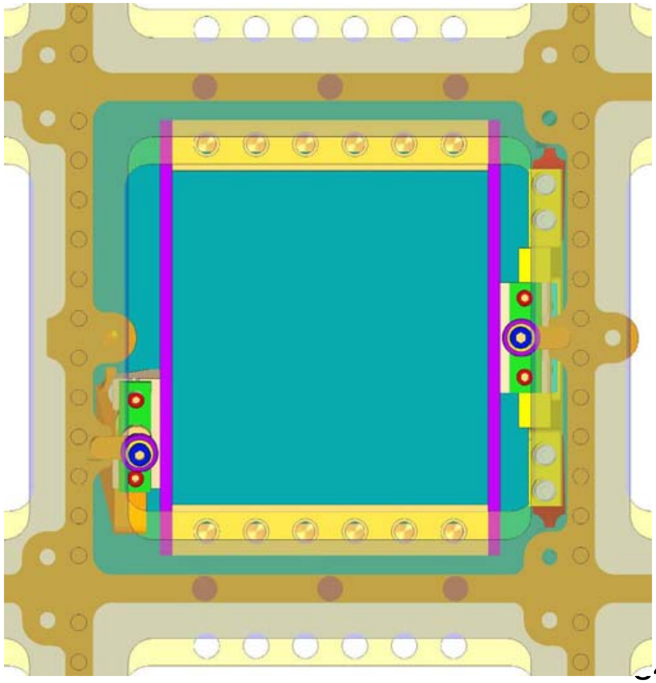


select connectors for FEE-BEE and FEE-CCD

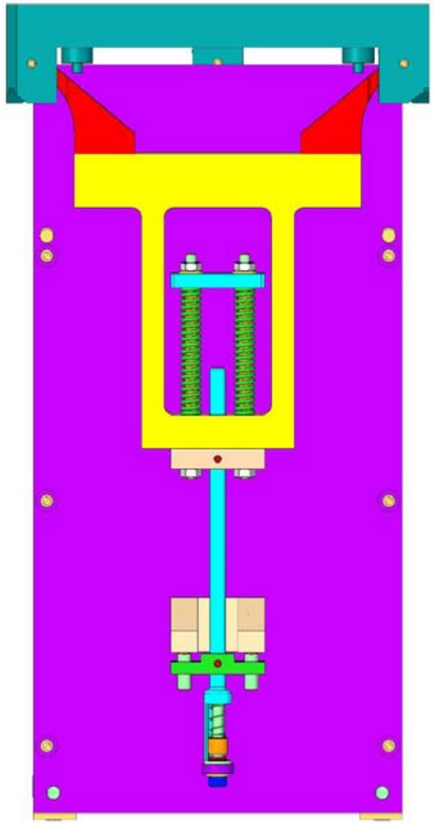


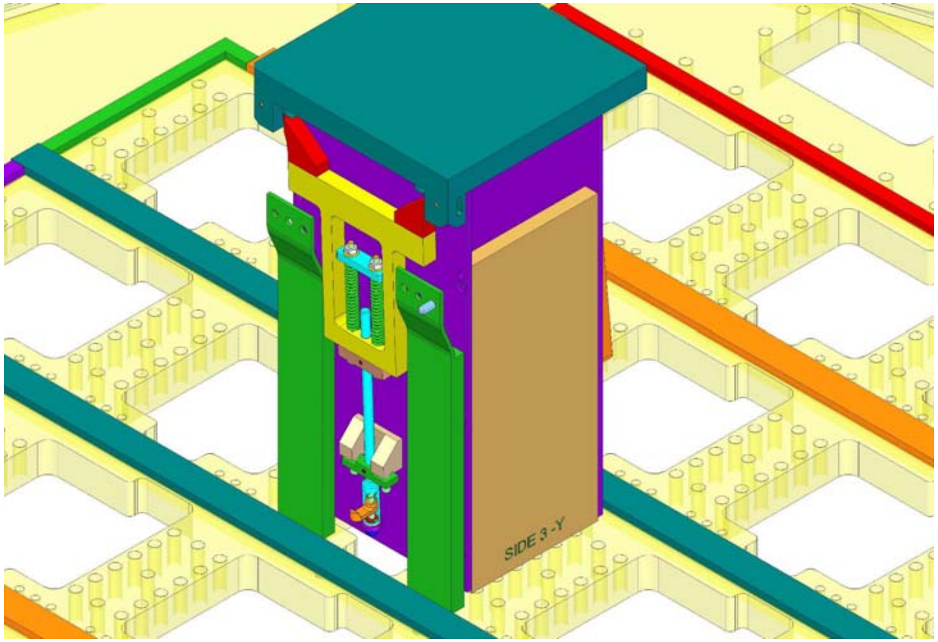


requires increased clearance at cryoplate interface, changed heat path



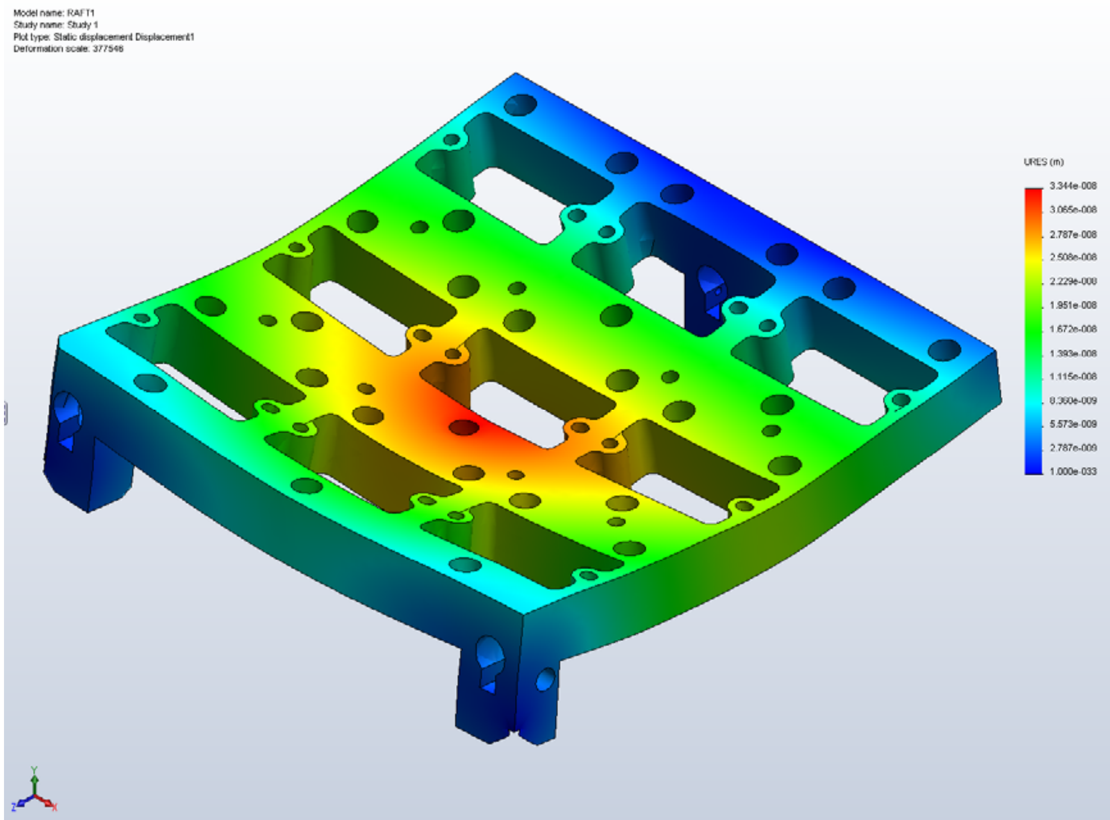
Revised design of raft-GRID hold-down (see cryostat and corner raft presentations)





- raft preload maintained constant during load transfer from Cage to GRID
- cryoplate no longer supports raft-GRID preload
- occupies more volume in bay

Beginning analysis of deflection under cabling point load

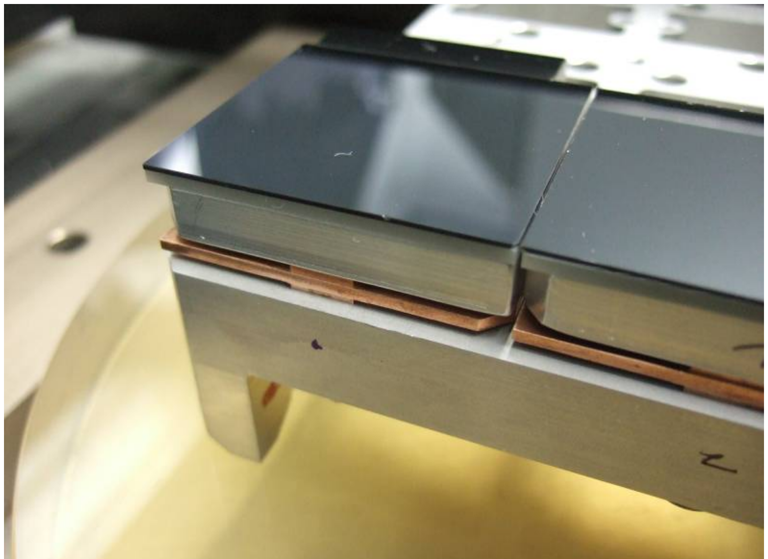


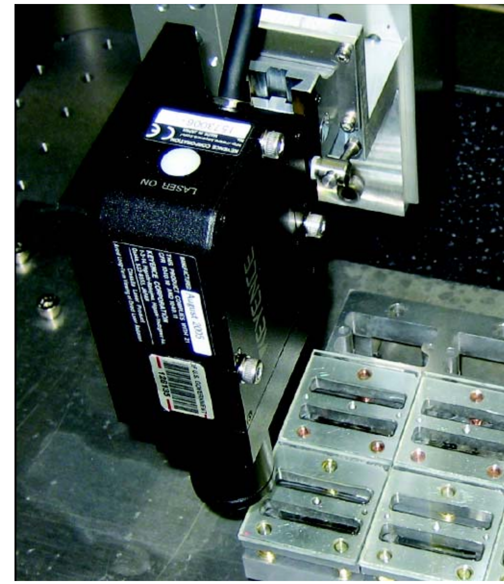
Poco SuperSiC raft
Load case:
    1N at center bolt hole
max. defl. 8.5nm

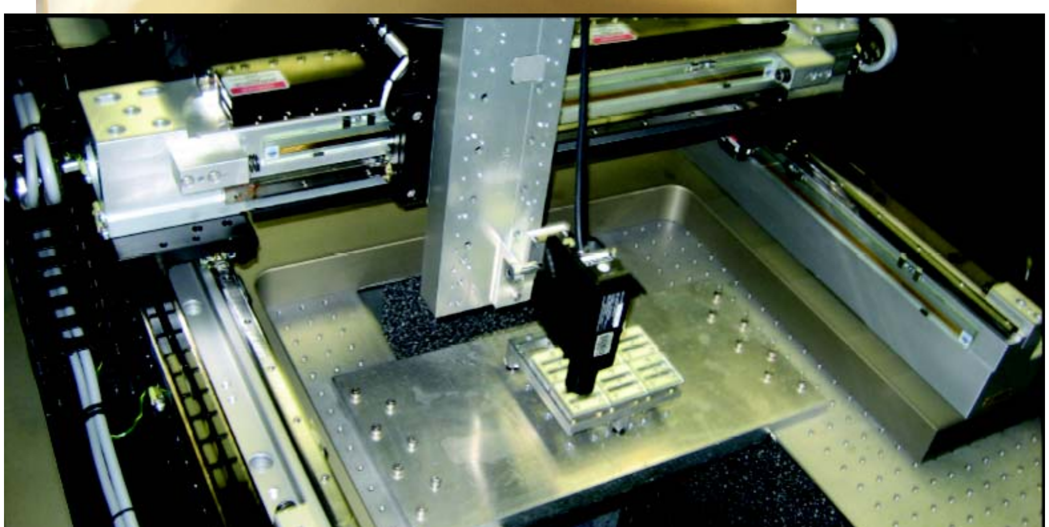
Raft Tower Module (RTM) Flatness metrology

Metrology samples

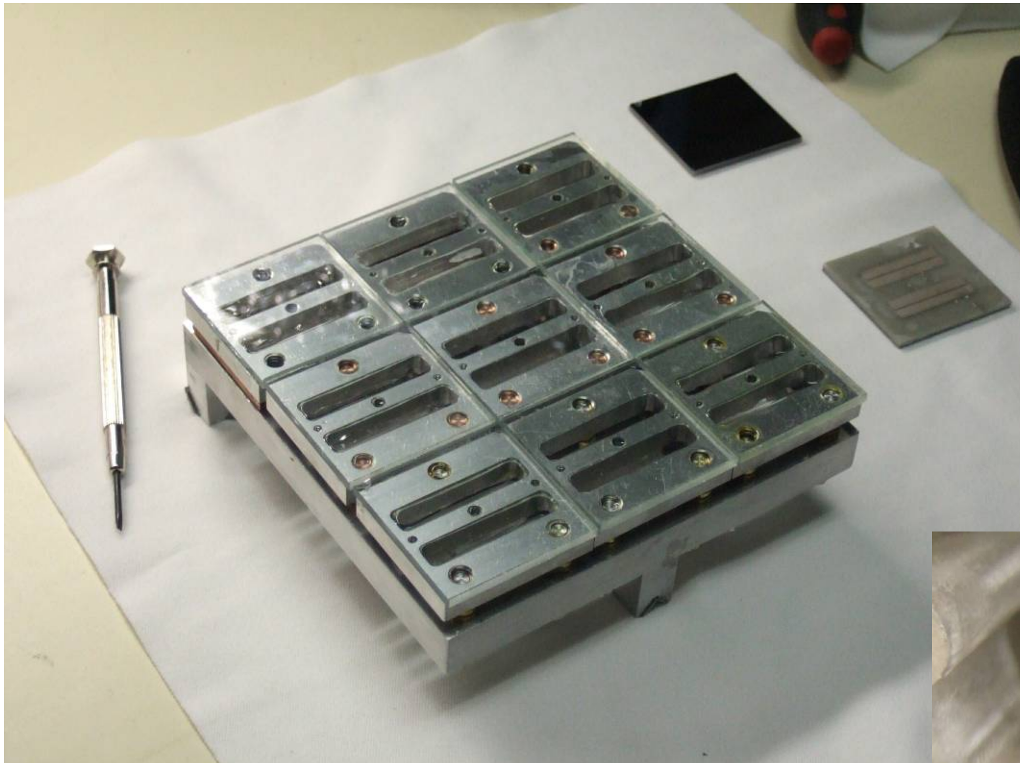
Large Synoptic Survey Telescope

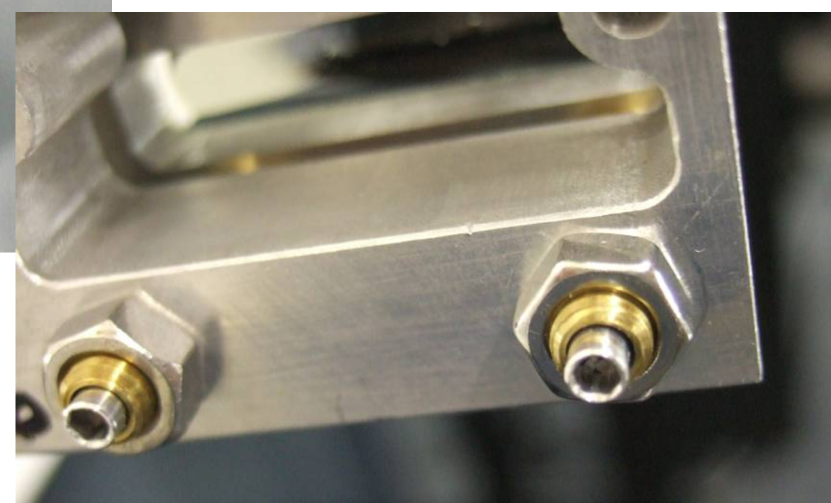




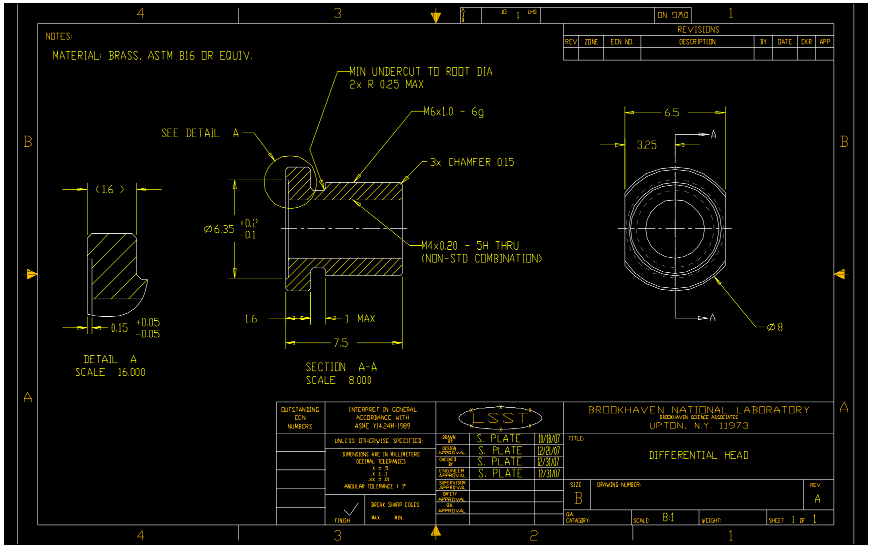


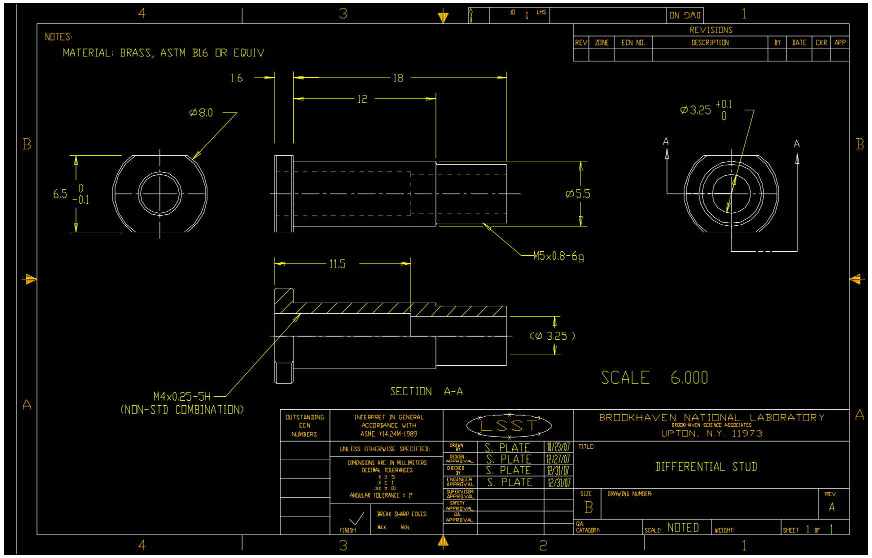
Float glass tiles, differential adjusters

