Camera Calibration

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SRD Photometric Specifications

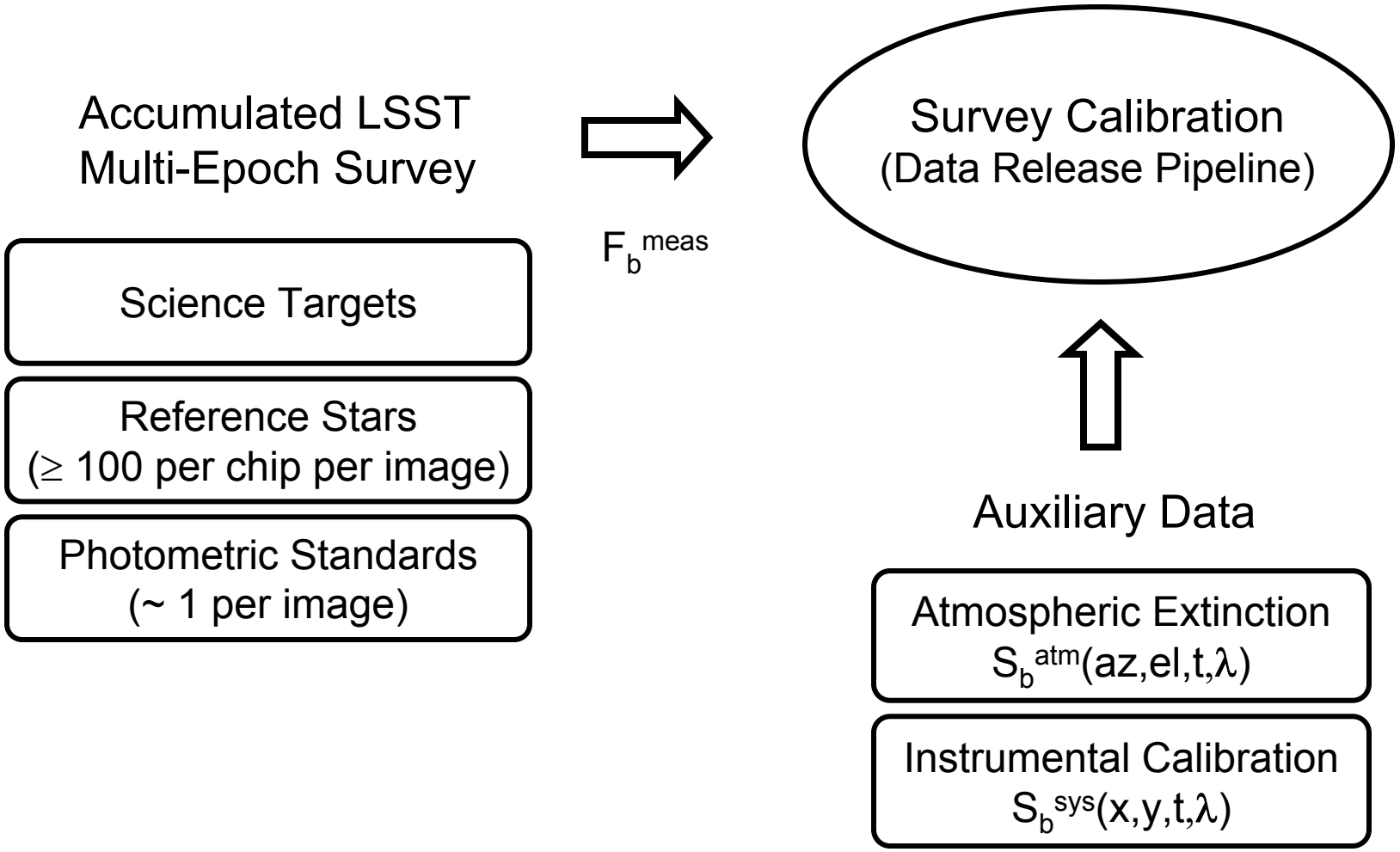
- Repeatability of measured flux over epochs 0.005 mag (rms)
- Internal zero-point uniformity for all stars across the sky 0.010 mag (rms) in *g,r,i,z* ; 0.020 in other bands
- Transformations between internal photometric bands known to 0.005 mag (rms) in *g,r,i,z*; 0.010 to other bands
- Transformation to a physical scale with accuracy of 0.010 mag

LSST specifications are “factor of two” tighter than typically achieved.

