Camera Focal-Plane Metrology

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- LSST camera's focal plane (FP) is formed out of 21 science rafts (189 science sensors) and 4 corner rafts (8 guide sensors, 8 WF sensors) mounted a rigid and stable optical bench (GRID)
- Efficient I&T favors a parallelized, hierarchical and modular design: identical sensors assembled onto identical rafts, and identical rafts mounted onto the GRID, prepared to feature a coplanar arrangement of Kinematic Coupling parts when cold and under representative load
- Compared to alternative scenarios, this approach shifts workload between raft production (BNL) and FP integration (SLAC) – but will reduce handling at a time when exposure should be minimized

Drivers for FP Flatness

The main issues

- Imaging performance in the face of wide field, fast optical beam (Ω~$10^{\square}$; F/1.2)
- PSF shape control in a slightly astigmatic and vignetted beam formed by optics actively compensated for environmentally induced deformations
- Adopted FP non-flatness allowance is 10μm P-V: Equal to pixel size and smaller than 100μm baseline sensor thickness
- Error budget for the focal plane includes terms at various scales (sensor, raft, focal plane) as well as dynamical terms. The P-V allocation is considered a placeholder, and will be replaced with a more realistic distribution function
- Current baseline flatness limits: Sensor → Raft → Focal Plane:: 5.0μm → 6.5μm → 8.5μm

Current, Hierarchical FP flatness error budget (2006, Layton Hale, LLNL)

	Component	Error Source	Comment	PV / RMS	PV	RMS	±2σ	±3σ
	Focal Plane Array	*Total: 1, 2, 3, 4, 5, 6*		*14.90*	*24.55*	*1.65*	*6.59*	*9.89*
1	*Sensor*	*Subtotal: 1.1 - 1.6*		*5.61*	*6.30*	*1.12*	*4.49*	*6.74*
1.1		Manufacturing tolerance		4.50	5.00	1.11		
1.2		120º C cool down		4.50	0.50	0.11		
1.3		Mounting influence		4.50	0.50	0.11		
1.4		Heat load		4.50	0.10	0.02		
1.5		Changing gravity vector		4.50	0.10	0.02		
1.6		Long-term stability		4.50	0.10	0.02		
2	*Adjustable sensor mount*	*Subtotal: 2.1 - 2.5*		*7.54*	*2.60*	*0.34*	*1.38*	*2.07*
2.1		Adjustment increment		3.85	1.00	0.26		
2.2		Measurement uncertainty		3.85	0.50	0.13		
2.3		120º C cool down	Variation among mounts	3.85	0.50	0.13		
2.4		Changing gravity vector	Variation among mounts	3.85	0.10	0.03		
2.5		Long-term stability	Variation among mounts	3.85	0.50	0.13		
3	*Raft plate*	*Subtotal: 3.1 - 3.4*		*8.03*	*2.20*	*0.27*	*1.10*	*1.64*
3.1		120º C cool down	Repeatability	4.50	0.10	0.02		
3.2		Mounting influence		4.50	0.50	0.11		
3.3		Changing gravity vector		4.50	0.50	0.11		
3.4		Long-term stability		4.50	0.10	0.02		
3.4		Field curvature	Flat-plate approximation	4.50	1.00	0.22		
4	*Kinematic raft mount*	*Subtotal: 4.1 - 4.7*		*9.73*	*4.00*	*0.41*	*1.64*	*2.47*
4.1		Adjustment increment		3.85	0.50	0.13		
4.2		Measurement uncertainty		3.85	0.50	0.13		
4.3		Repeatability		3.85	1.00	0.26		
4.4		Variation w.r.t. master	Ball size, vee geom., etc.	3.85	0.50	0.13		
4.5		120º C cool down	Variation among mounts	3.85	0.50	0.13		
4.6		Changing gravity vector	Variation among mounts	3.85	0.50	0.13		
4.7		Long-term stability	Variation among mounts	3.85	0.50	0.13		
5	*Grid*	*Subtotal: 5.1 - 5.5*		*10.06*	*1.25*	*0.12*	*0.50*	*0.75*
5.1		120º C cool down	Repeatability	4.50	0.25	0.06		
5.2		Changing gravity vector		4.50	0.25	0.06		
5.3		Raft/mount loads	Correction error	4.50	0.25	0.06		
5.4		Heat loads		4.50	0.25	0.06		
5.5		Long-term stability		4.50	0.25	0.06		
6	*Dynamic errors*	*Subtotal: 6.1 - 6.6*		*7.91*	*8.20*	*1.04*	*4.15*	*6.22*
6.1		X-Y-θ motion flexures	Geometric error motion	3.85	0.20	0.05		
6.2		WFS measurement noise	Assume curvature sensors	4.50	2.00	0.44		
6.3		Image-to-FPA vibration	Wind shake, step & settle	2.82	1.00	0.35		
6.4		Hexapod least increment		3.46	2.00	0.58		
6.5		Rotator error motion	Bearing noise	3.46	1.00	0.29		
6.6		Calibration to the sky	Thru-focus step test	3.46	2.00	0.58		

Table 1 Focal-plane-array error budget. All errors are in units of micrometers (0.001 mm).