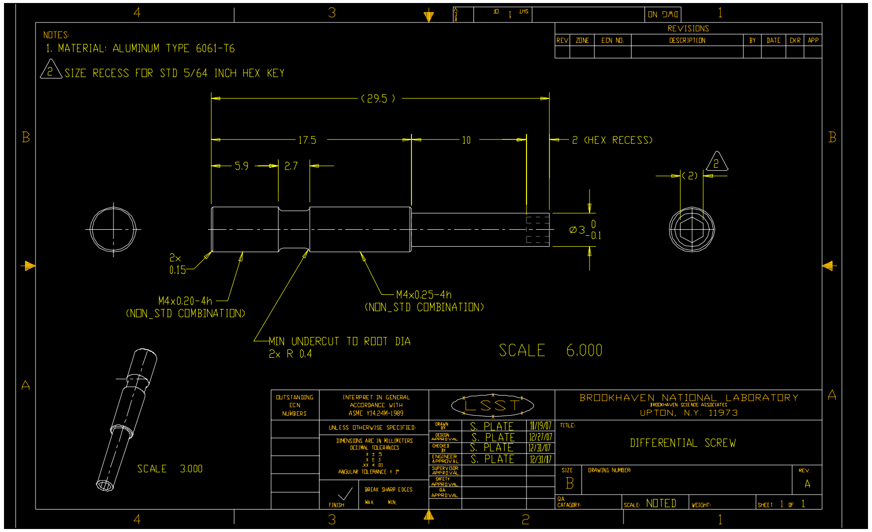




Differential screw adjustor



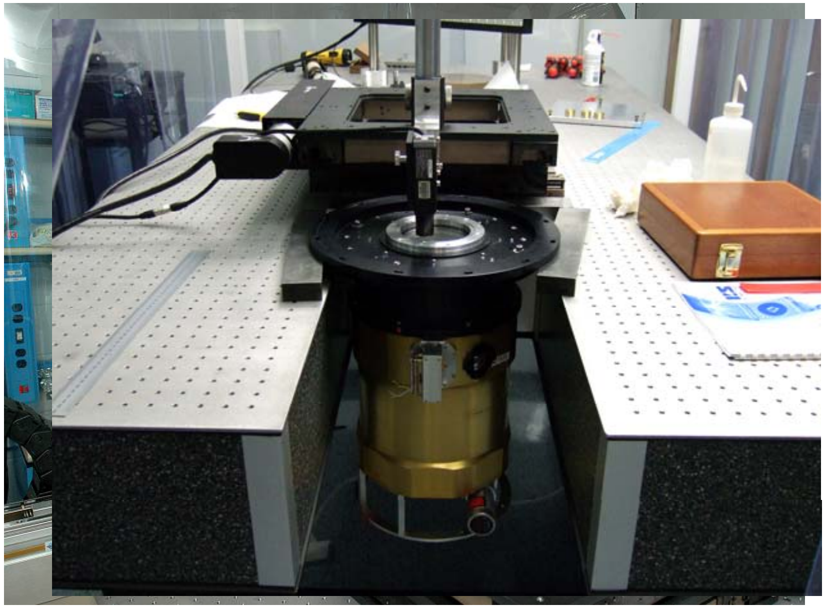




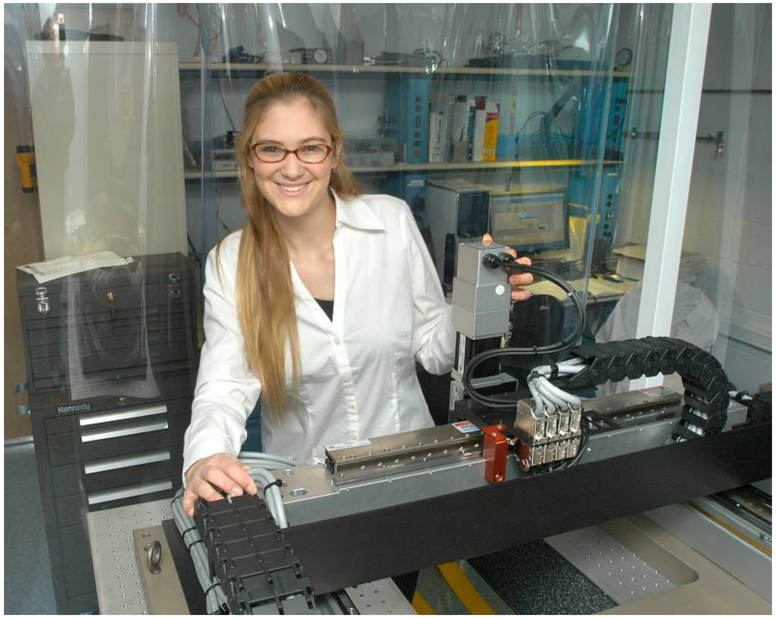
2 versions designed and fabricated
50μm and 60μm per turn

New custom gantry xyz stage

old system

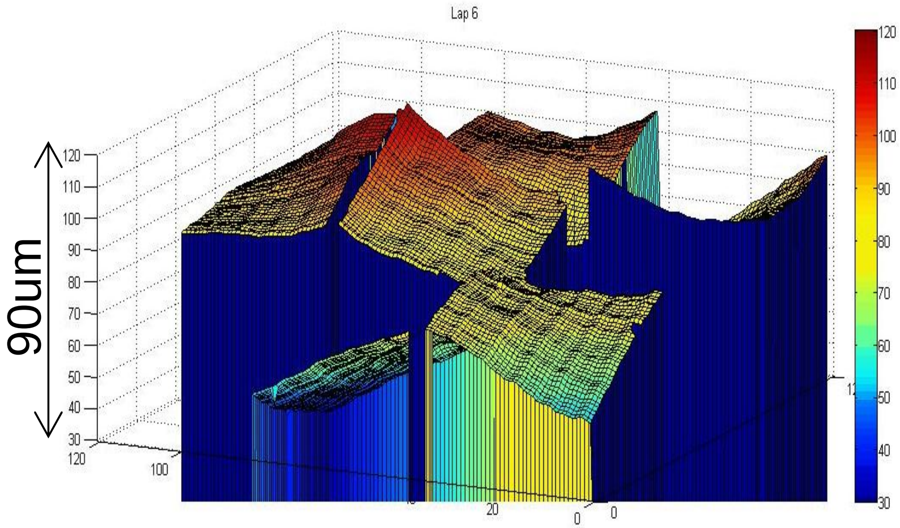


new 400mm system

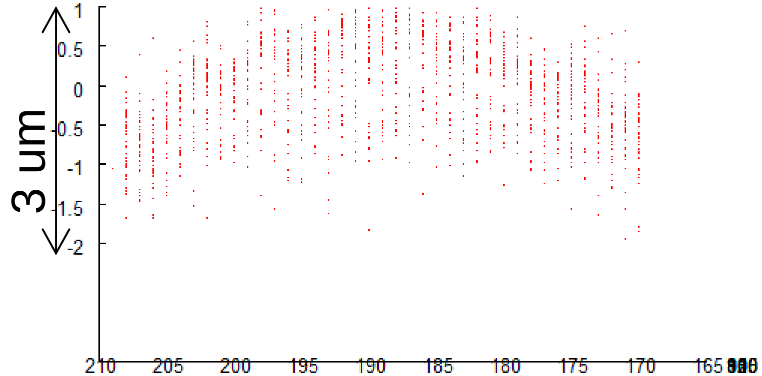


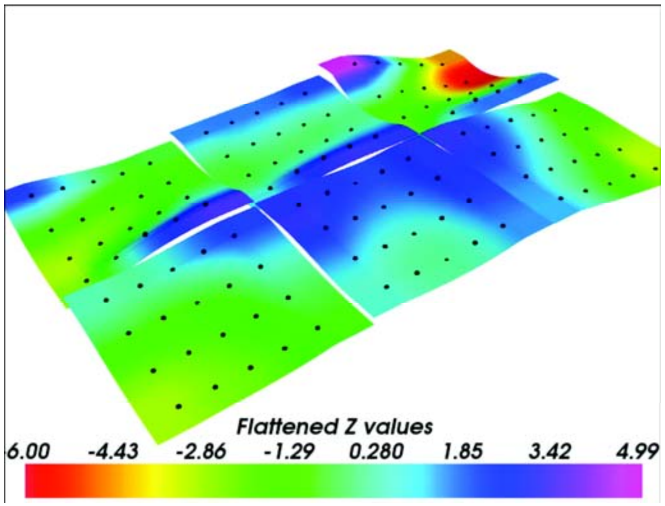
Surface flatness of two material samples

0.65mm Si wafer, laser cut, CA glue to AlN ceramic

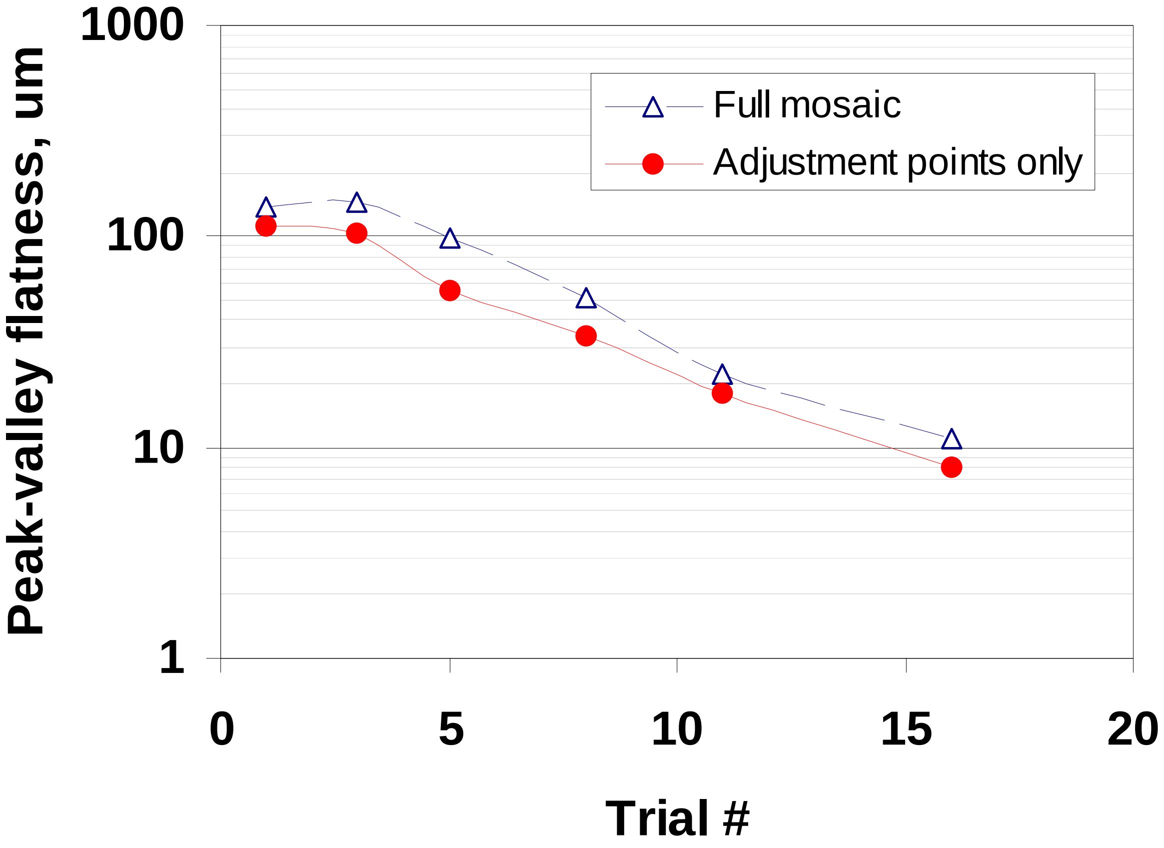


2.4mm float glass, epoxy to Al frame





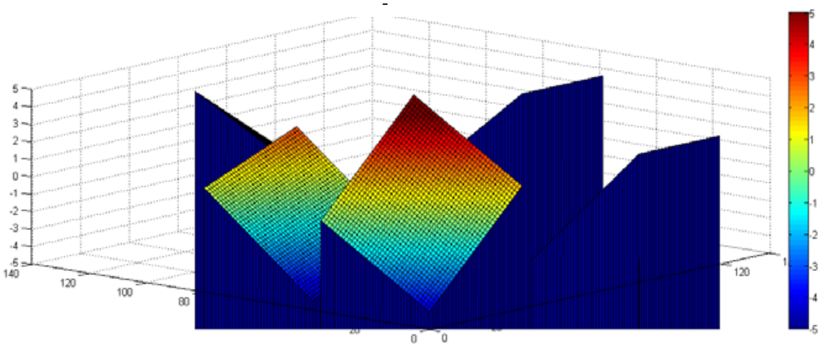
Flatness adjustment using lapped spacers



Best achieved flatness

Lapped spacers

10μm



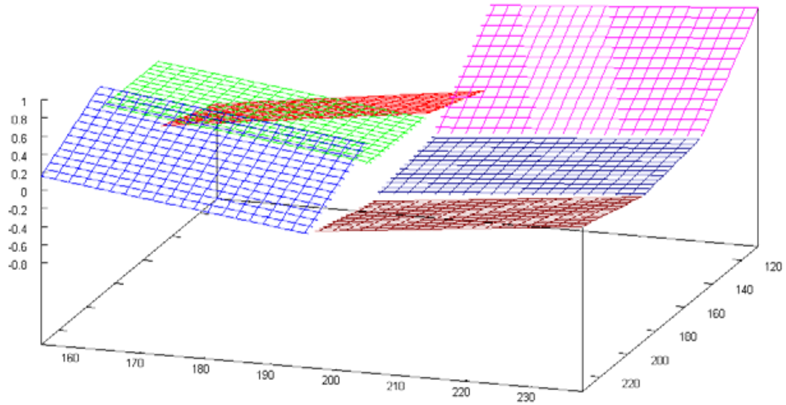
Peak to Valley Overall: 11μm

Peak to Valley 18pts: 8μm

best fit plane to each tile (remove warpage)

Differential screw adjustors

1.8μm p-v



Aside -- Objet Eden 260 3D printer

Technical Specifications

Build size (X x Y x Z)

260mm x 260mm x 200mm

(10.2 X 10.2 X 7.9 inches)