E. g. SDSS Sky Server catalogs internal relative calibrations to ~ 2%.

Ivezic, et al. (2004).

Photometric Calibration Elements



Flow Down of SRD Specifications to Measured Quantities

Design Specification	Repeatability (millimag)	Uniformity (millimag)	Color Accuracy (millimag)
SRD (rms)	5	10	5
Instrumental S_b^{sys}	3	5	3
Atmosphere S_b^{atm}	3	5	3
Image Process F_b^{meas}	3	7	3

Telescope and Camera

Flowdown to Camera

- Stability – budget is 0.2% for uncontrolled variations in throughput.
  - (QE(t) • CTE • Gain(t)) stable to < 0.2% over times shorter than calibration cadences:
    - Dome screen beginning and end of each night
    - Sky standards every epoch (3-4 days)

- Uniformity – budget is 0.35% for uncontrolled variations in throughput.
  - Relative (QE(x,y) • CTE • Gain(x,y)) controlled to < 0.25%.
  - Relative optics/filter transmission T(x,y) controlled to < 0.25%.

→ The product of these two is what really matters.

- Color zero-points – budget is 0.2% for uncontrolled variations.
  - Measure relative (T(λ) • QE(λ)) (over passbands) with error < 0.2%.

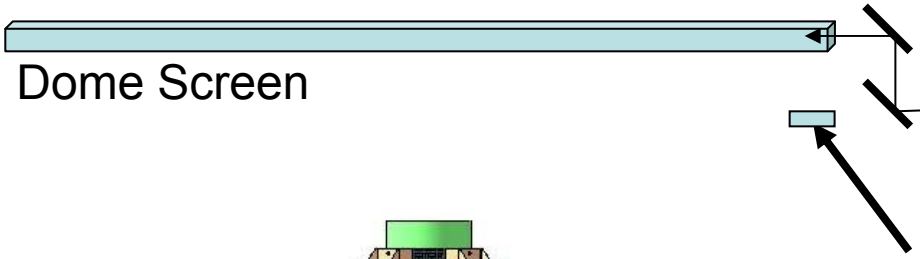
Camera Calibration Matrix

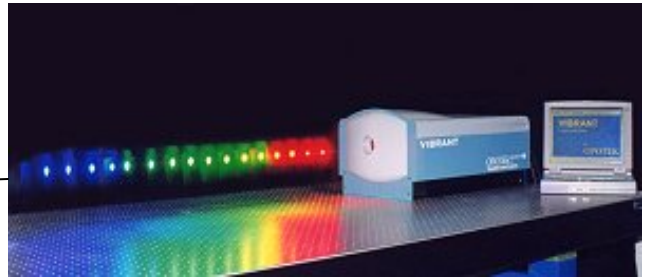
Large Synoptic Survey Telescope

Parameter			Summary Specification	Production Tests	Raft Tests	Camera I&T Calibration	Dome/Sky Calibration
Sensors and Elex							
	QE(λ,x,y)			x	x	x	
	CTE(x,y)			x	x	x	
	Gain(e-,x,y)		Non-linear < 3% Full Well	x	x		
	Full Well		90000 e-	x	x	x	x
	Cross Talk		residual < 3σ(sky)	s	s	xx	??
	Fringe(λ)		< 5% (p2p)			xx	xx
	Dark Current(x,y)		< 1 e-/s/pix	x	x	xx	xx
	Electronic Noise		< 5 e- rms	x	x	xx	xx
	Persistent Charge		< 0.02% Full Well (20 e-)	s	s	x	x
	Bad Pix Map		<1% bad pix	x	xx	xx	xx
	Thermal Variation				x	xx	
Throughput and Scattered Light							
	Optics/Filters T(λ,x,y)			x			
	T(λ,x,y)·QE(λ,x,y)		0.25% rel meas error			??	
	CTE·Gain(e-,x,y)		0.25% rel meas error			xx	??
	Throughput (λ,e-,x,y)		0.35% rel meas error			xx	
	Scattered Light (λ,x,y)		< 3% model error	(TPC)		xx	
Key:	x	Acceptance value					
	xx	Calibration value					
	s	sample test only					

Instrumental Optical Calibration

Every point on the screen must provide uniform illumination of the angular FOV.