sensor

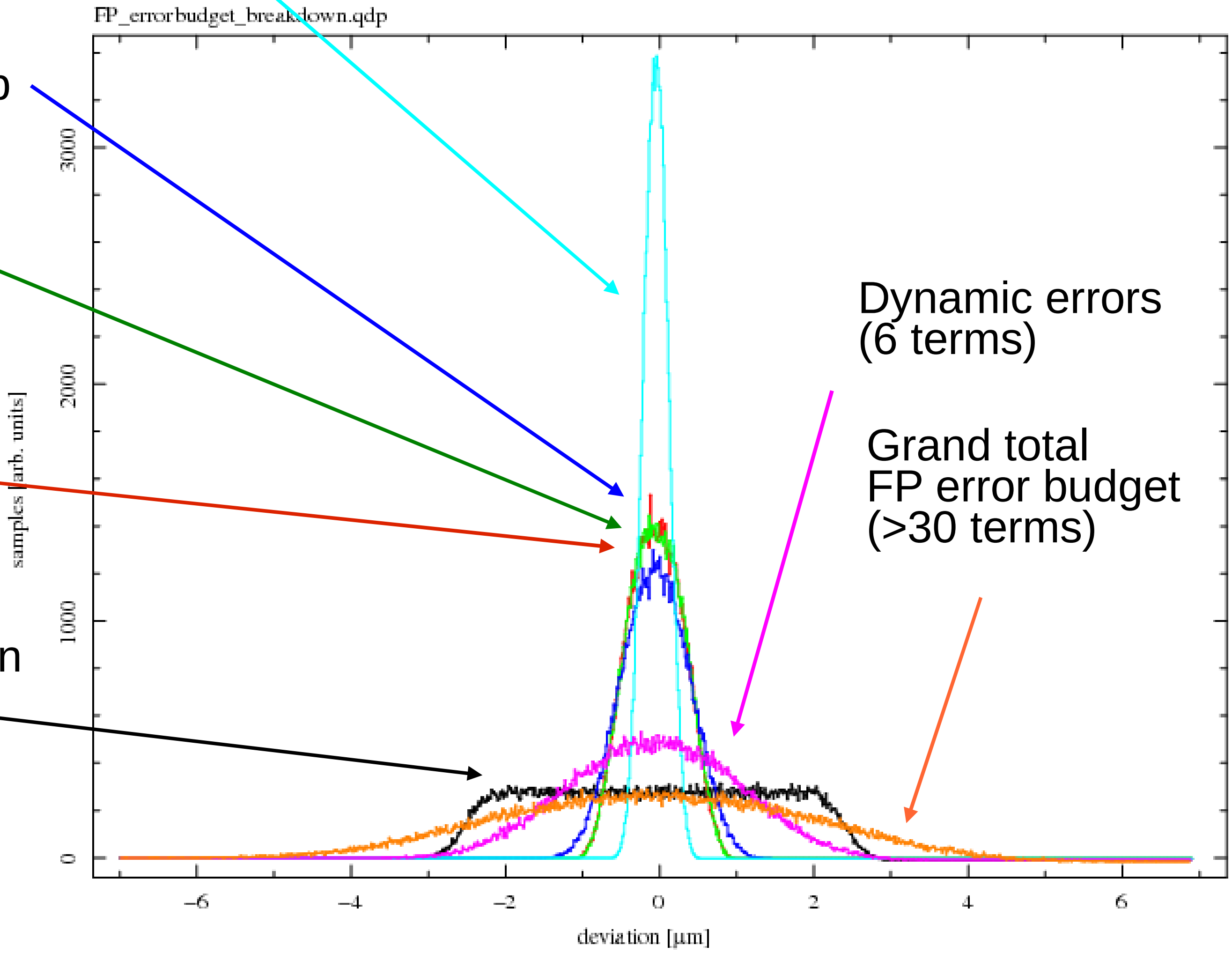
(adj.) sensor
mount

Raft Plate

Kinematic mount
(Raft)

Grid

Dynamical errors



Grid contribution
(5 terms)

Kinematic raft mount contrib
(7 terms)

Raft plate contribution
(4 terms)

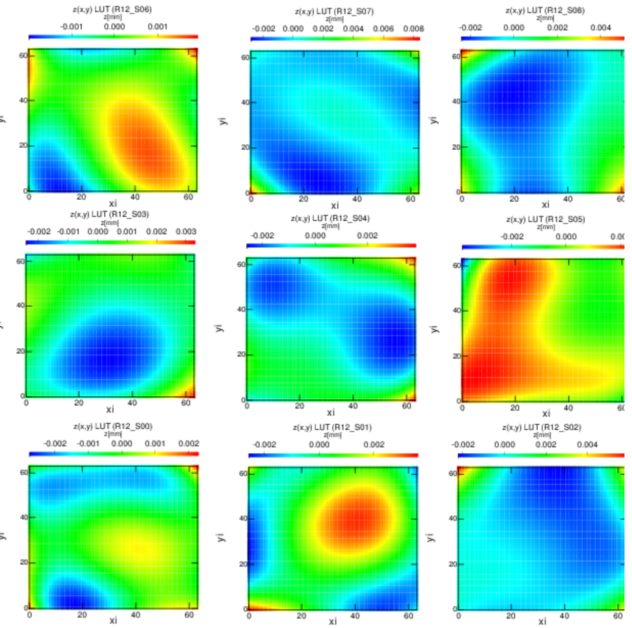
Adj. Sensor mount contrib
(5 terms)

Sensor level contribution
(6 terms)

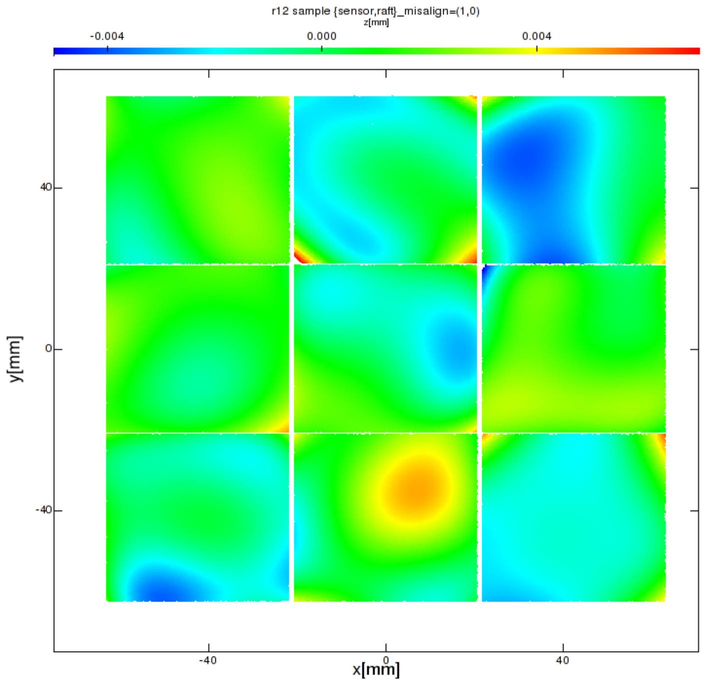
Dynamic errors
(6 terms)