Print Resolution

X-axis: 600 dpi: 42 µ

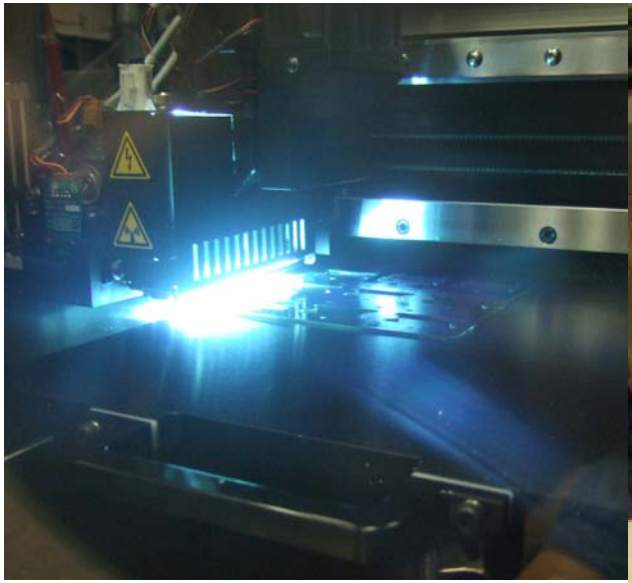
Y-axis: 300 dpi: 84 µ

Z-axis: 1600 dpi: 16 µ

FullCure®840 VeroBlue

Property	ASTM	Results (Metric)		Results (Imperial)	
Tensile Strength	D-638-03	MPa	55.1	psi	7,990
Modulus of Elasticity	D-638-04	MPa	2,740	psi	397,300
Elongation at Break	D-638-05	%	20	%	20
Flexural Strength	D-790-03	MPa	83.6	psi	12,122
Flexural Modulus	D-790-04	MPa	1,983	psi	287,535
Compressive Strength	D-695-02	MPa	79.3	psi	11,499
Izod Notched Impact	D-256-06	J/m	23.6	ft lb/in	0.44
Shore Hardness	Scale D	Scale D	83	Scale D	83
Rockwell Hardness	Scale M	Scale M	81	Scale M	81
HDT at 0.45 MPa	D-648-06	ºC	48.8	ºF	120
HDT at 1.82MPa	D-648-07	ºC	44.8	ºF	113
Tg	DMA, E"	ºC	48.7	ºF	120
Ash Content	NA	%	<0.3	%	<0.3
Water Absorption	D570-98 24 Hr	%	1.87	%	1.87

Property	ASTM	Results in Metric Units		Results in Imperial Units	
Tensile Strength	D-638-03	MPa	21.3	psi	3,089
Modulus of Elasticity	D-638-04	MPa	1135.8	psi	164,691
Elongation at Break	D-638-05	%	44.2	%	44
Flexural Strength	D-790-03	MPa	33.2	psi	4,814
Flexural Modulus	D-790-04	MPa	1,026.1	psi	148,785
Compressive Strength	D-695-02	MPa	30.7	psi	4,452
Izod Notched Impact	D-256-06	J/m	44.22	ft lb/in	0.83
Shore Hardness	D-2240-03	Scale D	76	Scale D	76
Rockwell Hardness	D-785-03	Scale M	97	Scale M	97
HDT at 0.45 MPa	D-648-06	ºC	43	ºF	109
HDT at 1.82 MPa	D-648-07	ºC	40	ºF	104
Tg	DMA, E"	ºC	35.9	ºF	97
Water Absorption	D570-98 24 Hr	%	1.69	%	1.69



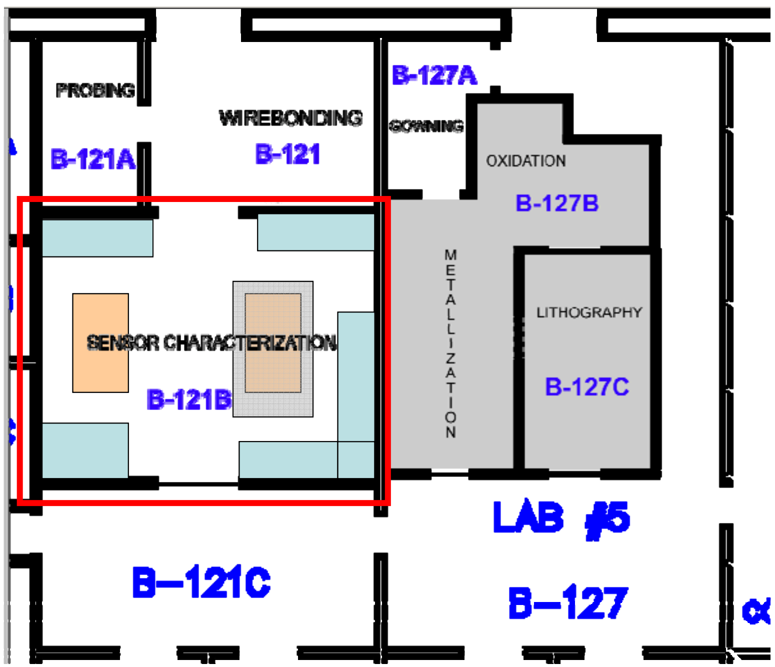

OBJET

Expansion of LSST cleanroom

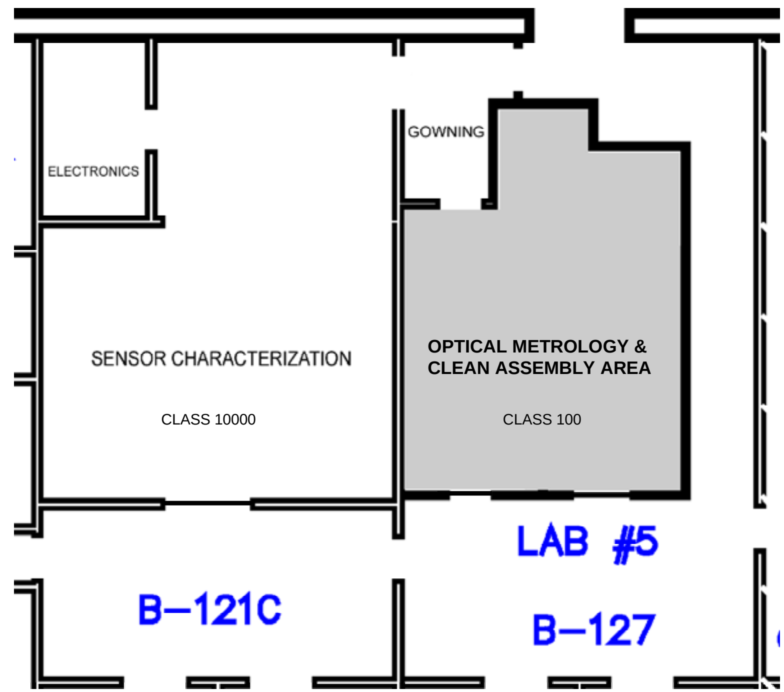
Existing facility

LSST test area

Silicon detector laboratory

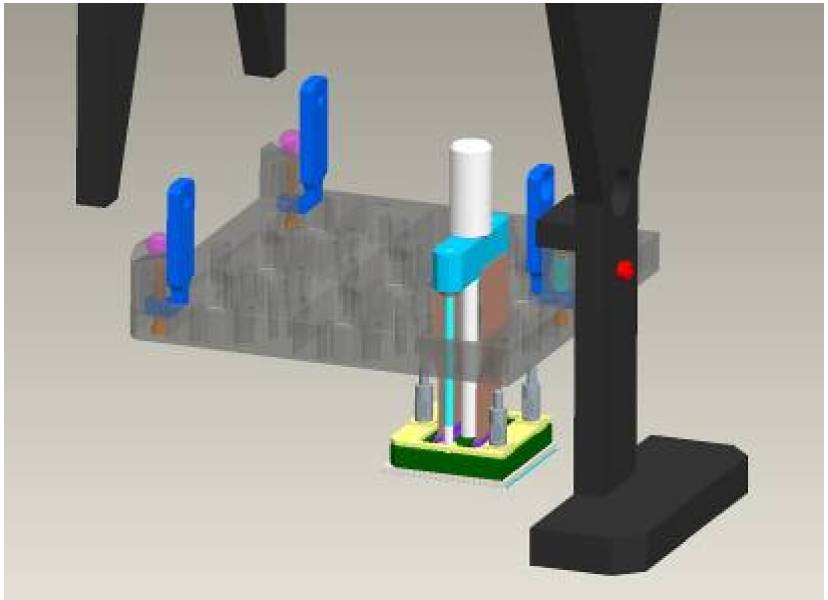


Proposed expanded facility

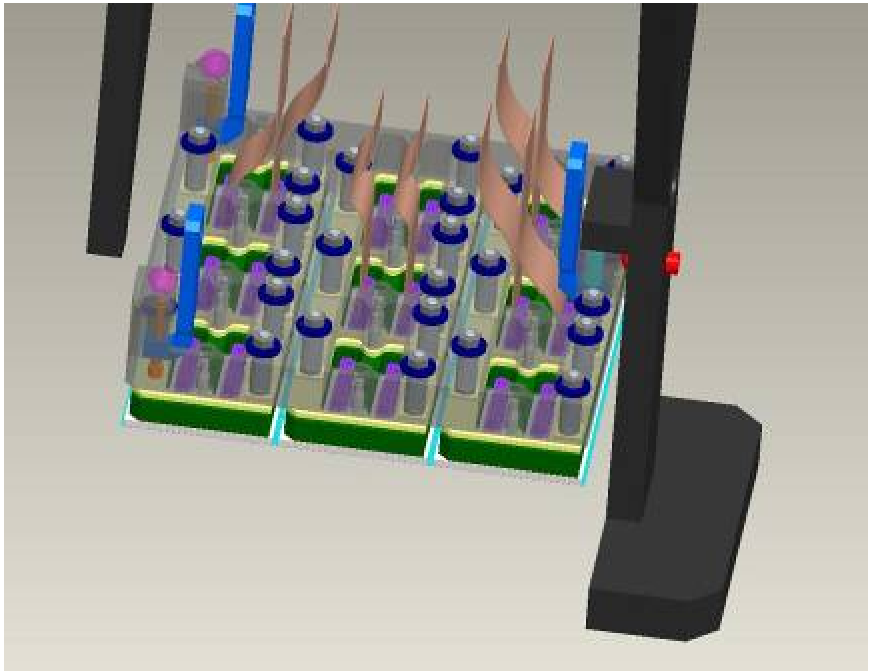


Tower assembly sequence – 1

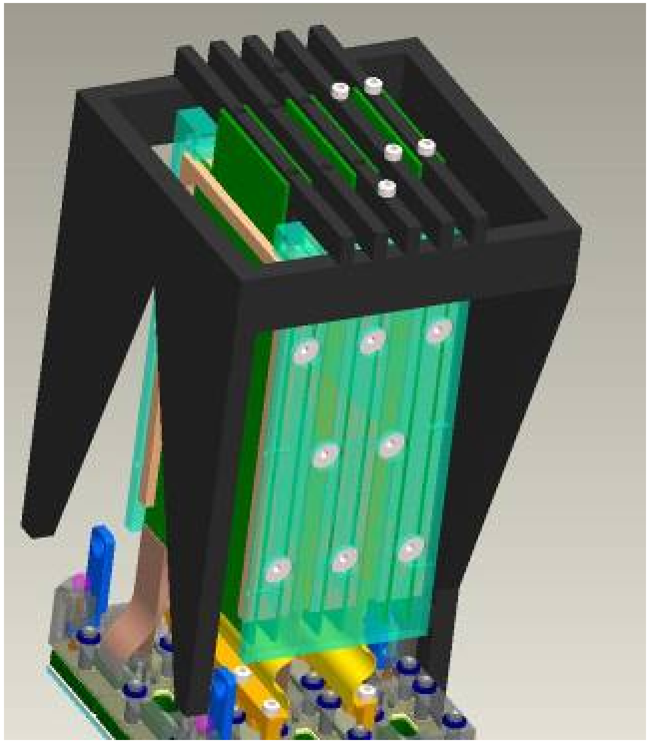
assemble pre-cabled CCDs to raft



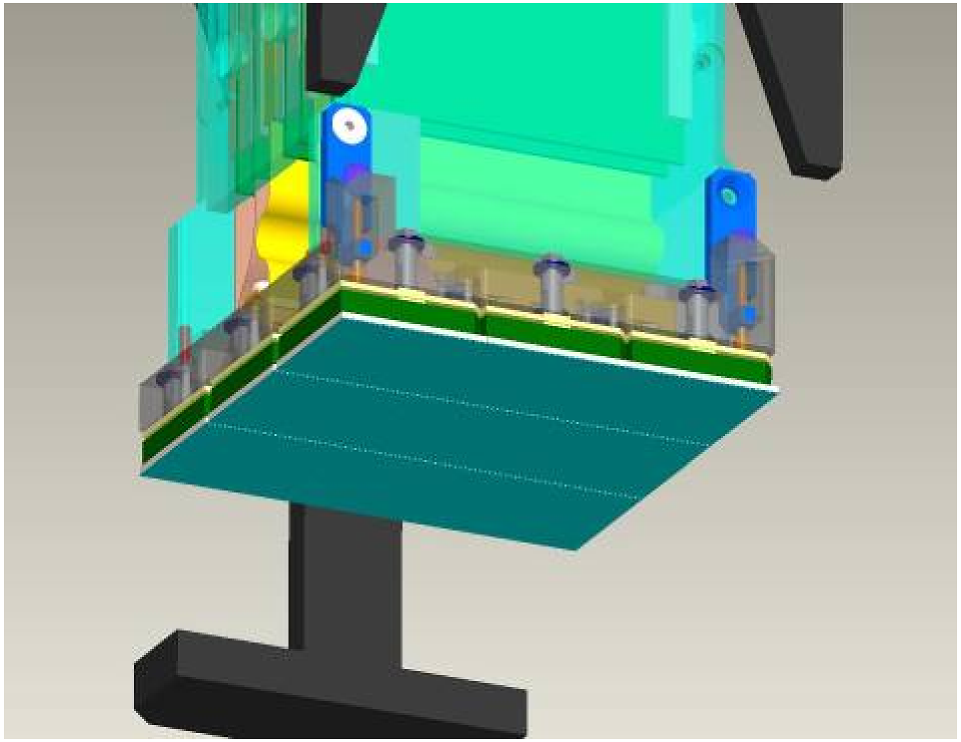
metrology scan



Tower assembly sequence – 3



install housing sides 3 & 4



install housing sides 1 & 2

RTM Integration procedure (preliminary)

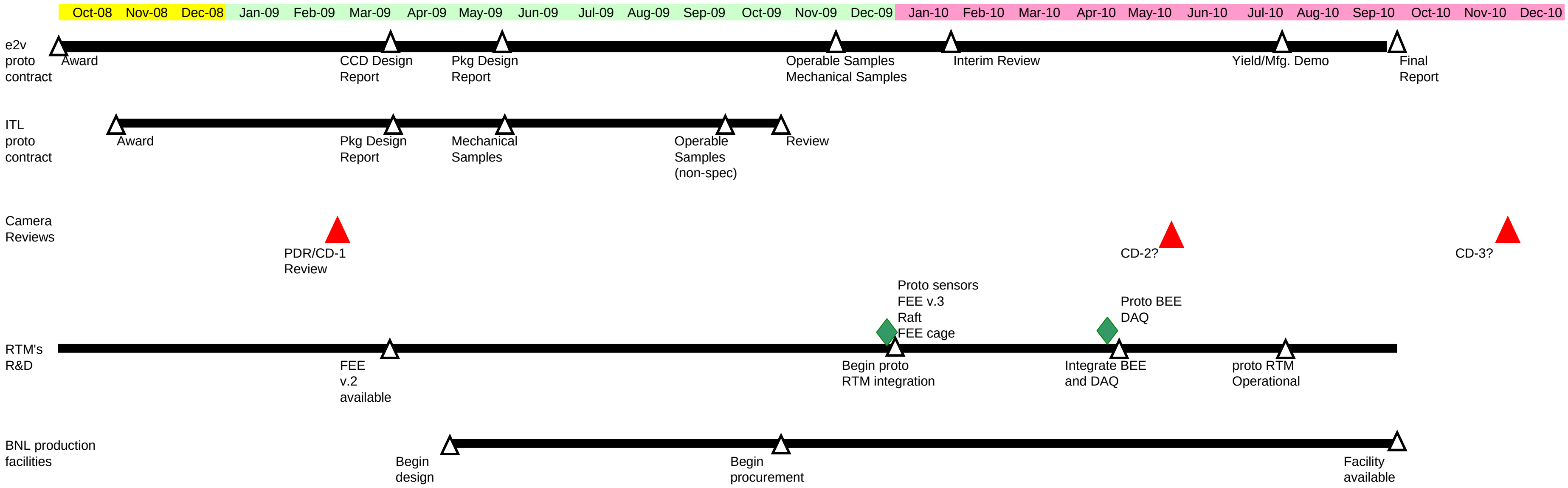
- **Tooling and fixturing**
  - *raft metrology jig, height transfer standard, flatness standard, displacement sensor, gantry xyz stage, adjustment tooling, assembly fixture*
  - *Dewar, Dewar mount, vacuum system, cryosystem, xray source carriage, control and readout electronics*
  - *Optical testbench: source, filters, monochromator, sphere, baffles, monitor photodiodes*
- **Inventory of qualified components**
  - *CCDs, raft baseplates, mounting hardware, cage mechanics, FEBs, cooling straps, heaters, spring preload hardware, cables, MLI(?)*
- **Serial numbering**
- **Vacuum-prepare materials**
- **Assemble CCDs to raft**
- **Transfer to metrology jig, survey flatness and piston**
- **Align as necessary (may require disassembly-reassembly)**
- **Transfer to assembly fixture**
- **Assemble FEBs, cooling planes, cooling straps, heaters, cage sides, spring preload mechanisms, MLI**
- **Transfer RTM to metrology jig, verify flatness and piston**
- **Transfer to cryo-metrology test station, evacuate, cooldown, apply power, run final verification test**
- **Warm up, transfer tested RTM to shipping container**
- **Prepare test report and update database**