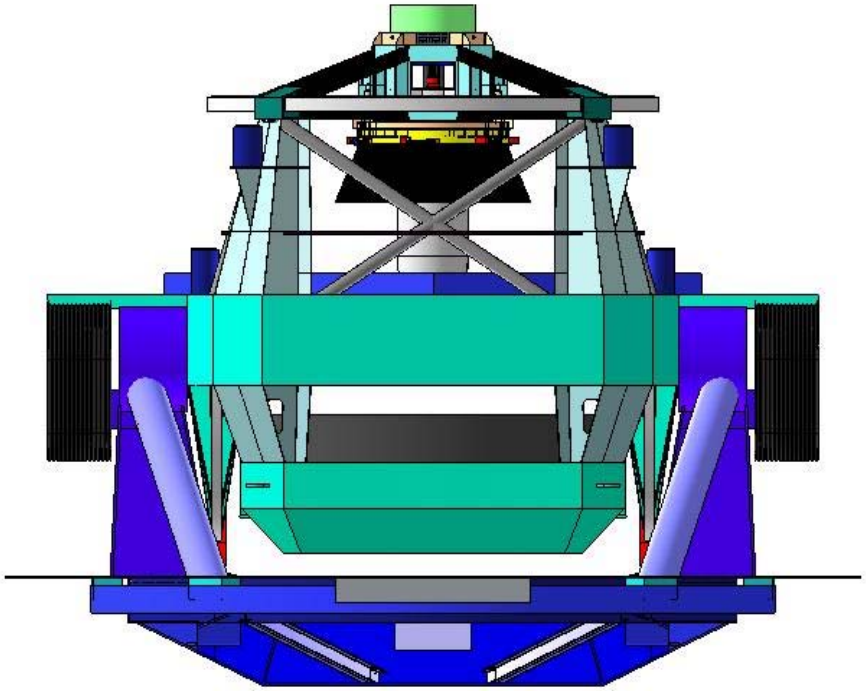




Tunable Laser

Calibrated Photodiode

NIST relative calibration across wavelength (*griz*) to ~ 10^{-3}

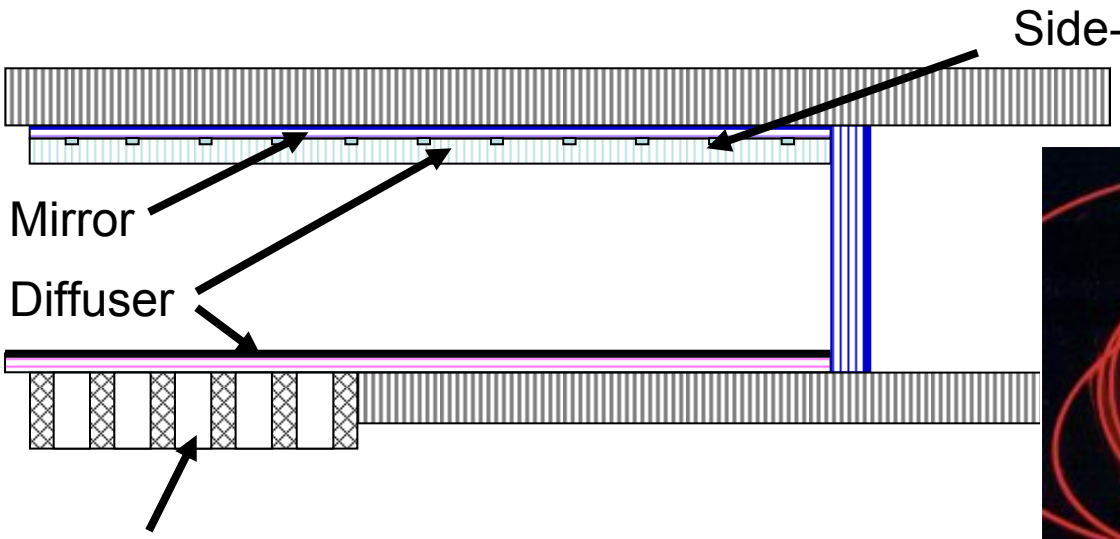


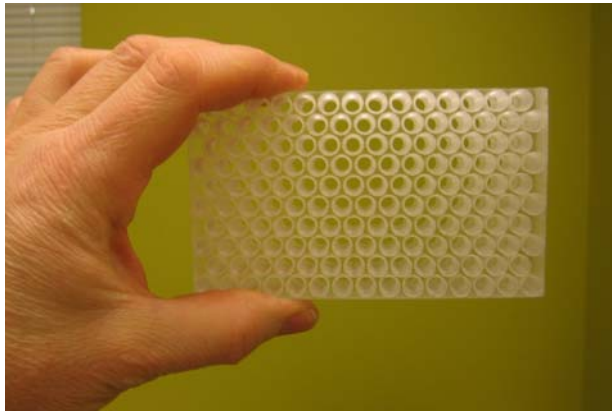
Harvard (Stubbs)

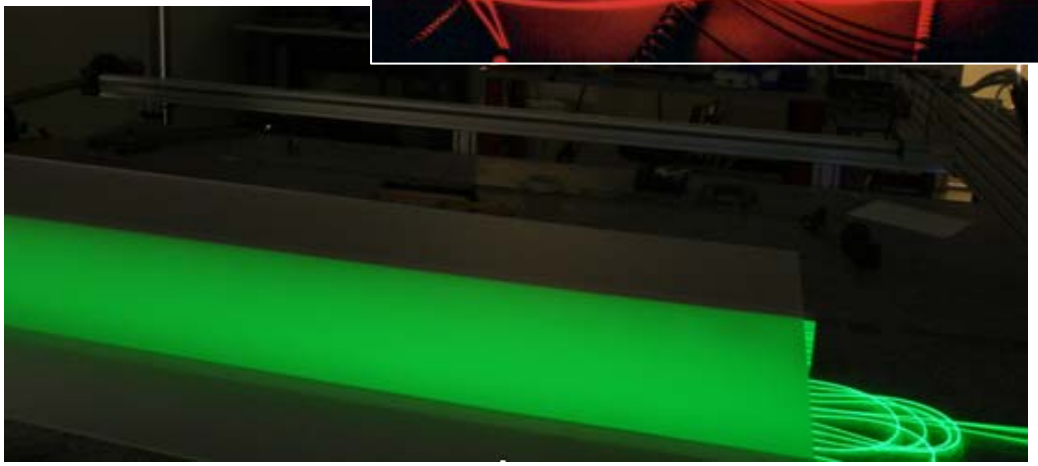
Issues

- Illumination uniformity
  → Prototype
- Stray and scattered light
  → Simulation
- Tunable sources below 400nm

Embedded Fiber Prototype







Camera I&T Calibration Goals

Large Synoptic Survey Telescope

Purpose: Establish camera photometric performance before integration with telescope.

- Determine fixed operating parameters.
- Determine system response times.
- Determine spatial uniformity and camera “flats”.
- Measure chromatic bandpasses.
- Validate ghosting (scattered light) model.

⟶ Separate camera and telescope performance.

Integrated Camera Calibration

When …

Camera is completed and sitting in SLAC assembly room.
Electronics and DAQ working.
Peripherals (shutter, filters, etc) in place and working.

Goal

Verify we are ready to ship the Camera to the mountain.

Method

Run the camera as if it were taking data on the telescope!