Grand total
FP error budget
(>30 terms)

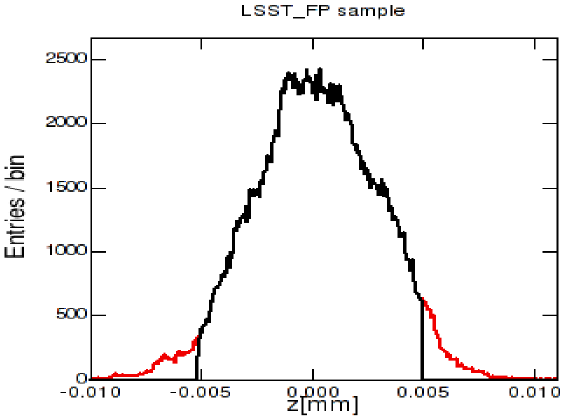
A “realistic” (?) LSST_FP: hierarchical/modular design



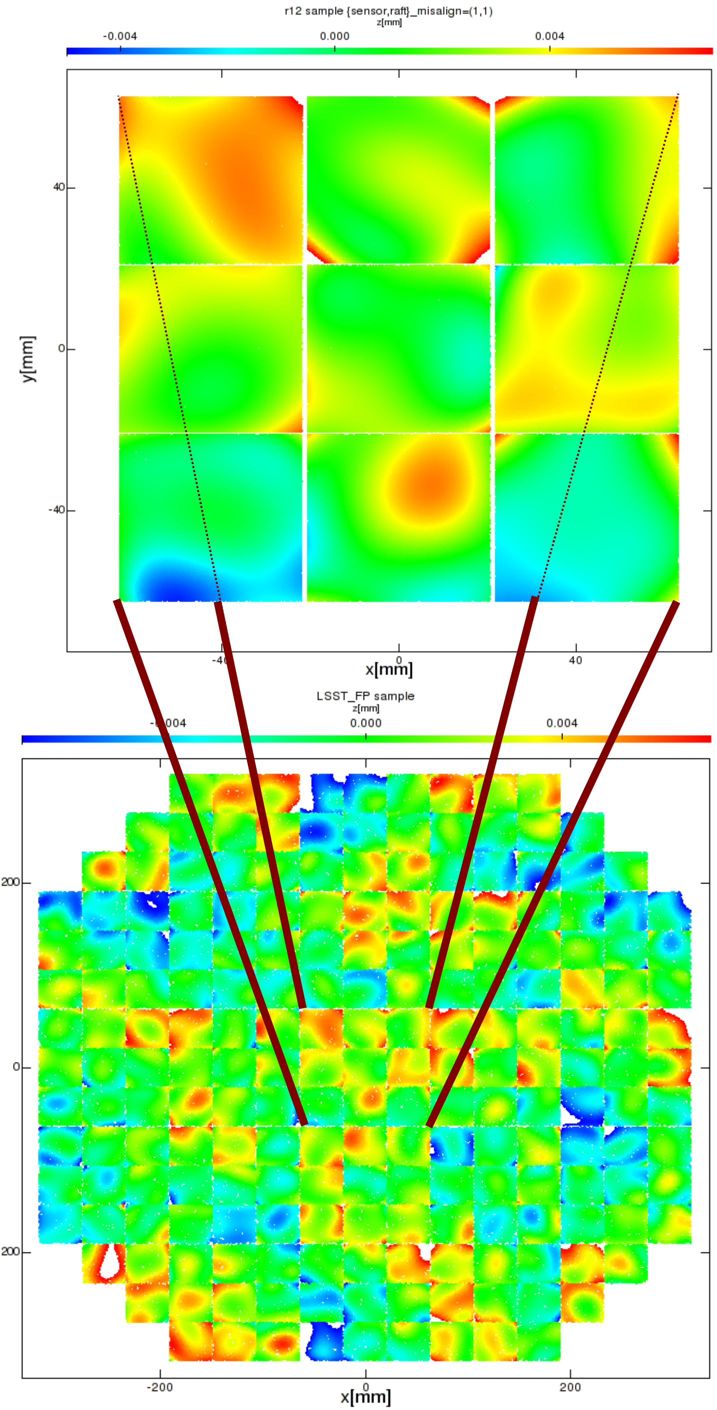
Metrology of individual sensors (e.g. Fizeau interferograms)



Noninterferometric, noncontact metrology of an assembled raft. (phase ambiguity across gaps)