RTM R&D Activities 2008 – 2010

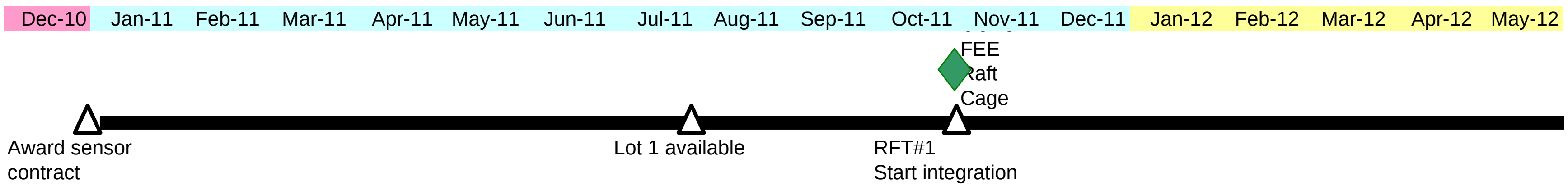
- **Finalize design of science raft hold-down**
- **Evaluate need for molecular flow barrier**
- **Evaluate candidate raft materials, vendors**
- **Fabricate and test raft prototype with dummy sensors**
- **Develop assembly tooling:**
  - *raft assembly jig*
  - *RTM assembly fixture*
  - *Cryo test stand for final test*
    - mechanics, optics, xray, cryo, vacuum, electronics
- **Cleanroom preparation**
- **Software: DAQ, analysis, database**

Timelines

R&D Timeline


Oct-08 Nov-08 Dec-08 Jan-09 Feb-09 Mar-09 Apr-09 May-09 Jun-09 Jul-09 Aug-09 Sep-09 Oct-09 Nov-09 Dec-09 Jan-10 Feb-10 Mar-10 Apr-10 May-10 Jun-10 Jul-10 Aug-10 Sep-10 Oct-10 Nov-10 Dec-10
e2v proto contract
Award
CCD Design Report
Pkg Design Report
Operable Samples Mechanical Samples
Interim Review
Yield/Mfg. Demo
Final Report
ITL proto contract
Award
Pkg Design Report
Mechanical Samples
Operable Samples (non-spec)
Review
Camera Reviews
PDR/CD-1 Review
CD-2?
CD-3?
Proto sensors FEE v.3 Raft FEE cage
Proto BEE DAQ
RTM's R&D
FEE v.2 available
Begin proto RTM integration
Integrate BEE and DAQ
proto RTM Operational
BNL production facilities
Begin design
Begin procurement
Facility available

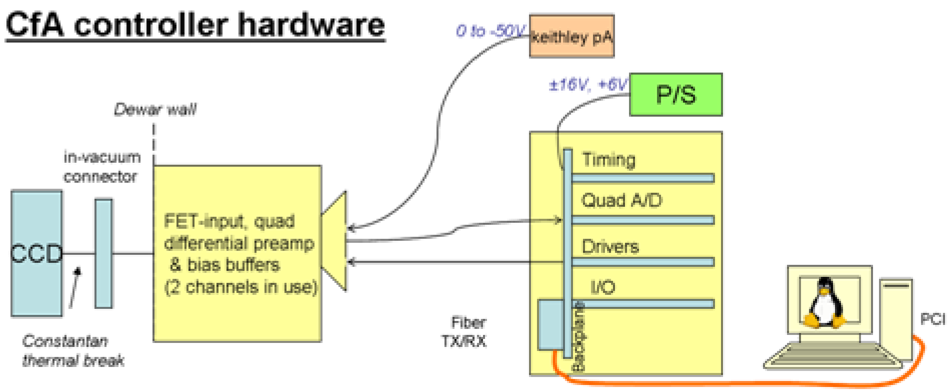
Production timeline



BACKUPS

CfA camera controller

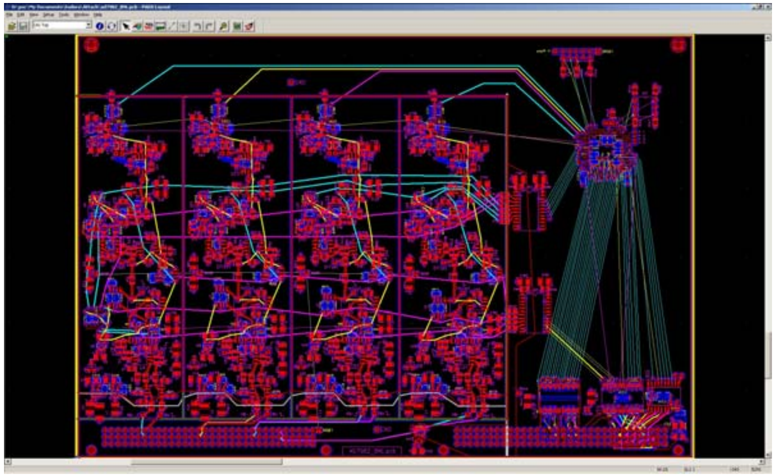
- provides clock and bias signals to operate the CCD(s).
- receives video signals, digitizes to 16 bits, writes FITS file to Linux host over optical link.
- 4 channels per A/D board; up to 16 channels.
- latest in a succession of camera controllers for ground and space astronomy projects (MMT Megacam, Kepler)

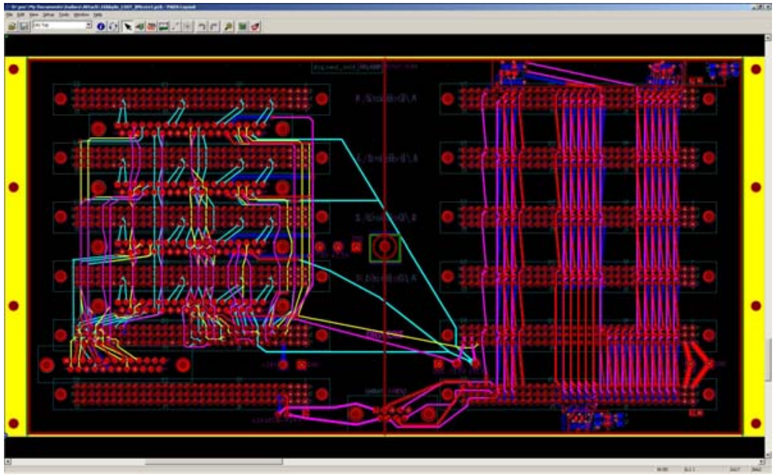


- Clock rate limited to < 200kpix/s.
- Clocking patterns not easy to modify.
- Unavailability of schematics.
- Noise contribution not accurately known, may be significant.
- Preamp box hard-mounted to Dewar; need to break vacuum to service.

- We asked Geary for a new controller able to evaluate LSST sensors (16 outputs) at full clock rate (500 kpix/s).
- A new board set has been designed.
- Boards are fabbed in IO PC shop. First boards delivered to CfA; still need to fab a couple more.
- After debug, 5 copies of controller to be built for:
  - *BNL (we are the guinea pig for the new design)*
  - *SLAC*
  - *Purdue*
  - *LPNHE*
  - *UC Davis*

Fast multichannel controller

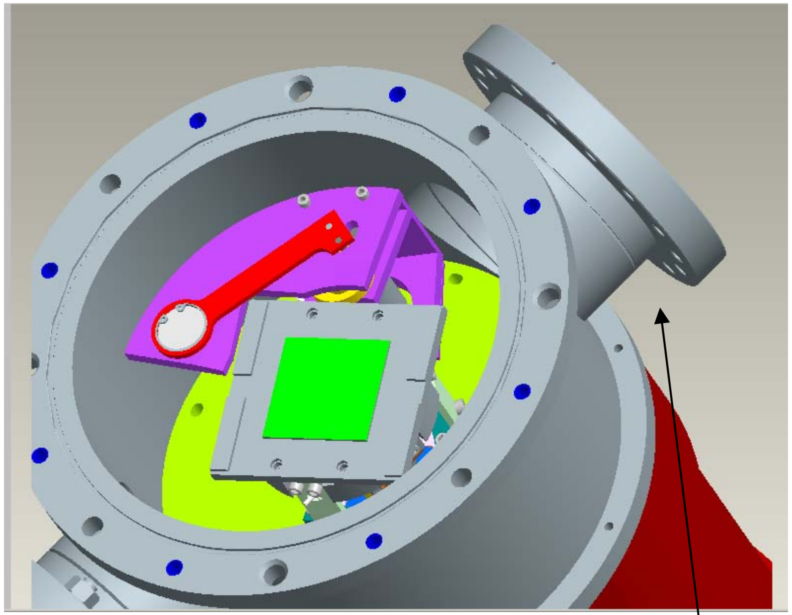


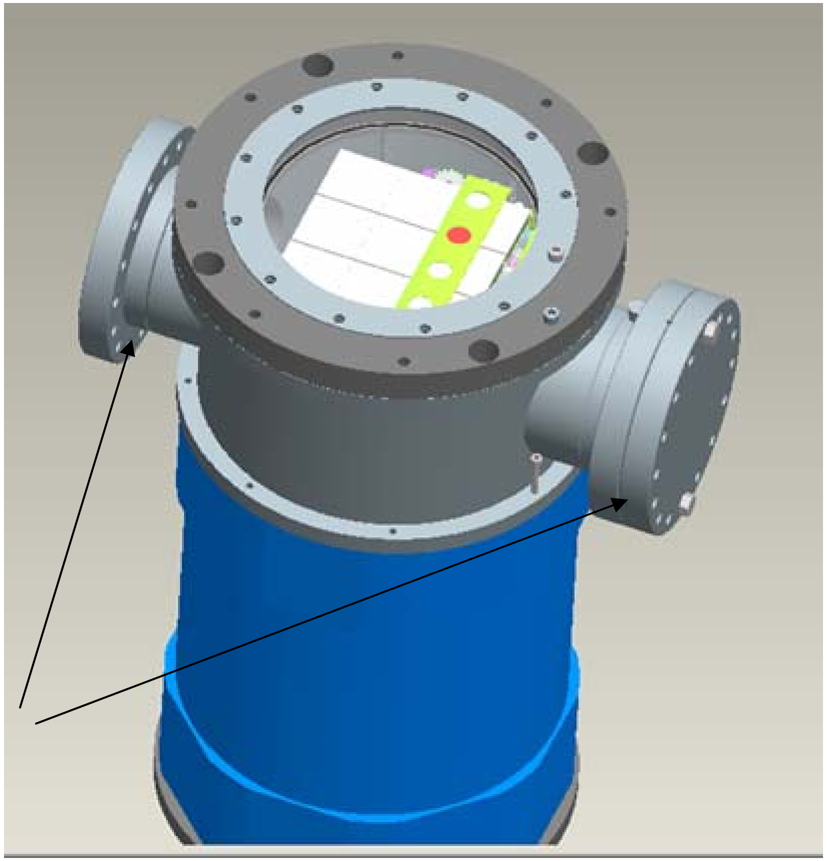


Xray mechanisms for single 4K^2 and fully populated raft

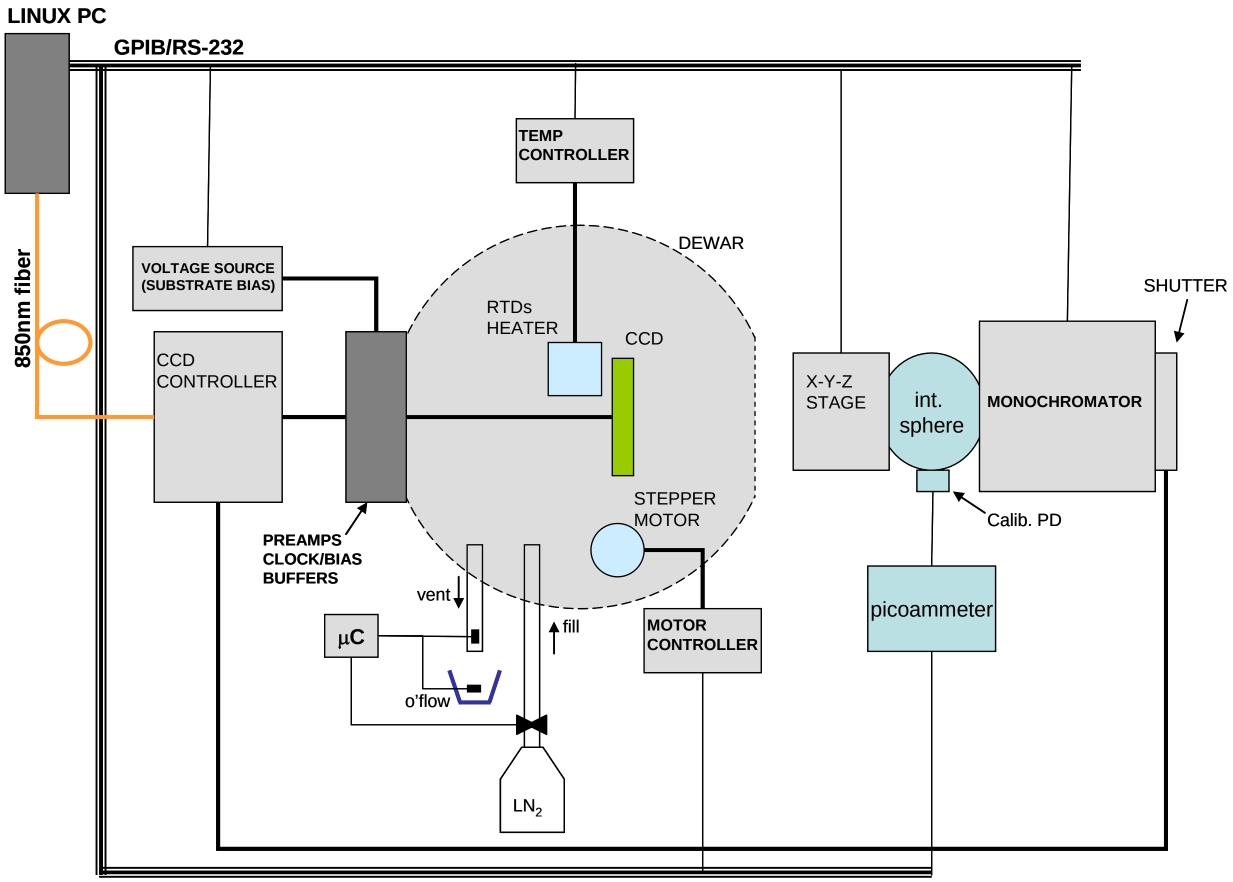
modified swing arm for 4K^2

xray “carriage” for raft



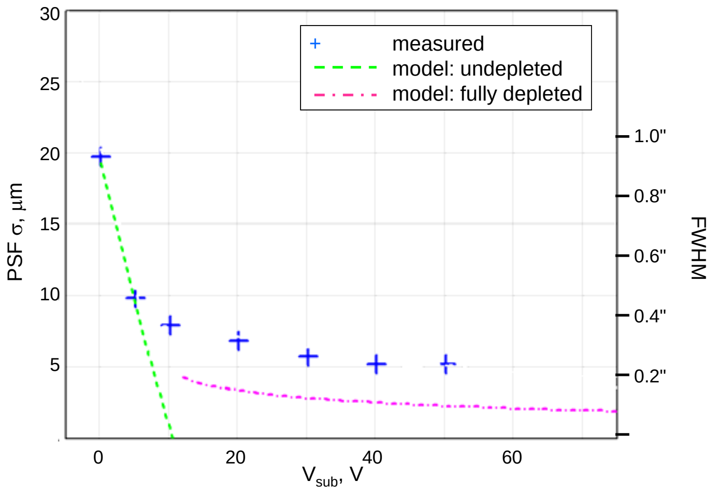


153-pin vacuum feedthroughs

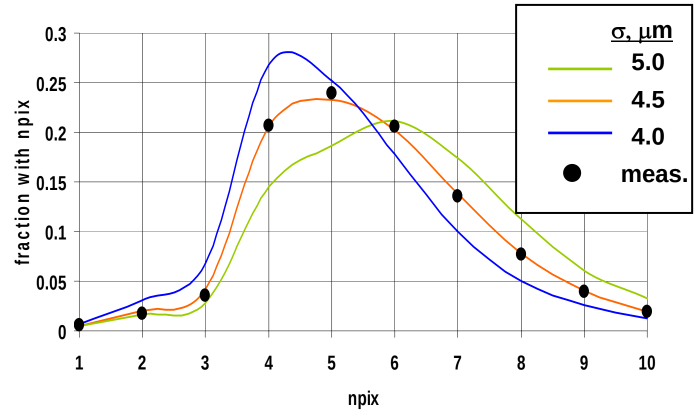

LINUX PC
GPIB/RS-232
850nm fiber
TEMP CONTROLLER
DEWAR
VOLTAGE SOURCE (SUBSTRATE BIAS)
RTDs HEATER
CCD
CCD CONTROLLER
X-Y-Z STAGE
int. sphere
MONOCHROMATOR
SHUTTER
STEPPER MOTOR
Calib. PD
PREAMPS CLOCK/BIAS BUFFERS
vent
µC
fill
MOTOR CONTROLLER
picoammeter
o'flow
LN_2