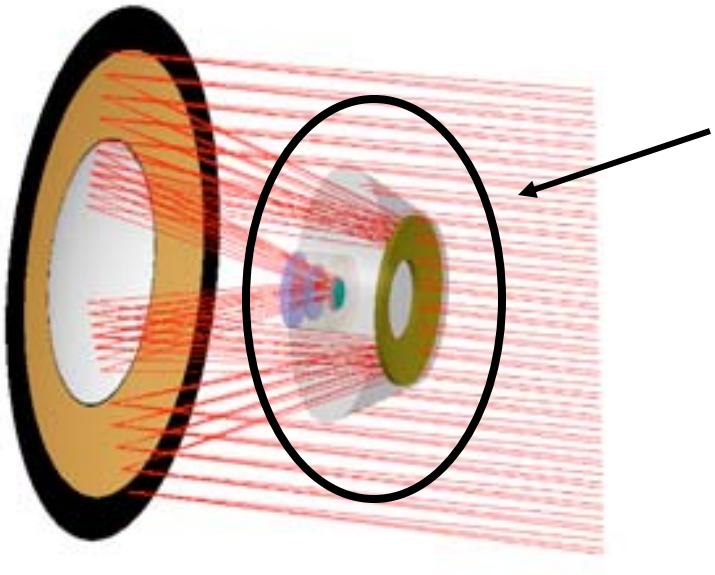
→ Camera Calibration Optical Bench

Images to Record and Analyze

Bias frames.
Darks (long and short).
Calibration Images

Barrau, et al.

ZEMAX Model Calculations



- Consider only the camera
  - Three lenses
  - Filter
  - CCD surface
- LSST non-sequential ZEMAX model