>93% with |z| < 5µm

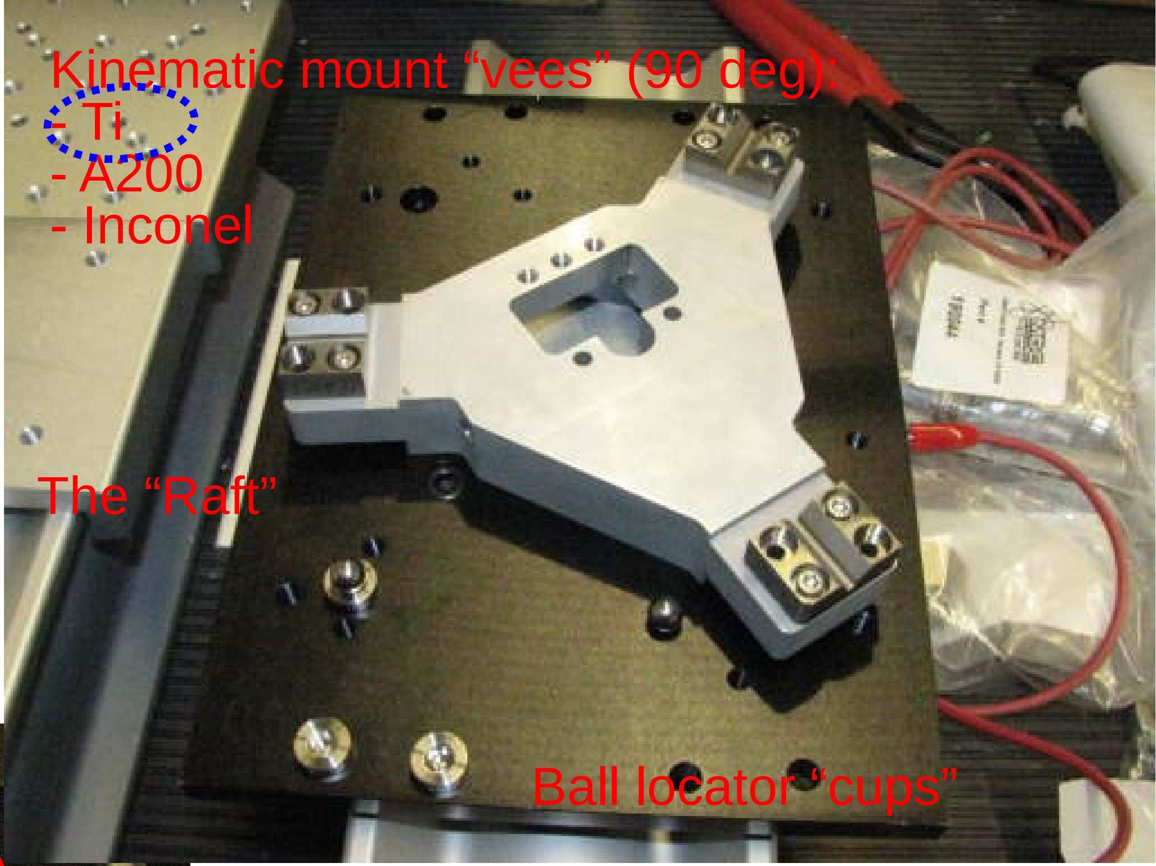


Major R&D Directions

- Development of Metrology tools, methodology and plans for building a ~850mm diameter FP using ~200 sensors that will have 10µm P-V flatness under operational conditions
- Materials and surface finish quality selection for kinematic mount (KM) components to improve repeatability, minimize wear associated with environmental cycling in the cryostat, etc

Kinematic Mount (KM) testing using a "raft prototype"

Characterize components (establish wear-in cycle and resulting stability for candidate mounting hardware: 6 constraint mount, maximally compliant to thermally induced differential expansion..



Kinematic mount "vees" (90 deg):
- Ti
- A200
- Inconel

The "Raft"

Ball locator "cups"

Commercially available grade 5, 8mm balls (nom. 5μ" control)

Si3N4
HRC 80 (typ.)

Tungsten Carbide (WC)
56-70 HRC

SS 440
HRC 62

Goals:

Guide materials choice, surface finish/coating that minimize impact, static load and frictional wear – which can frustrate co-alignment efforts across sensors and rafts in LSST focal plane.

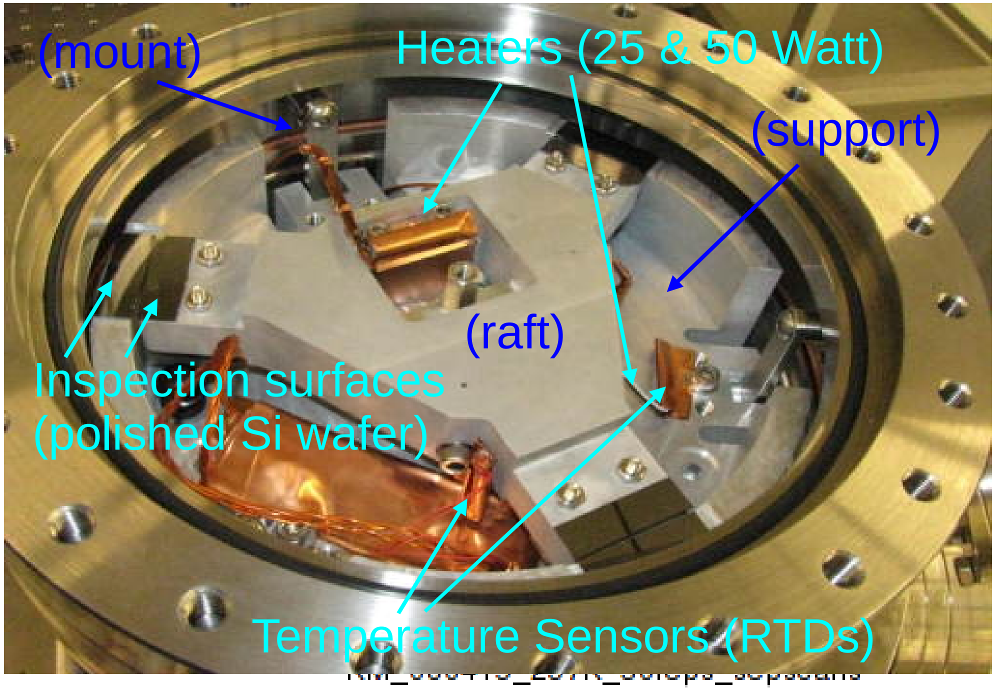
Metrology Tools Under Development

Main features of our approach:

- Non-contact surface metrology of a finite element surface (interferometry may be appropriate for sensor flatness screening)
- Differential metrology (against a reference) combined with stitching obviates tight temperature control or space requirements to host a CMM
- Rapid feedback – scans are performed over times shorter than thermal time scales, and covering just a fraction of FP at a time
- Through – lens (L3 or vacuum barrier) inspection for FP metrology under representative conditions (T ~ -100°C, varying gravity load)

Testing facility for KM studies (a *thermo-vac/*metrology facility bearing minor resemblance to LSST camera)

Raft/Prototype to test kinematic mount components under representative conditions



(mount)

Heaters (25 & 50 Watt)

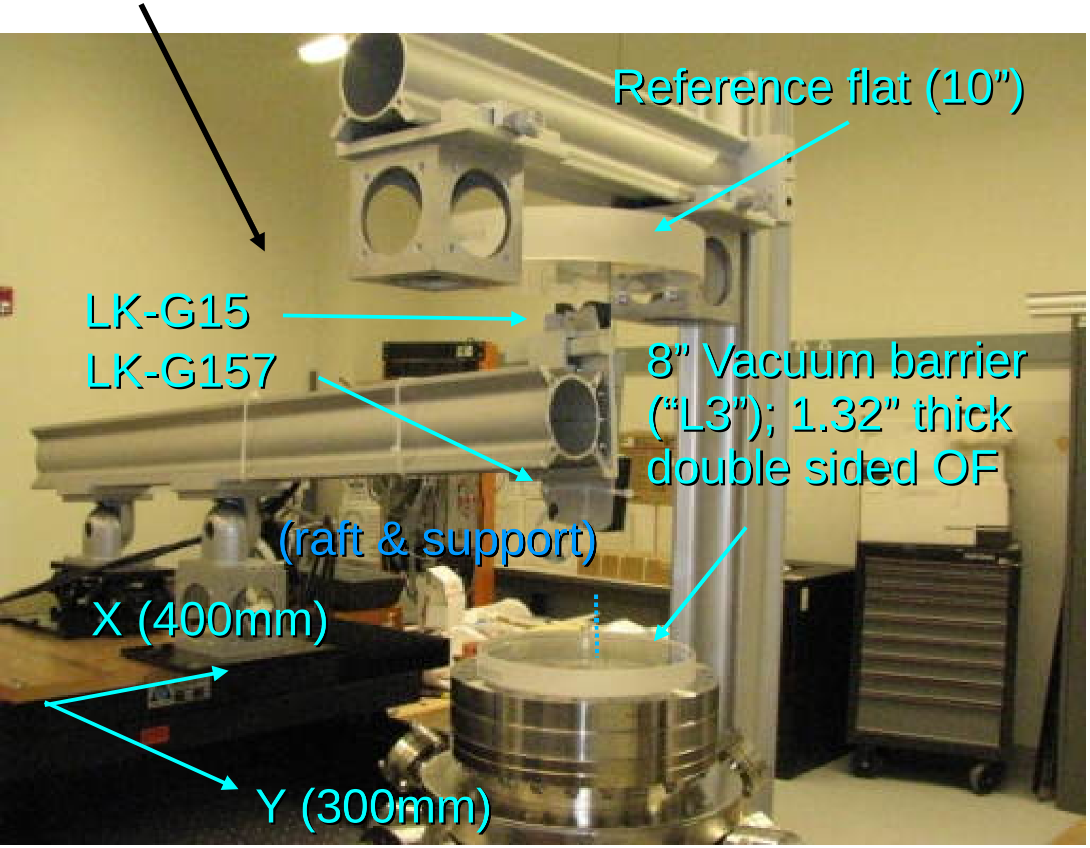
(support)

(raft)

Inspection surfaces (polished Si wafer)

Temperature Sensors (RTDs)

Differential displacement sensor metrology robot & thermal/vac sample holder



Reference flat (10")

LK-G15

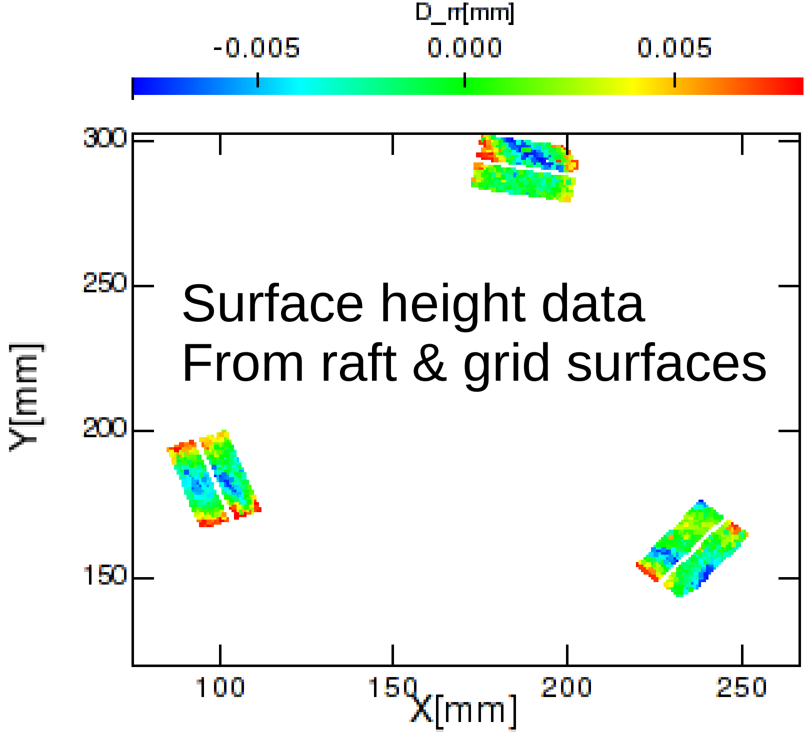
LK-G157

8" Vacuum barrier ("L3"); 1.32" thick double sided OF

(raft & support)