4 methods of measuring PSF under study

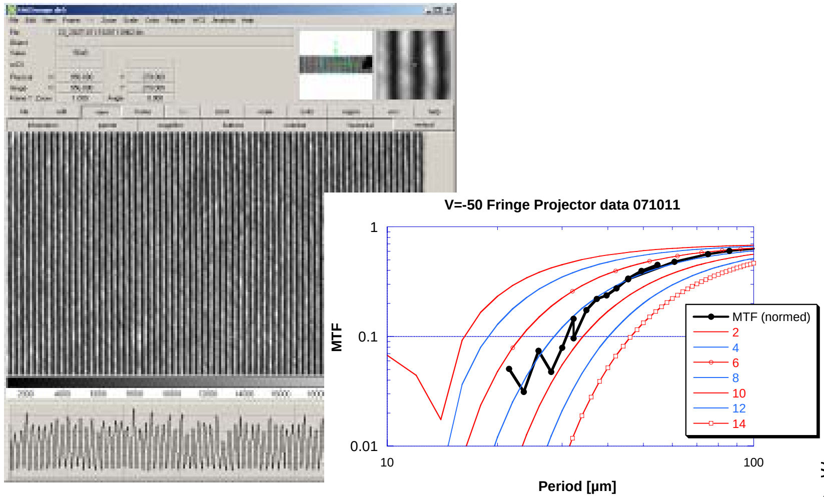
VIRTUAL KNIFE EDGE



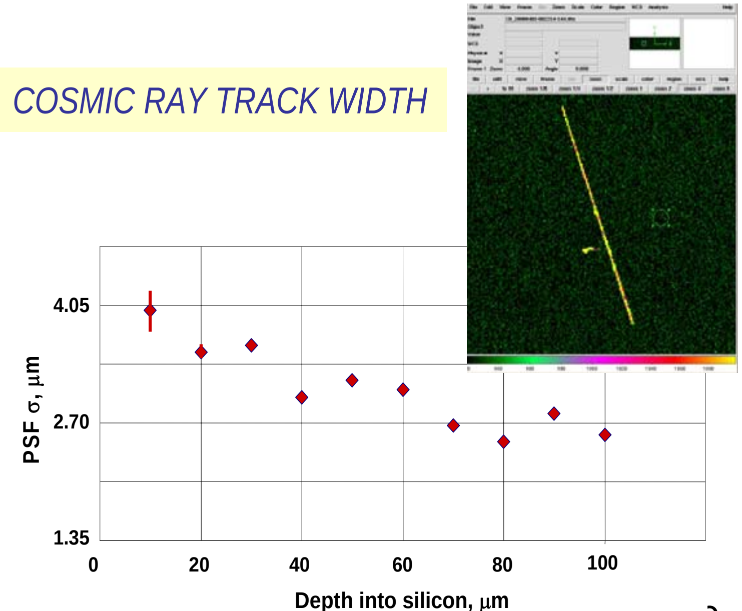
XRAY CLUSTER SIZE



MODULATION TRANSFER FUNCTION

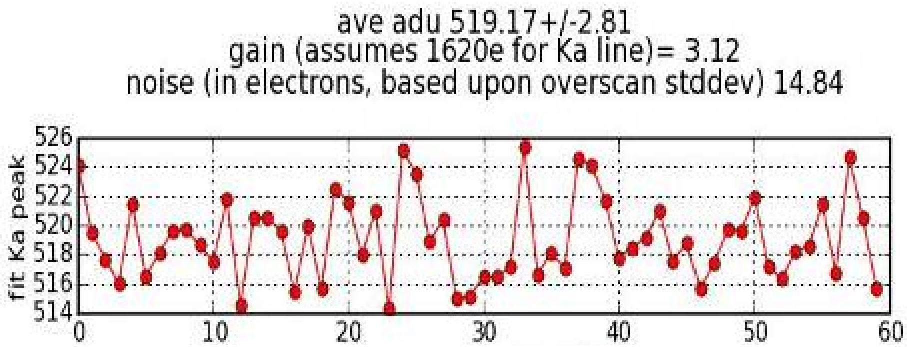


COSMIC RAY TRACK WIDTH



QE reproducibility

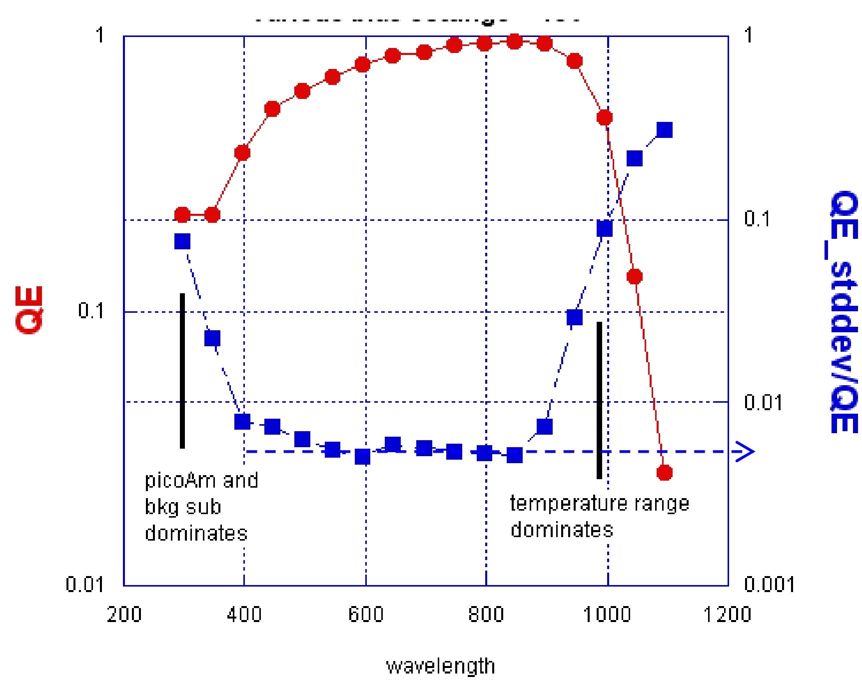
CCD gain determination (repeated ^{55}Fe runs)



run number

0.5% (individual run)
0.07% (average of 60 runs)

QE scan (23 runsets)



Methods

- **Dark current + defects**
  - *36 bias frames; six 600s exposures*
- **Xray transfer**
  - *36 bias frames; 49 exposures to ~5μCi 55Fe source*
- **QE scan**
  - *25 bias frames; 17 flatfield exposures to monochromatic light 300-1100nm at 50nm intervals*
- **Linearity**
  - *20 bias frames; 23 flatfields from dark to full well at 830nm*
- **PSF**
  - *20 bias frames; focus point projector on CCD surface; scan in 2um steps for 10 pixels in x- and y-direction*
- **Mechanical flatness**
  - *mount CCD on xy stage; measure z-height at 0.5 x 0.5mm grid*

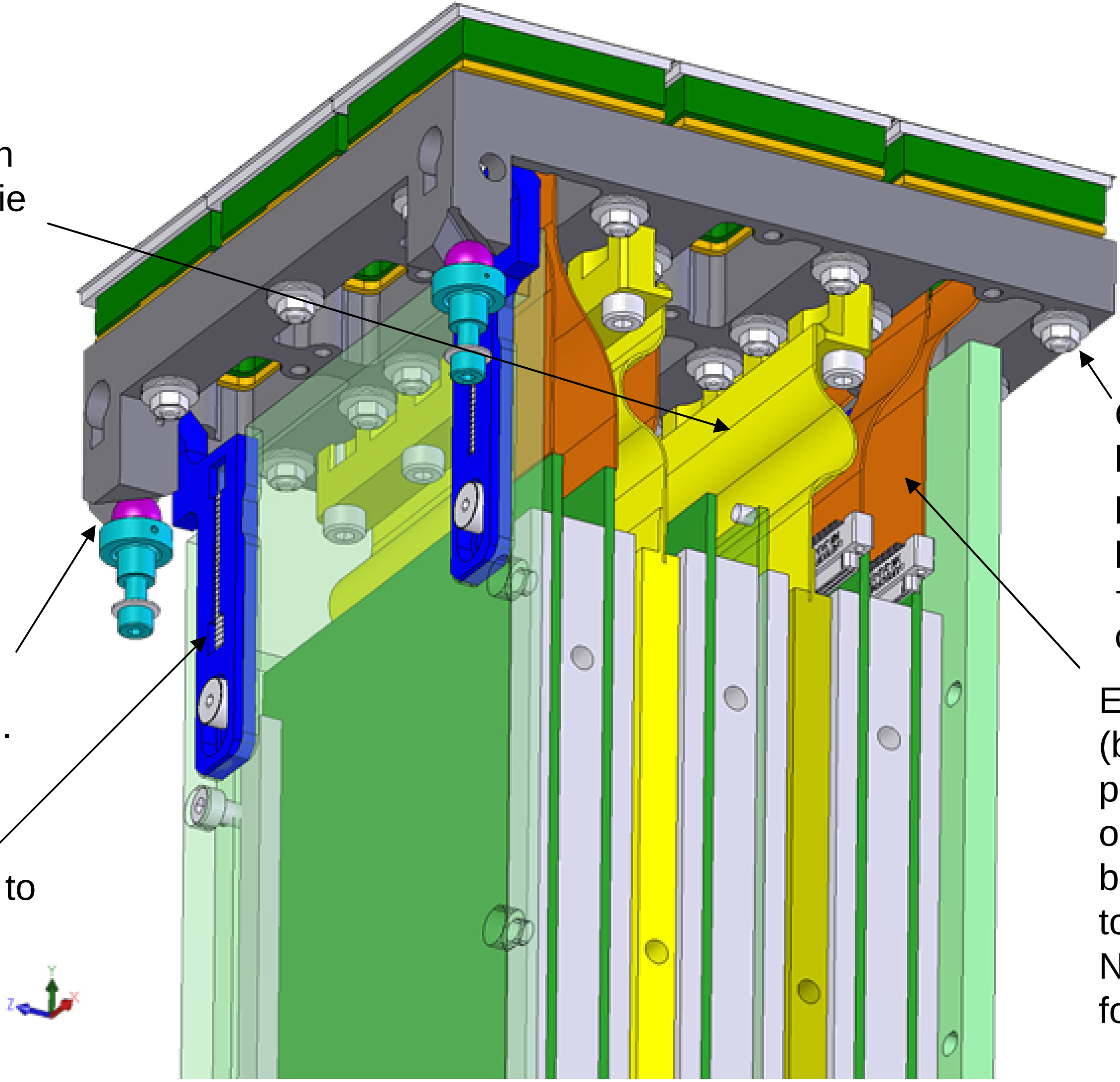
we have developed an automated script that performs these measurements and most of the analysis
three temperatures and one bias setting
requires about ***6 hours*** to run and generates ***816 image files***
we plan to add PSF measurement

Data reduction for QE

- **Flux determination:**
  - *calibrated photodiode is placed behind precision aperture at the CCD location*
  - *second photodiode mounted in auxiliary port of integrating sphere*
  - *measure photocurrent vs. wavelength in both diodes*
  - *check ratio for reproducibility*
  - *also check irradiance pattern at CCD location*
  - *use sphere PD for flux monitoring during QE scan of CCDE*
- **Gain determination:**
  - *irradiate CCD with 5.9keV xrays from ^{55}Fe source mounted inside Dewar*
  - *collect ~10^5 events from multiple exposures to avoid crowding*
  - *use clustering algorithm to analyze xray hits to get xray spectrum*
  - *fit spectrum to Mn $K\alpha$ and $K\beta$ peaks; determine peak ADU for each line*
  - *convert peak ADU to gain using known xray energies and pair creation energy of silicon (temperature dependent)*
- **Repeat for each temperature and bias setting**

Detail of electrical cabling and thermal straps

Thermal straps (yellow) provide thermal connection to raft baseplate, tie to copper planes attached to -130C cryoplate



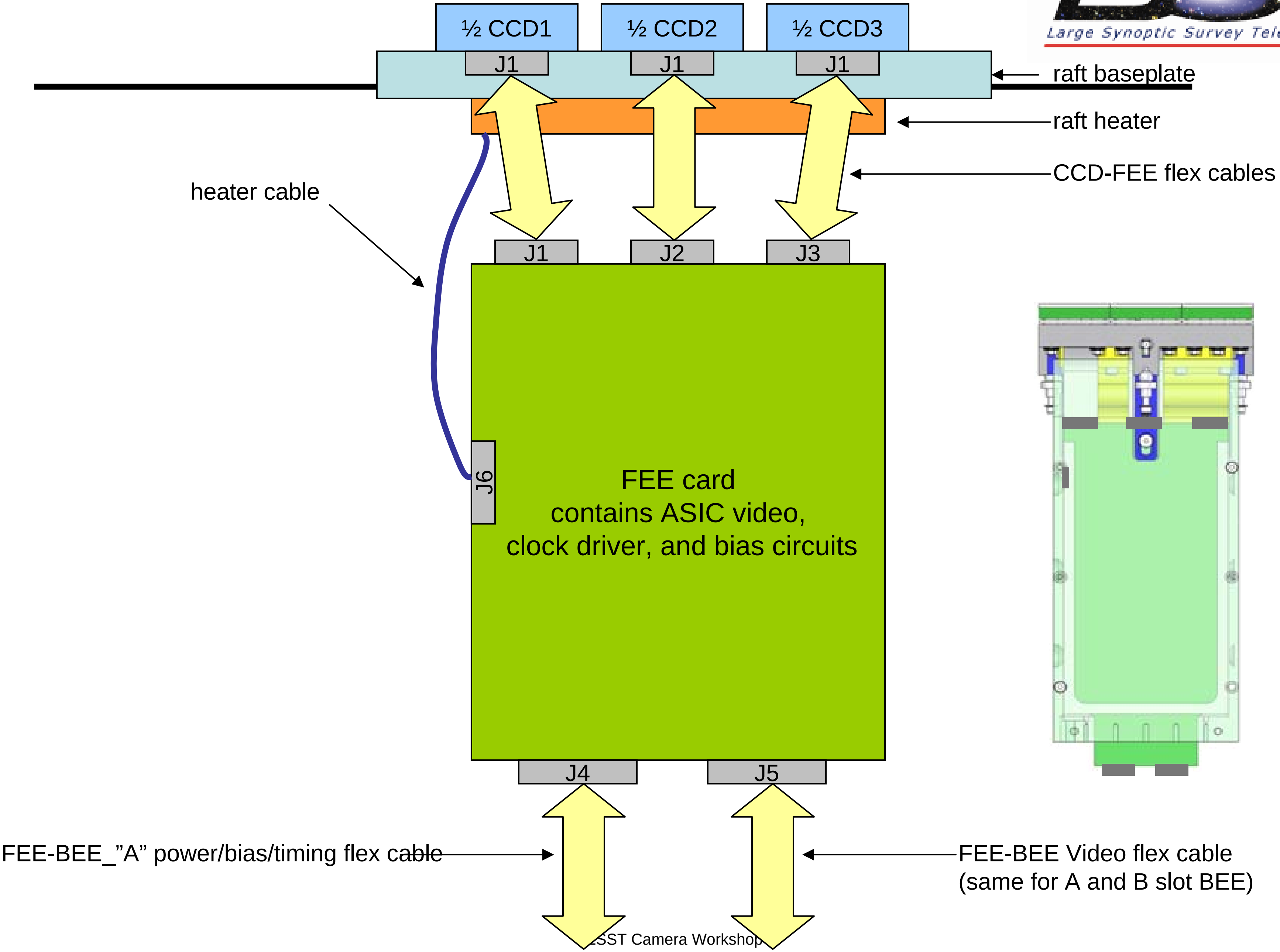
CCDs bolt to raft baseplate at 3 points; mount points provide mechanical + thermal connection to raft.

Kinematic 3-point ball-in-vee mount raft to support grid.

Electrical flex cables (brown) from CCDs pass through openings in raft baseplate, connect to FEE boards. Note: limited width for connectors.