Bechtol, Scacco, and Sonnenfeld

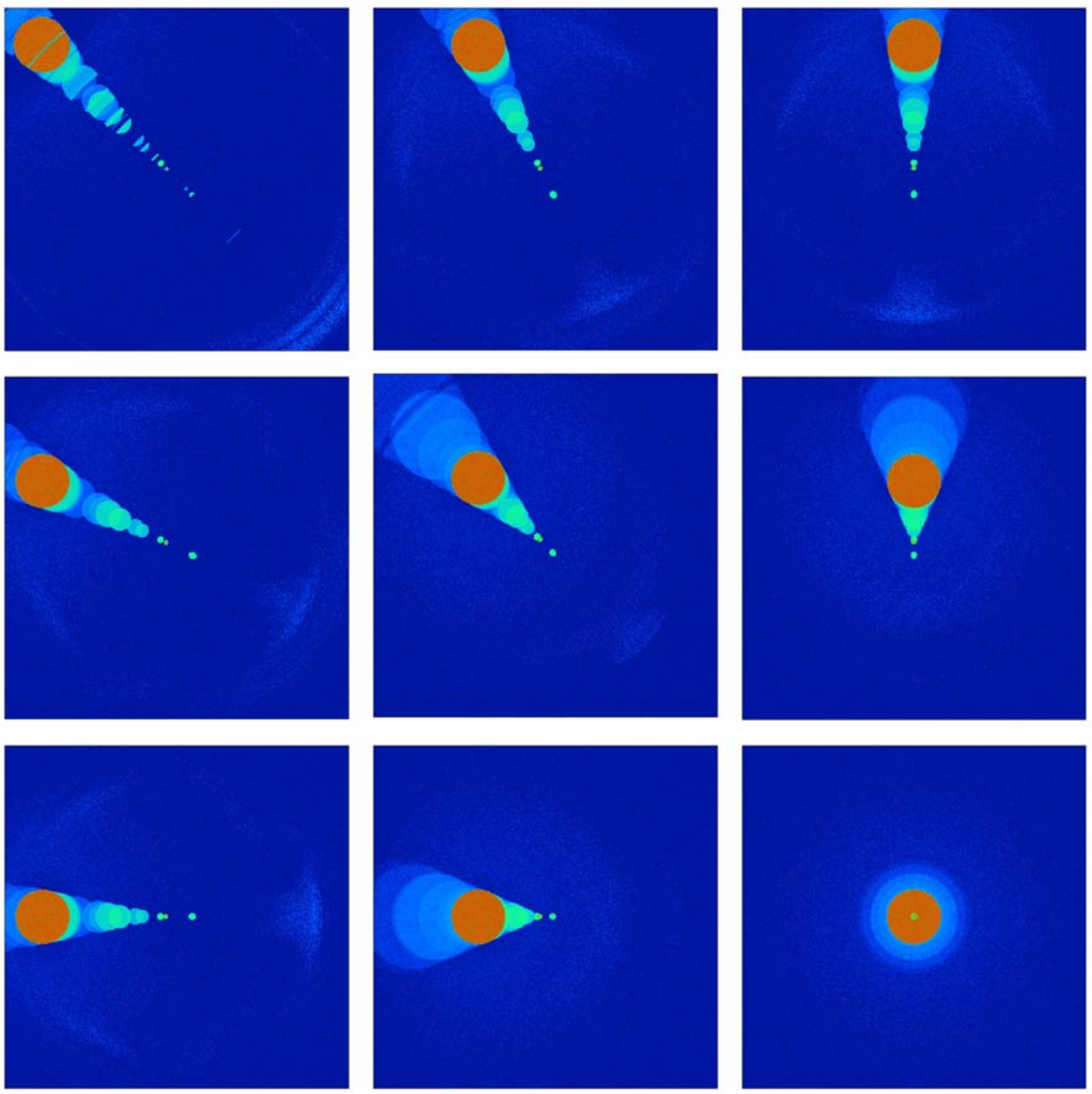
“Headlight” Beam

Large Synoptic Survey Telescope

Center 10 cm diameter beam over a grid of positions

(250,250)	(125,250)	(0,250)
(250,125)	(125,125)	(0,125)
(250,0)	(150,0)	(0,0)

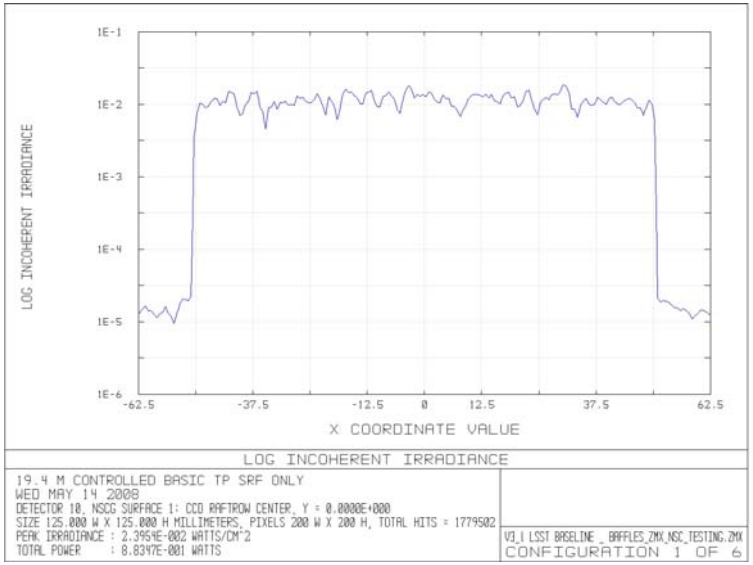
Beam Positions (cm)



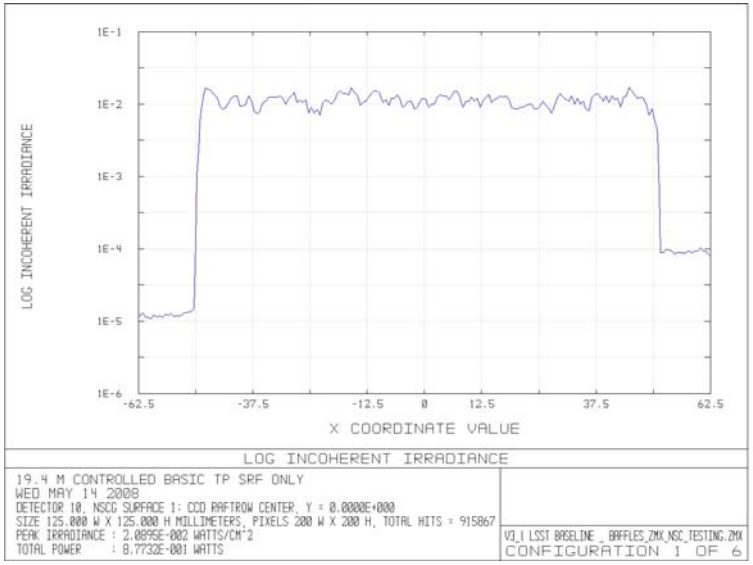
Incoherent irradiance (W / cm²)