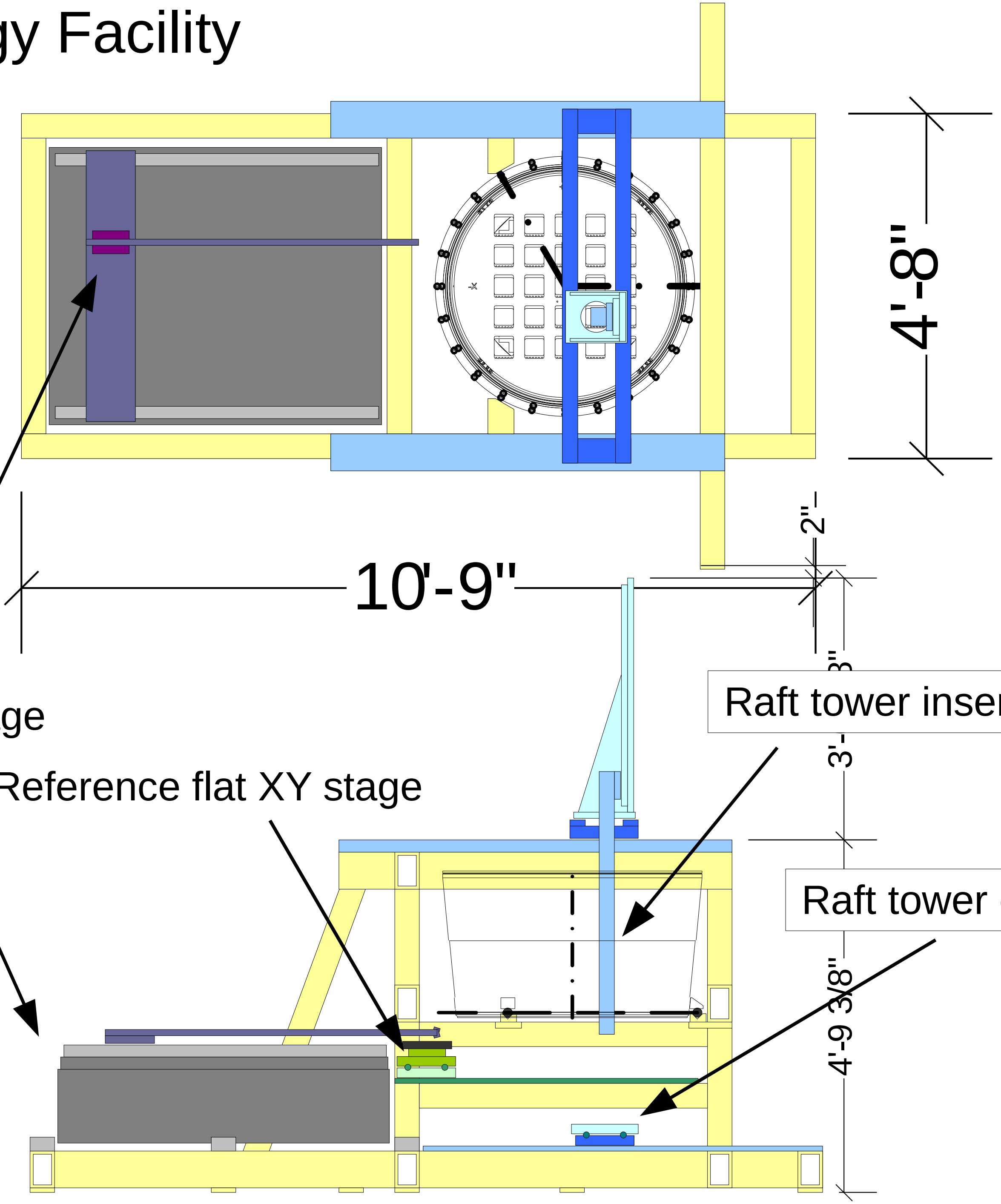
X (400mm)

Y (300mm)