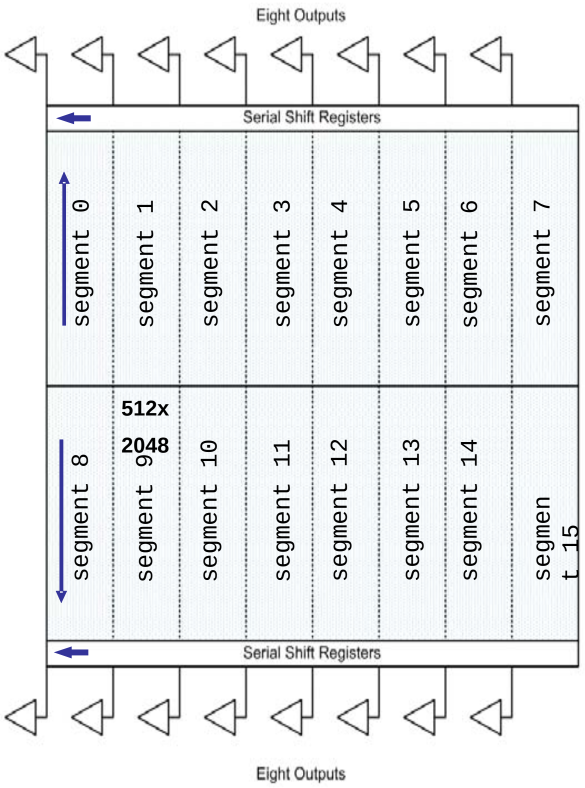
Spring-loaded pretension of raft to support grid.

Electrical interface



Electrical interface

- CCD has 16 segments
- all bond pads on 2 edges
- parallel clocks driven from both ends
- assume 2 flex pigtails from CCD
- flex cable length ~ 6 – 9 cm
- shielding needed for excellent crosstalk rejection
- flex pinouts should be as similar as possible to allow FEE boards to be identical
- each flex has individual segment OD, OS, and possibly OG,RD
- one flex has serial clocks and reset gate
- one flex has parallel clocks (requires bussing on package ceramic)
- strawman flex pinout on next slide (for conceptual design purposes only)



Strawman CCD pinout

Connector J1

Pin	REF	Description
1	OS0	Output Source, segment 0
2	OG0	Output Gate, segment 0
3	OD0	Output Drain, segment 0
4	RD0	Reset Drain, segment 0
5	S1	Serial Clock Phase 1
6	OS1	Output Source, segment 1
7	OG1	Output Gate, segment 1
8	OD1	Output Drain, segment 1
9	RD1	Reset Drain, segment 1
10	S2	Serial Clock Phase 2
11	OS2	Output Source, segment 2
12	OG2	Output Gate, segment 2
13	OD2	Output Drain, segment 2
14	RD2	Reset Drain, segment 2
15	S3	Serial Clock Phase 3
16	OS3	Output Source, segment 3
17	OG3	Output Gate, segment 3
18	OD3	Output Drain, segment 3
19	RD3	Reset Drain, segment 3
20	SS	Substrate
21	OS4	Output Source, segment 4
22	OG4	Output Gate, segment 4
23	OD4	Output Drain, segment 4
24	RD4	Reset Drain, segment 4
25	RG	Reset Gate
26	OS5	Output Source, segment 5
27	OG5	Output Gate, segment 5
28	OD5	Output Drain, segment 5
29	RD5	Reset Drain, segment 5
30	TSFP	Temp Sense Force Positive
31	OS6	Output Source, segment 6
32	OG6	Output Gate, segment 6
33	OD6	Output Drain, segment 6
34	RD6	Reset Drain, segment 6
35	TSMP	Temp Sense Measure Positive
36	OS7	Output Source, segment 7
37	OG7	Output Gate, segment 7
38	OD7	Output Drain, segment 7
39	RD7	Reset Drain, segment 7

Connector J2

Pin	REF	Description
1	OS8	Output Source, segment 8
2	OG8	Output Gate, segment 8
3	OD8	Output Drain, segment 8
4	RD8	Reset Drain, segment 8
5	P1	Parallel Clock Phase 1
6	OS9	Output Source, segment 9
7	OG9	Output Gate, segment 9
8	OD9	Output Drain, segment 9
9	RD9	Reset Drain, segment 9
10	P2	Parallel Clock Phase 2
11	OS10	Output Source, segment 10
12	OG10	Output Gate, segment 10
13	OD10	Output Drain, segment 10
14	RD10	Reset Drain, segment 10
15	P3	Parallel Clock Phase 3
16	OS11	Output Source, segment 11
17	OG11	Output Gate, segment 11
18	OD11	Output Drain, segment 11
19	RD11	Reset Drain, segment 11
20	P4	Parallel Clock Phase 4
21	OS12	Output Source, segment 12
22	OG12	Output Gate, segment 12
23	OD12	Output Drain, segment 12
24	RD12	Reset Drain, segment 12
25	GD	Guard Drain
26	OS13	Output Source, segment 13
27	OG13	Output Gate, segment 13
28	OD13	Output Drain, segment 13
29	RD13	Reset Drain, segment 13
30	TSFM	Temp Sense Force Negative
31	OS14	Output Source, segment 14
32	OG14	Output Gate, segment 14
33	OD14	Output Drain, segment 14
34	RD14	Reset Drain, segment 14
35	TSMM	Temp Sense Measure Negative
36	OS15	Output Source, segment 15
37	OG15	Output Gate, segment 15
38	OD15	Output Drain, segment 15
39	RD15	Reset Drain, segment 15

Calibrations

- **Radiometry: factory-calibrated Hamamatsu photodiodes**
- **Wavelength: Hg, Xe arc lines**
- **Temperature: factory-calibrated RTD's**
- **Charge: ^{55}Fe xrays conversion in Si**
- **Height: precision, low expansion optical parallel**

Diffusion

Model

- **High field effects important at our electric field**
- **Drift time increase due to velocity saturation**
  - *substantially increases diffusion*
  - *effects hole transport differently than electrons*
- **Possible suppression of transverse diffusion coefficient at high fields**
  - *reduces diffusion, countering velocity saturation effect*
- **Possible non-uniform doping of high-rho silicon near entrance window**
  - *would leave thin undepleted, field-free region, leading to high diffusion*
- **Not easy to distinguish experimentally**

Measurement

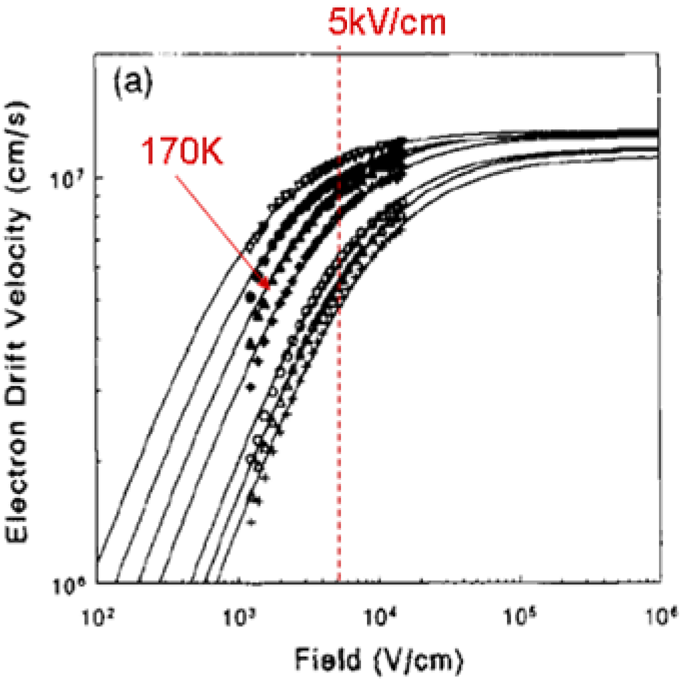
- **Virtual Knife Edge method**
  - *project small spot on detector, scan spot, calculate flux in virtual box*
  - *differentiate to get PSF*
- **Modulation transfer function method**
  - *project sinewave pattern on detector, measure contrast vs. spatial frequency*
- **Xray method**
  - *analyze distribution of xray cluster size, fit to PSF model*
- **Cosmic ray method**
  - *oblique-incident cosmic muons leave long track*
  - *track width on detector is indication of diffusion as function of depth*
  - *estimate diffusion vs. depth from track width (compare simulation)*

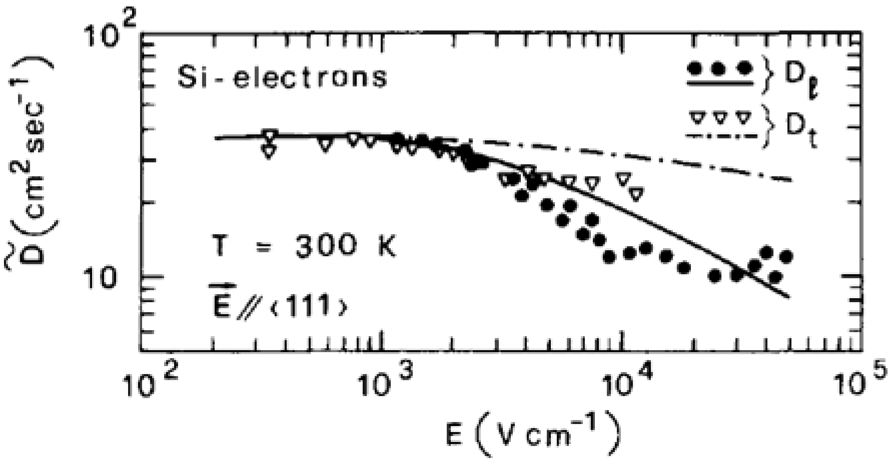
Diffusion calculation and measurement

Thk	100				75	45	193	280	um
Rho	3000				3000		3800	12800	Ohm-cm
Bias	-70				-50		133	80	V
Temp	163		203		200		140	140	K
	e-	h	e-	h	e	e	h	h	
No HFE	2	2	2.2	2.2	2.1	1.7	2.6	4.9	um
VS only	4.3	3.3	4	3.2	3.5	2.7	4.7	6.8	um
VS + DT-s	2.3	2.8	1.7	2.9	2.4	2	3.7	6.4	um
Meas.	5				3.1	1.9	3.9	6.3	um
Ref.	BNL				Tonry	Tonry	Karcher	Holland	

Camera requirement: 0.”25 FWHM = 5.30μm

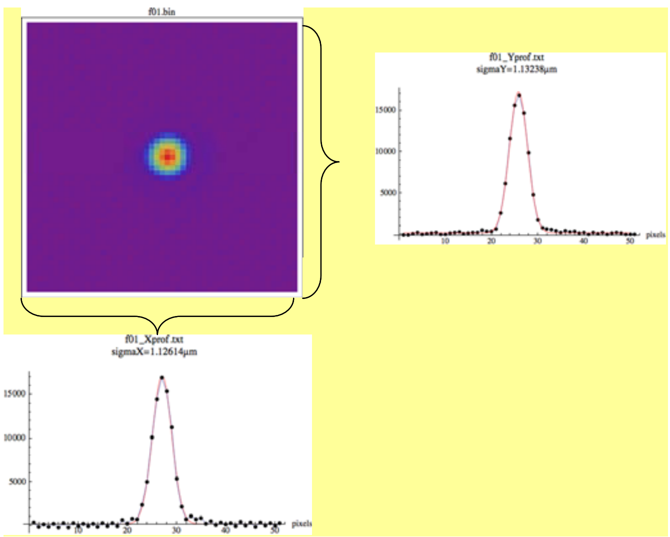
High-field electron transport in silicon





Point projector characterization

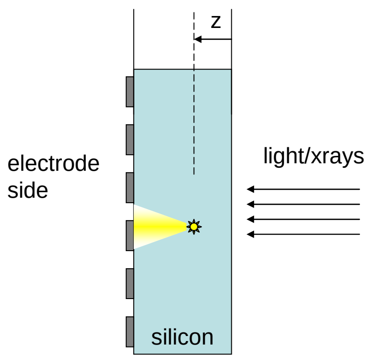
- Best image around +40µm position. Strehl = 0.112.
- Model calculations look very much like the measurements with the SI 1280XV camera.
- Although central image core is narrow, encircled energy indicates significant energy (65%) is outside the core in aberrated image vs. 18% for unaberrated image.
- This energy is spread over a large, diffuse area.
- Need to model how this image shape produces an observed spot on the sensor.
- Can observed sensor PSF be corrected for a broadened source image?
- Custom design required to produce a lens that is compensated for spherical aberration from the thick window.



Ghost image appears strongest when inside of focus.

Diffusion vs. depth into silicon

Geometry:



Drift time:

$$tdr(z) := \frac{d^2}{2 Vdepl \cdot \mu 0} \cdot \ln\left(\frac{u+1}{u-1+2\frac{z}{d}}\right) + \frac{d-z}{vs}$$

Gaussian rms of charge cloud due to diffusion:

$$\sigma d(tdr) := \sqrt{2D \cdot tdr}$$

where
z = conversion depth
d = thickness of CCD (100 or 150um)
Vdepl = depletion voltage (28V for 100um, 35V for 150um)
u = overdepletion factor ⌋≅ 2.4 for 50 – 70V bias of e2v devices
vs = saturated velocity of electrons = 10^7 cm/s
μ0 = low field drift mobility at 163K = 5800 cm^2/V-s
D = transverse diffusion coefficient at 163K = 83 cm^2/s

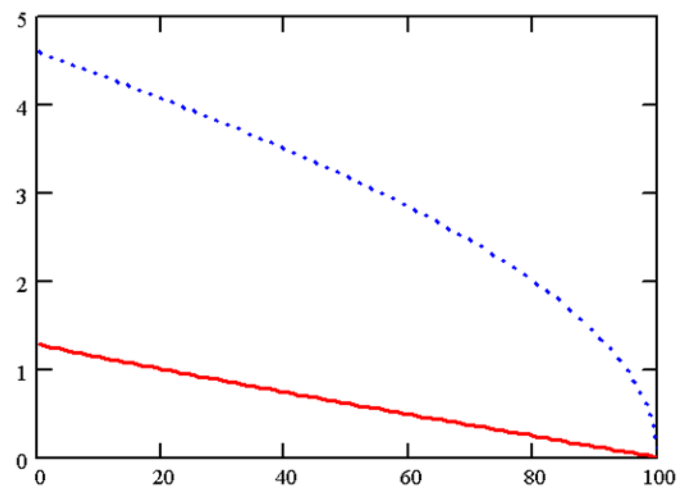
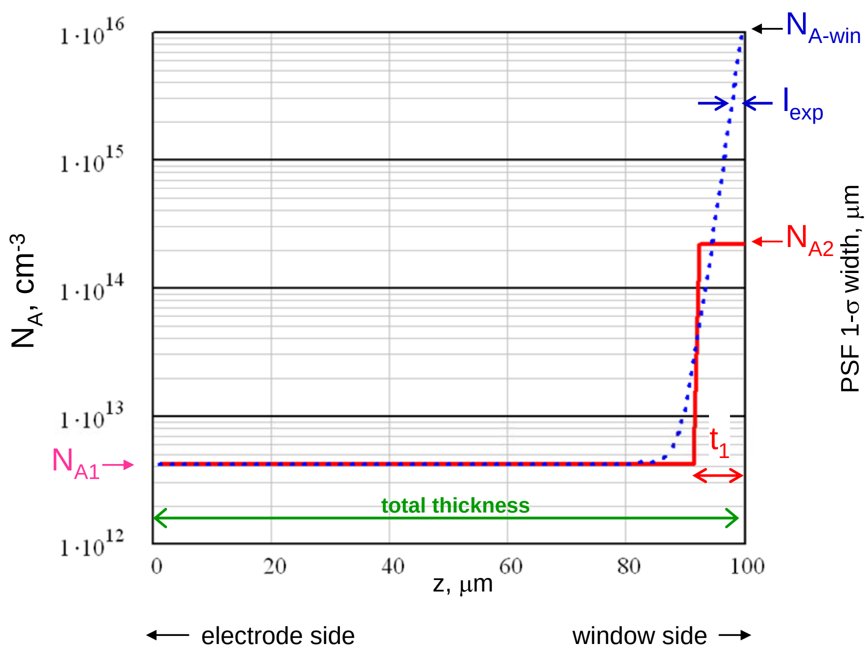
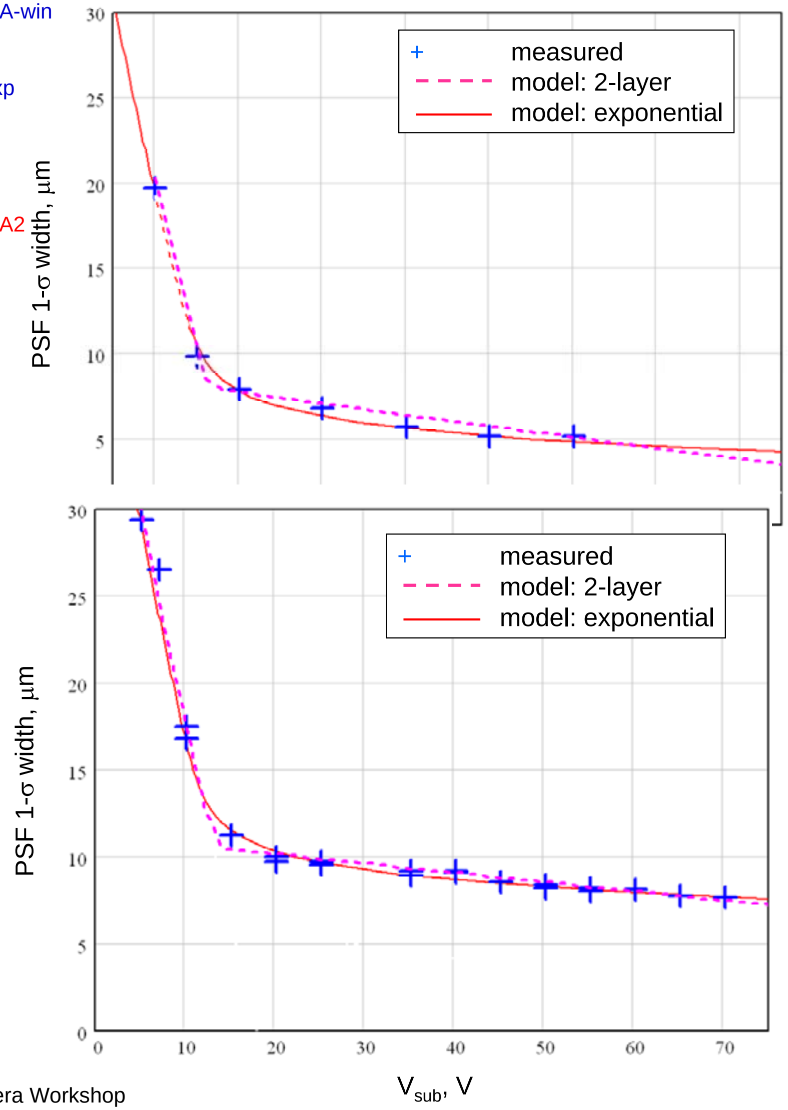