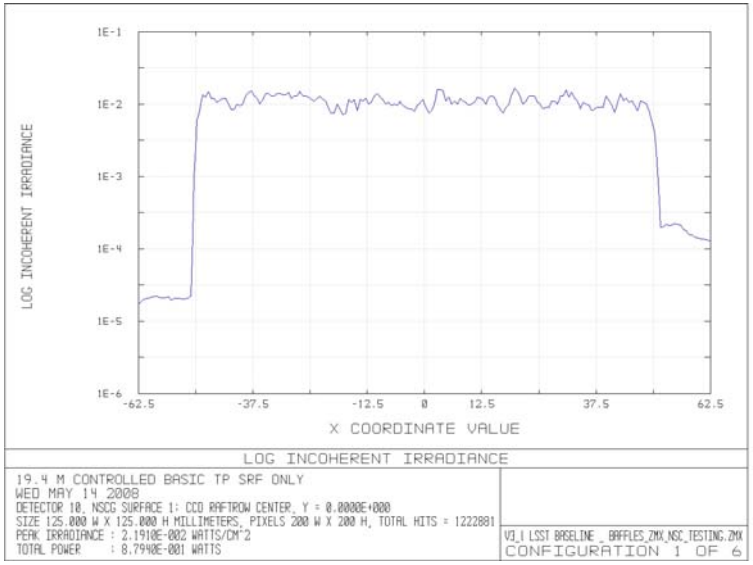
Beam Profiles at Focal Plane

Large Synoptic Survey Telescope



Center (0,0)





Offset 125 cm
(125cm,0)

Offset 250 cm
(250cm,0)

Test beam intensity profiles at focal plane – radial slices

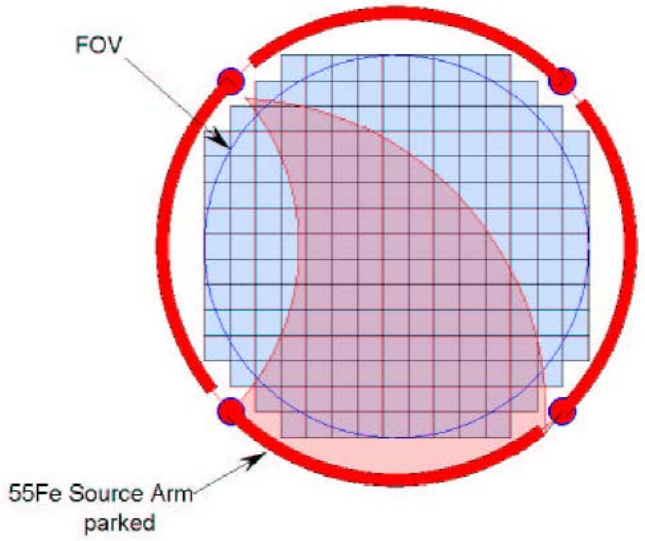
X-Ray Calibration During Camera I&T

Large Synoptic Survey Telescope

Considered implementation of an *in-situ* x-ray system.

Rejected in favor of a temporary "L3" source plate to be used during I&T (and perhaps later at the observatory as needed for recovery after maintenance).

Fixed and shuttered ^{55}Fe sources on the CCD (cold) side of a plate that replaces L3.



Activity and spacing of sources to provide ~ 10^3 hits per amplifier readout per 15 sec exposure.

No mechanical design yet.