Surface height data From raft & grid surfaces

Cryostat Integration Facility will include a Metrology Facility



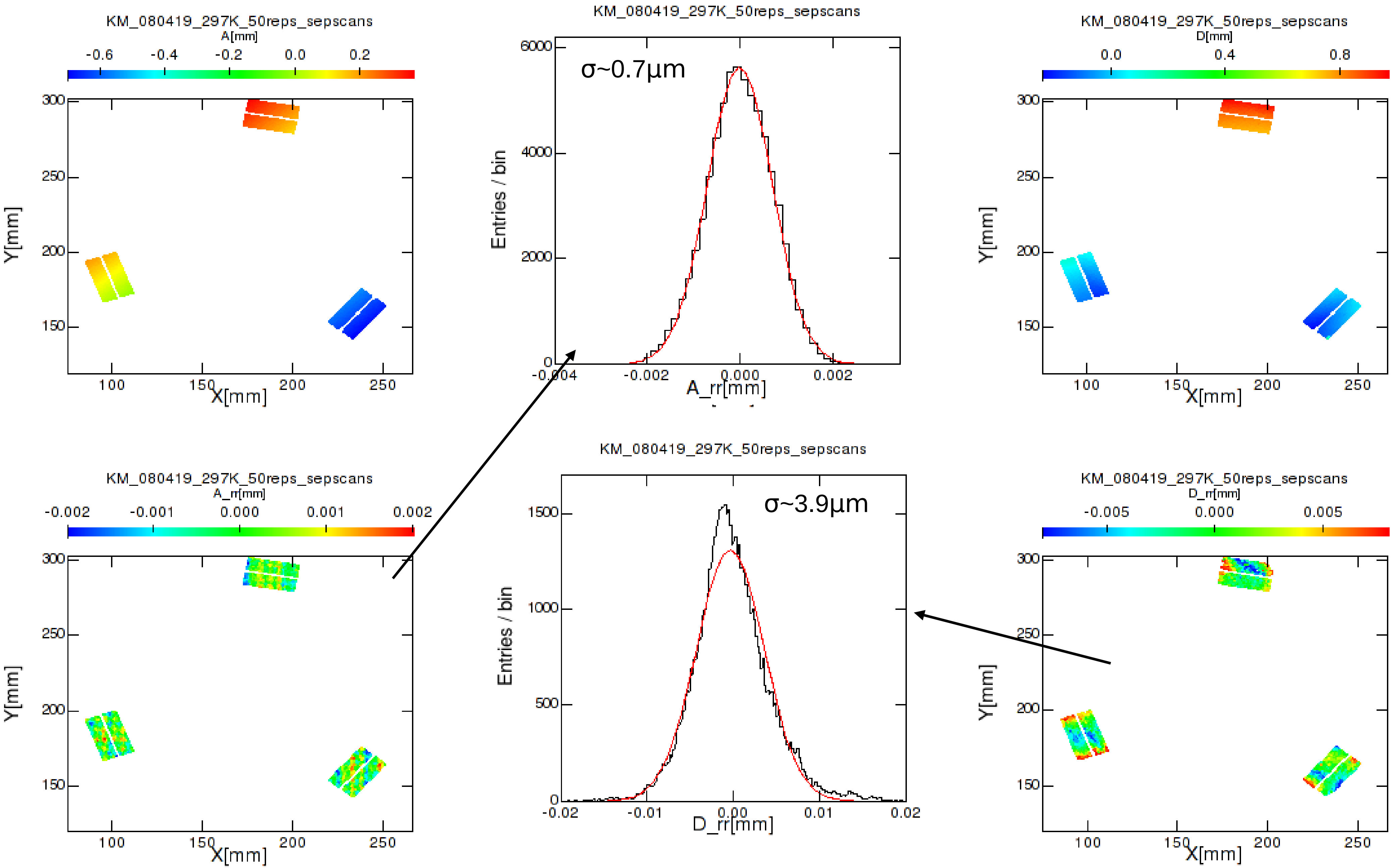
Metrology sensor arm XY stage

Reference flat XY stage

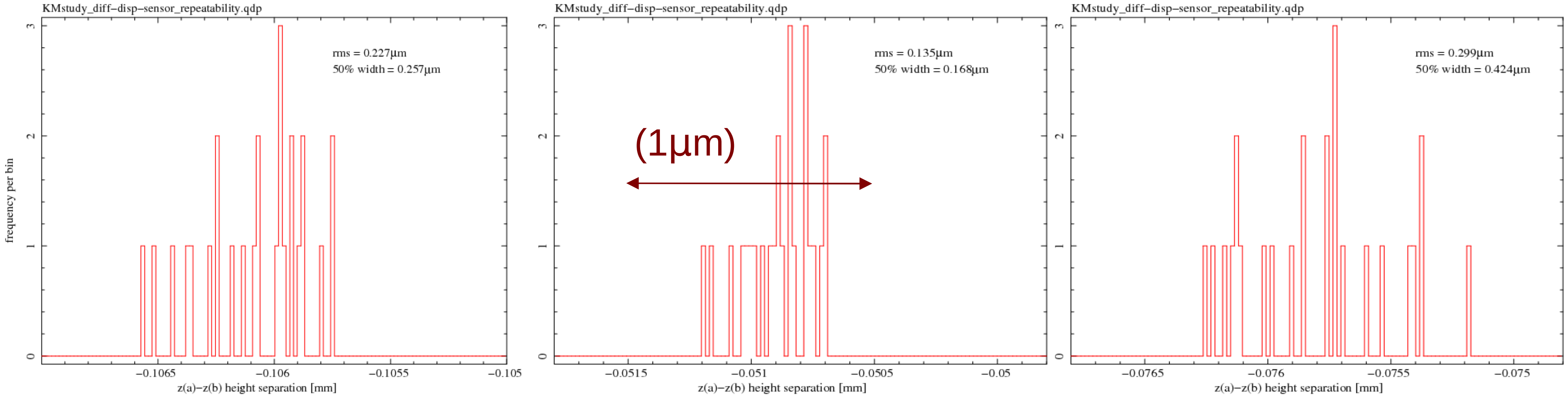
Raft tower insertion arm

Raft tower carriage

Sample data obtained in the KM-RP thermo-vac/metro facility



Established measurement precision: repeatability



- Representative conditions for measurement (thru-window, under vacuum)
- Distributions of fiducial z-height pair difference measurements performed by referencing off of an opposing optical flat (“differential non-contact metrology”)
- Measurement samples were inside an evacuated vacuum chamber at room temperature; 25mm from a 34mm thick double sided optical flat vacuum barrier (e.g., “L3”)
- Shown are 3 surface height difference distributions, performed 25 times each over 8 hours (6 minutes/scan, producing <σ(Δz)> ~ 0.22µm) [<σ>~0.27µm @3min/scan]