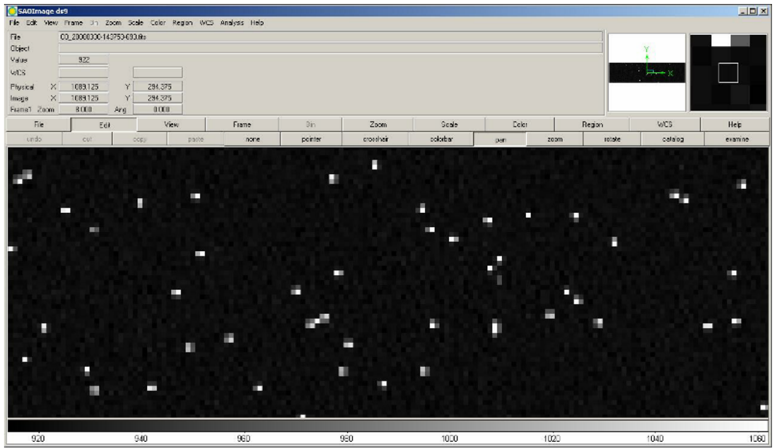
Figure 1: drift time (red) in ns, PSF (blue) in microns rms vs. conversion depth in microns for 100um-thick, fully depleted CCD at 163K

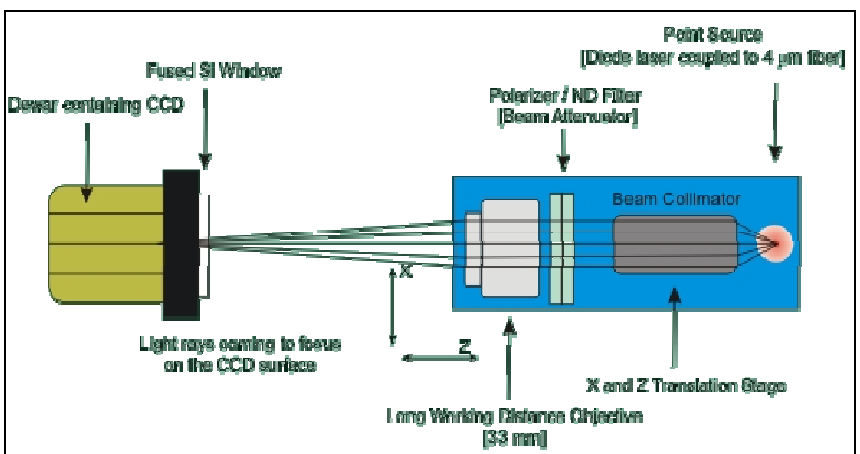
Nonuniform doping fits VKE measurement for two thicknesses



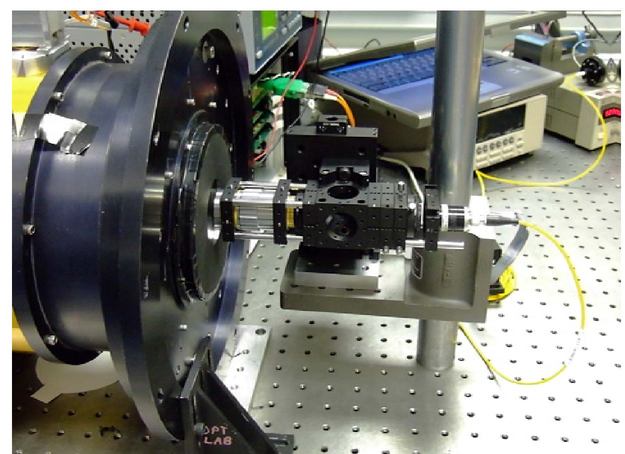


… but vendor says doping is uniform.

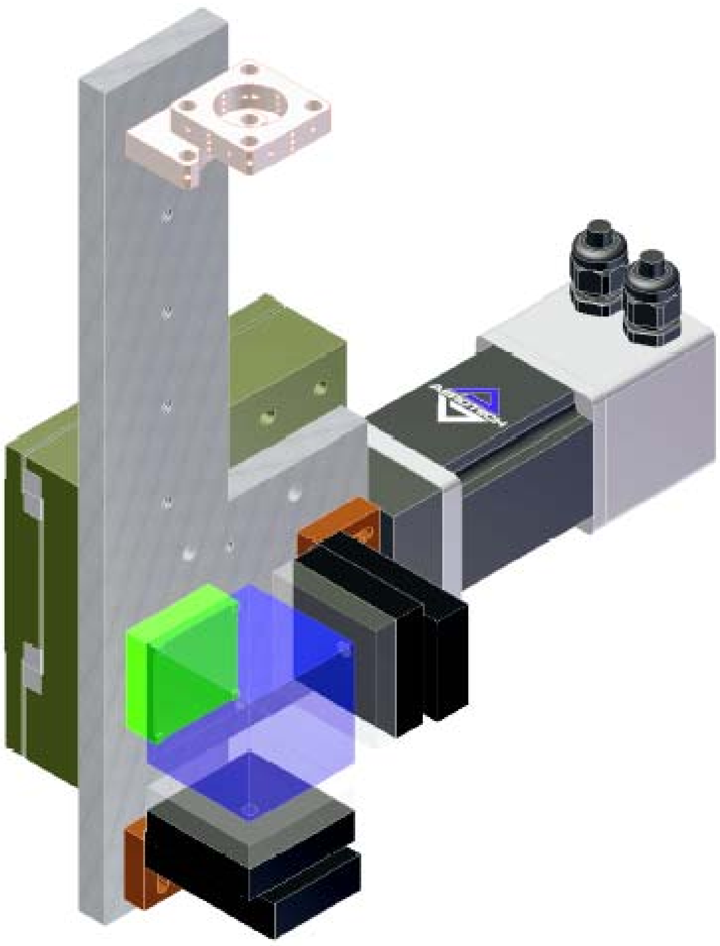


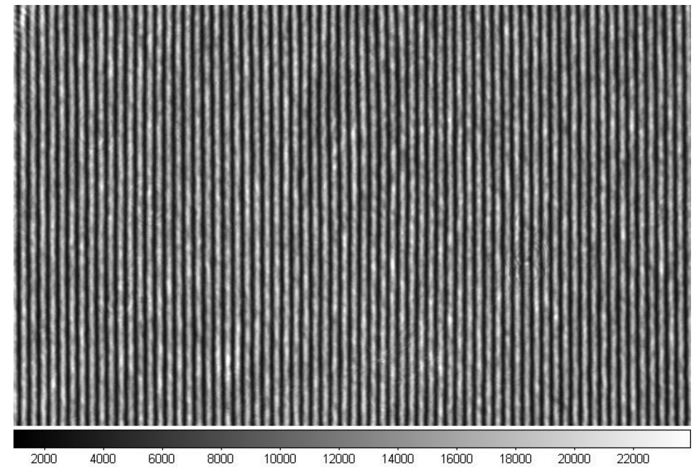


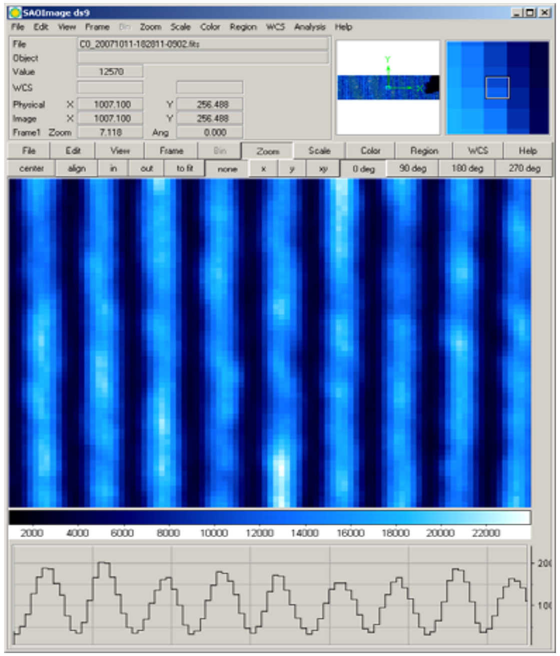
Point Source
[Diode laser coupled to 4 µm fiber]
Fused Si Window
Dewar containing CCD
Polarizer / ND Filter
[Beam Attenuator]
Beam Collimator
X
Z
Light rays coming to focus
on the CCD surface
X and Z Translation Stage
Long Working Distance Objective
[33 mm]



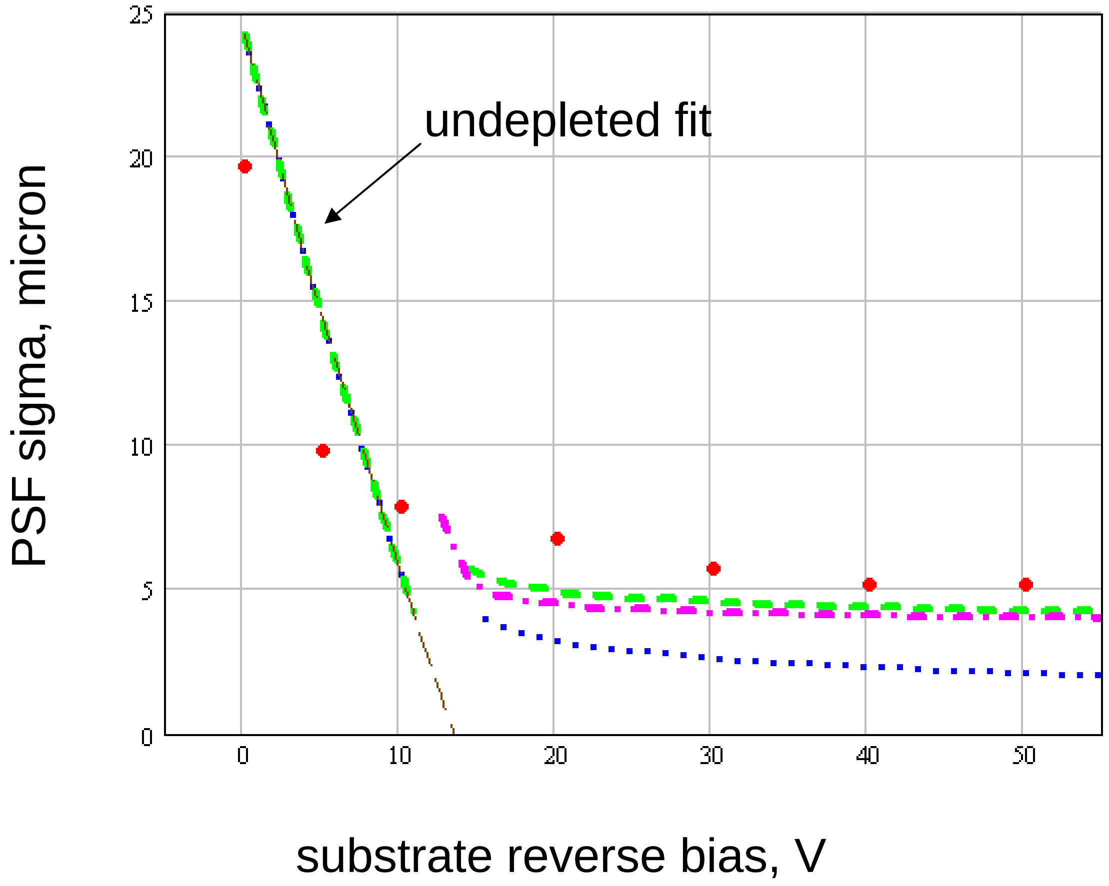
Fringe projector for MTF study





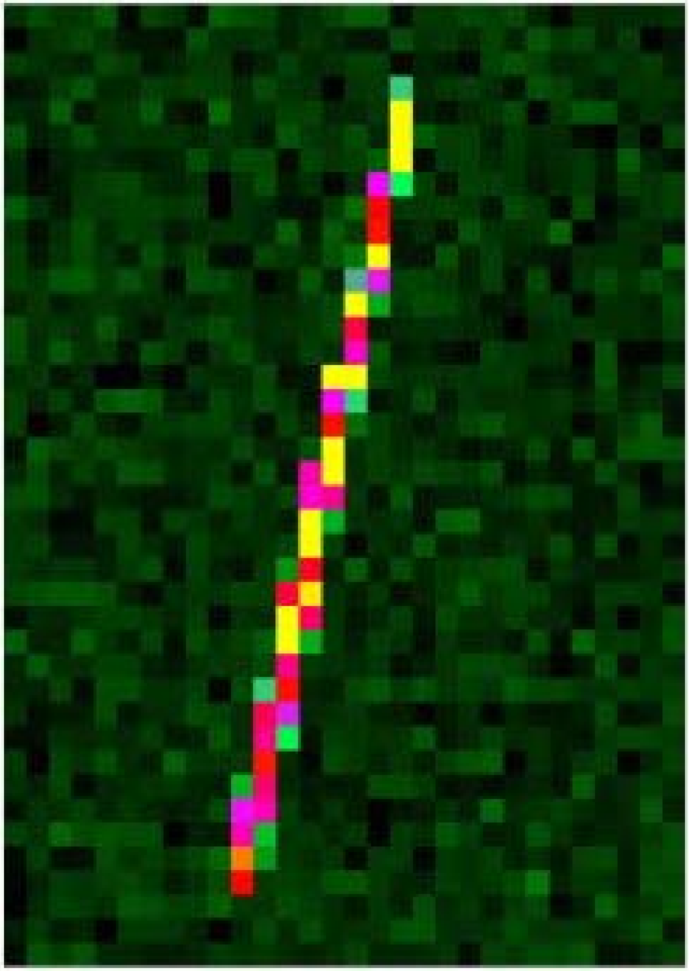


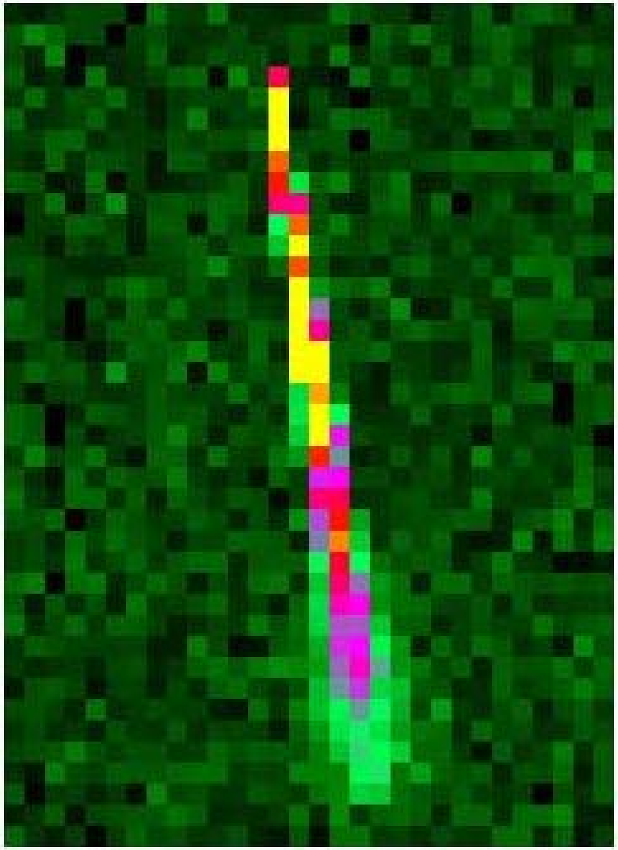
Virtual knife edge PSF measurement



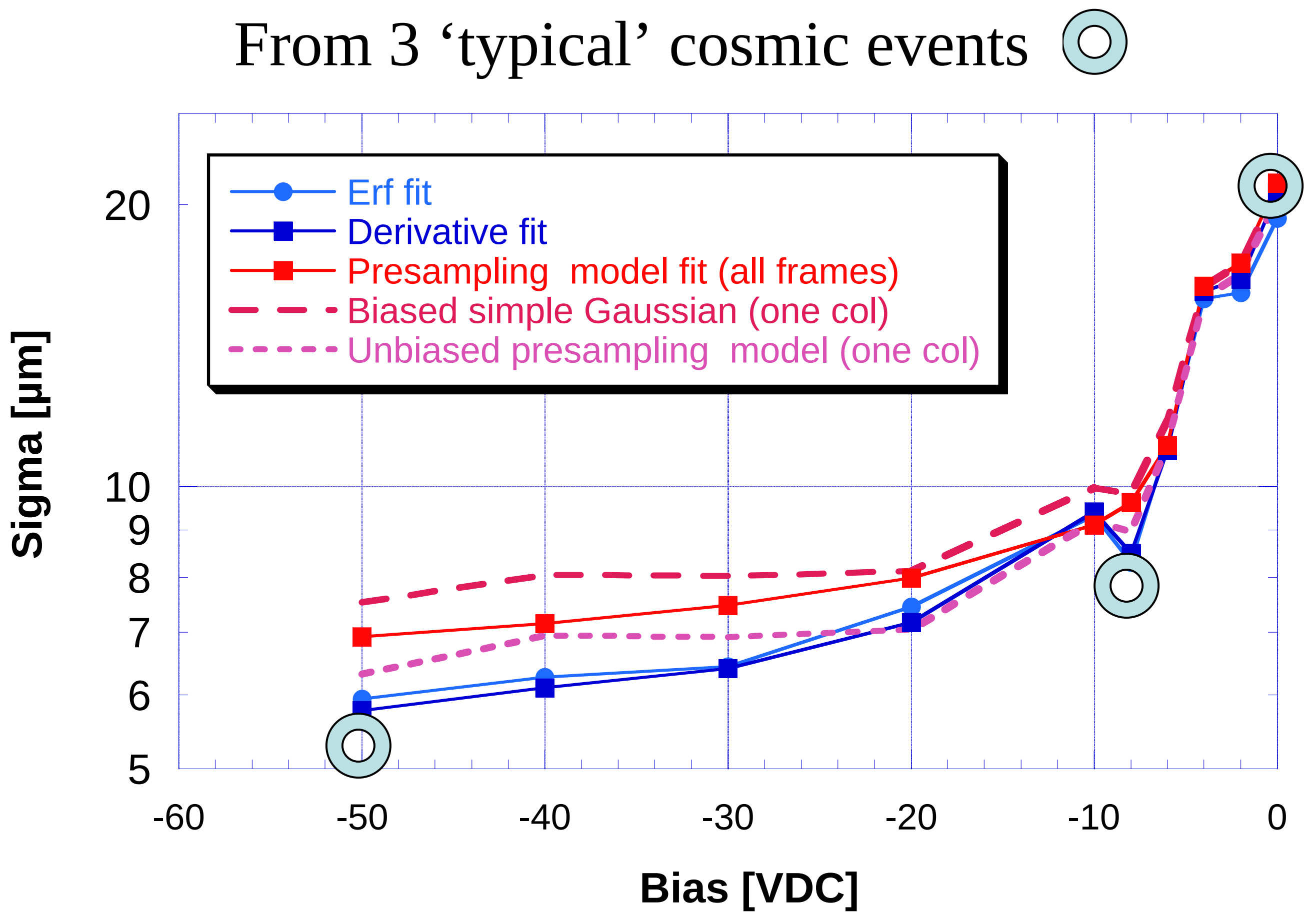
Two ‘typical’ cosmic tracks @

-50V bias 0V bias

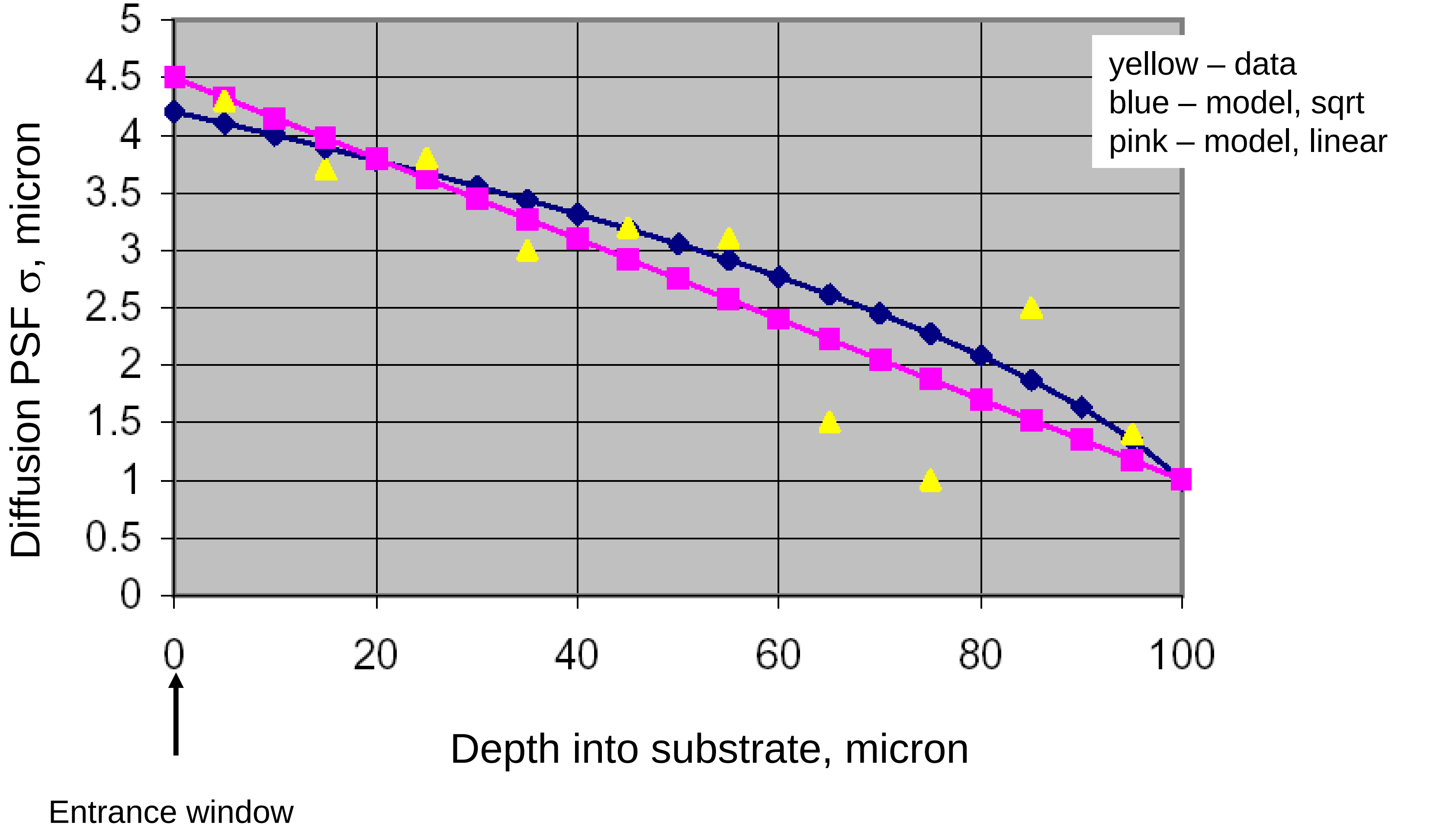




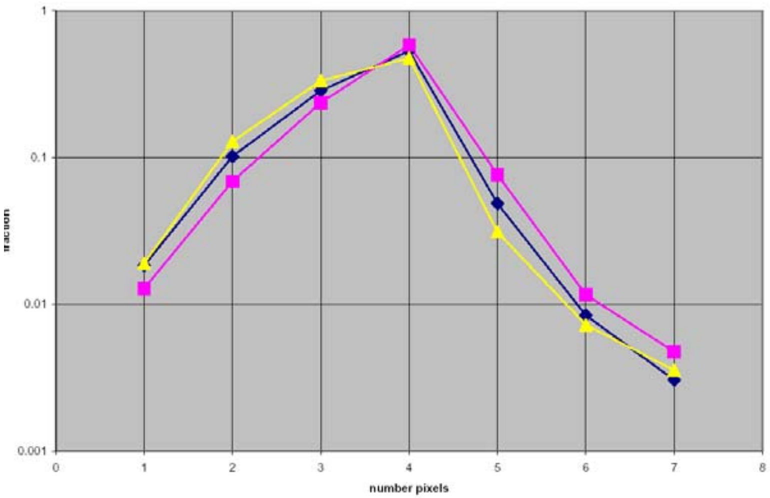
From 3 ‘typical’ cosmic events



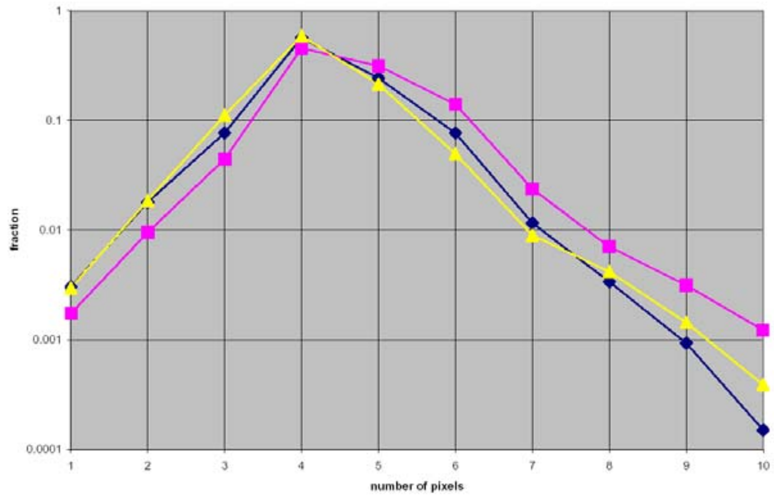
Diffusion PSF vs. depth from cosmic track analysis



Diffusion PSF from xray analysis



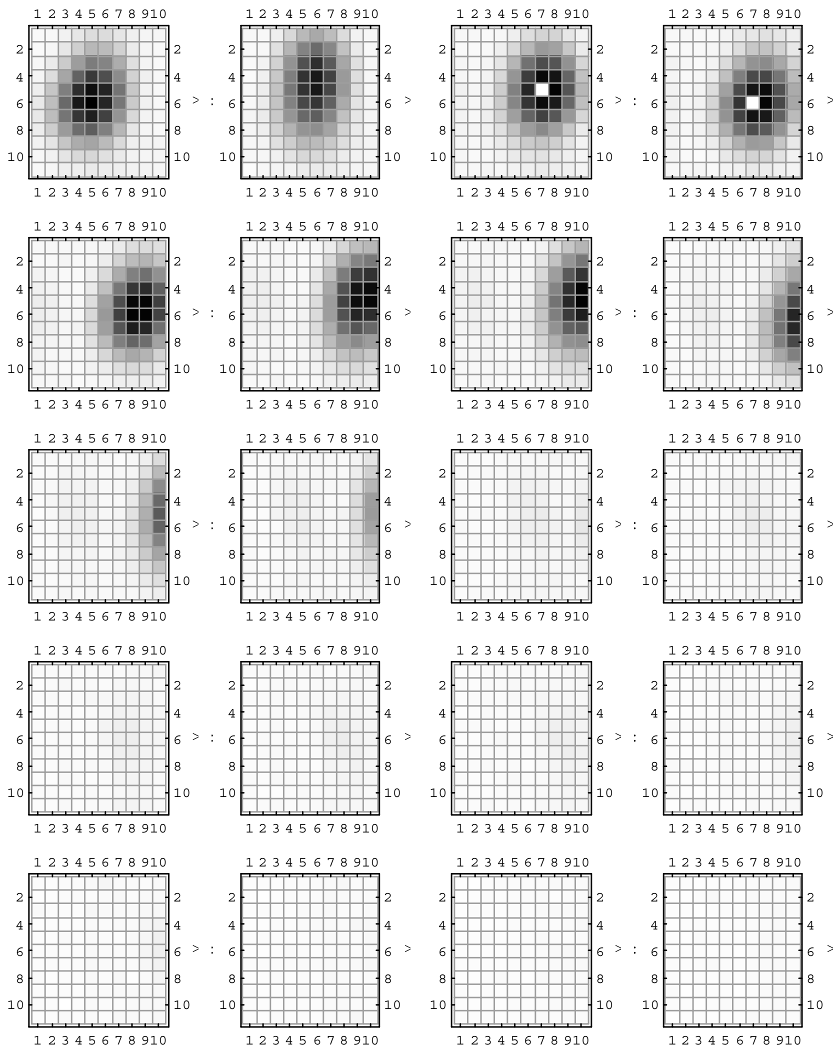
npix distribution
100um device, -75V
blue – measured
magenta -- model, VS included
yellow – model, VS + 0.8*DT



npix distribution
150um device, -75V
blue – measured
magenta -- model, VS incl.
yellow – model, vs + 0.8*DT

surface PSF ~ 4.5um

VKE scan analysis



Sum the intensity in the region as the spot moves across the right edge.

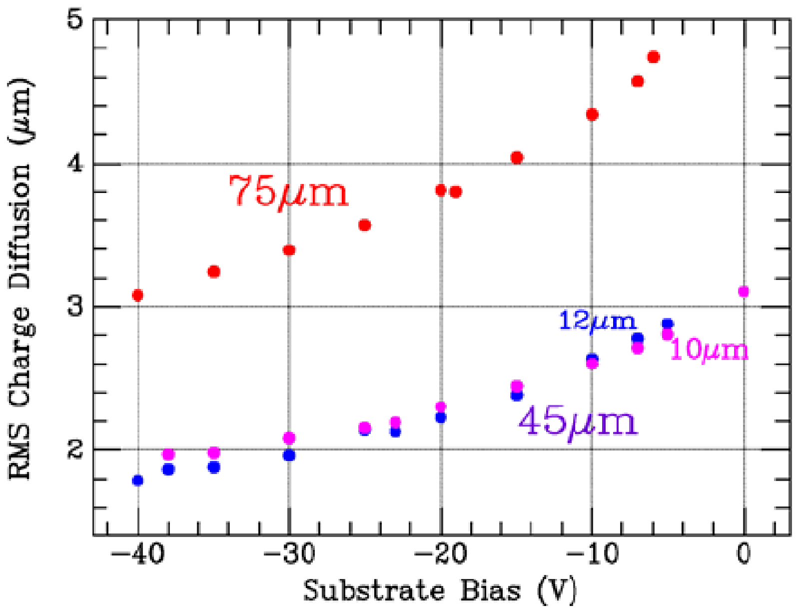
This defines the virtual knife edge.

Each frame corresponds to Δx of 0.5 microns in object space.

Pixel size is 0.5736 µm in object space.

Charge Diffusion (Physical Units)

- Convert <*Qdiff*> to surface diffusion lengths.
  - Different size pixels give identical physical diffusion
  - 75um device has greater diffusion, but OK at -40 V.



-27-

Scientific Detector Workshop, Taormina Sicily, June 2005

Temperature control

- **LSST science mission depends on a consistent stream of stable, homogeneous images**
- **The major source of variability of the camera will come from temperature variations, which affect:**
  - *sensor QE, dark current, responsivity, CTE, diffusion*
    - variations important for photometry and PSF stability
  - *electronics offset, gain, crosstalk*
  - *mechanical position of sensors*
- **Temperature stability of the camera depends on closely coordinated subsystems:**

Temp sensors and heaters	Rafts	BNL/Purdue
Heat generation on FEE	Electronics	Penn
ADC, DAC on BEE	Electronics	Harvard
Control loop algorithm	CCS	Santa Cruz/SLAC/UIUC
Cryogen temp and flow	Cryostat	SLAC
Temp of cryostat walls & L3	Cam. Body & Mech.	SLAC

$$\sigma_{\perp} = \sqrt{2 D_{\perp} t_{dr}}$$

$$\sigma(v_s)\big/d = \left(2\frac{kT}{q_e V_{op}}\right)^{1/2}\left[1+\frac{\mu_0(T)\bar{E}}{v_s}\right]^{1/2}\left[\frac{D_{\perp}(E)}{D(0)}\right]^{1/2}$$

We have performed a detailed analysis of carrier transport in the region where the mobility decreases due to velocity saturation and find the following:

1. There is an ***increase*** in the diffusion due to a longer carrier drift time than expected in the constant mobility case;
2. There is a ***decrease*** in the (transverse) diffusion coefficient due to the streamlining effect of the electric field on the carriers in random+drift motion .

The two opposing effects result in a net diffusion increase factor of ***~1.15*** for electrons (p-substrate sensors), and ***~ 1.32*** for holes (n-substrate), at 173k and 5kV/cm.

This analysis provides a close fit to the PSF measurement results obtained with the LBL CCDs, and with the Pan-STARRS CCDs.