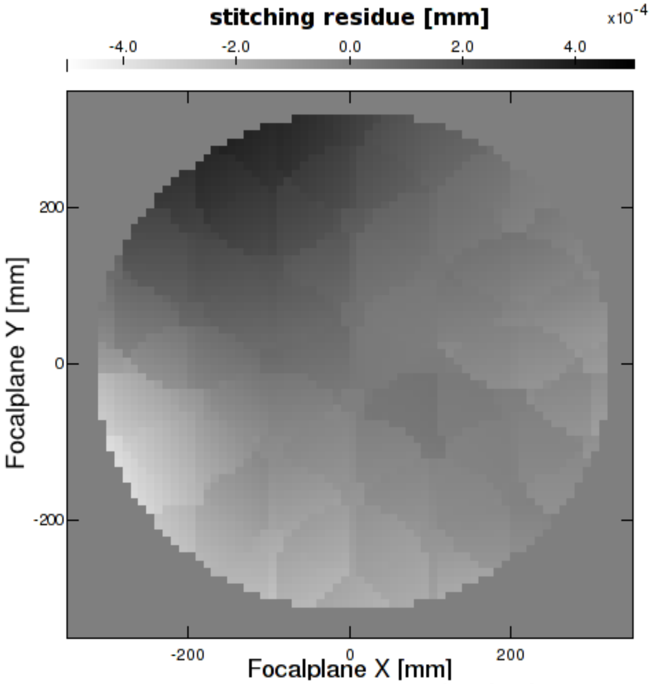
Stitching Methodology

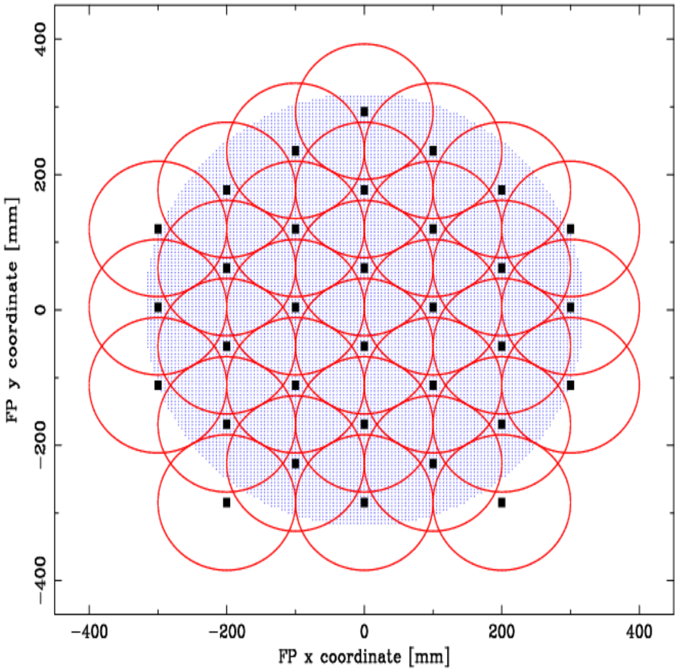
- Demonstration of expected “stitched” figure measurement errors, using a stitching algorithm together with representative measurement errors
- FWHM(z) ~ 0.5µm, 1000 points acquired in 1000 seconds in a single sample
- “Imprint” of sampling function is seen in the resulting stitched figure
- Amplitude of imprint is nearly identical to error distribution assumed initially

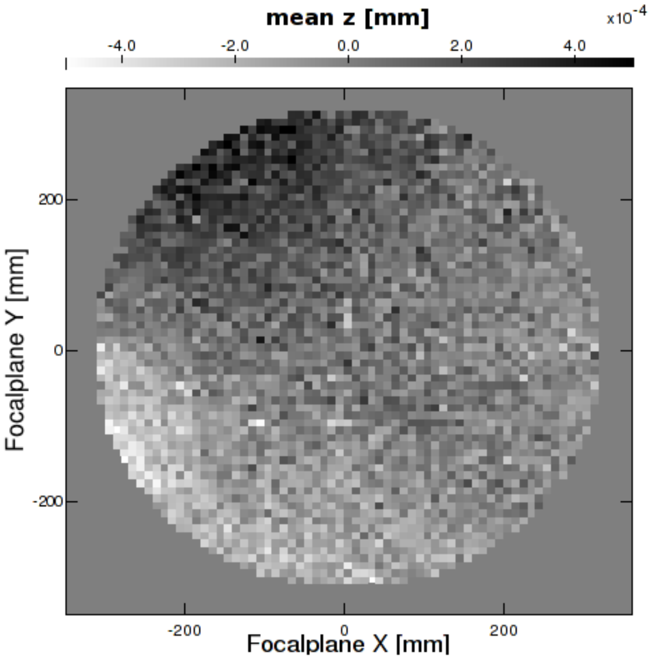
Stitching for FP Metrology

- Combine multiple, rapidly acquired measurements using arbitrary (but stable) reference flats

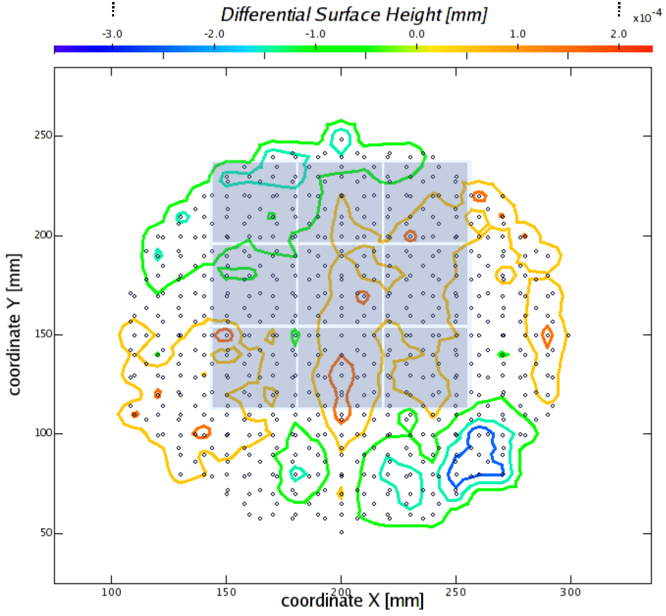
[Rasmussen et al. Proc. SPIE, Vol. 6273, 62732U (2006)]



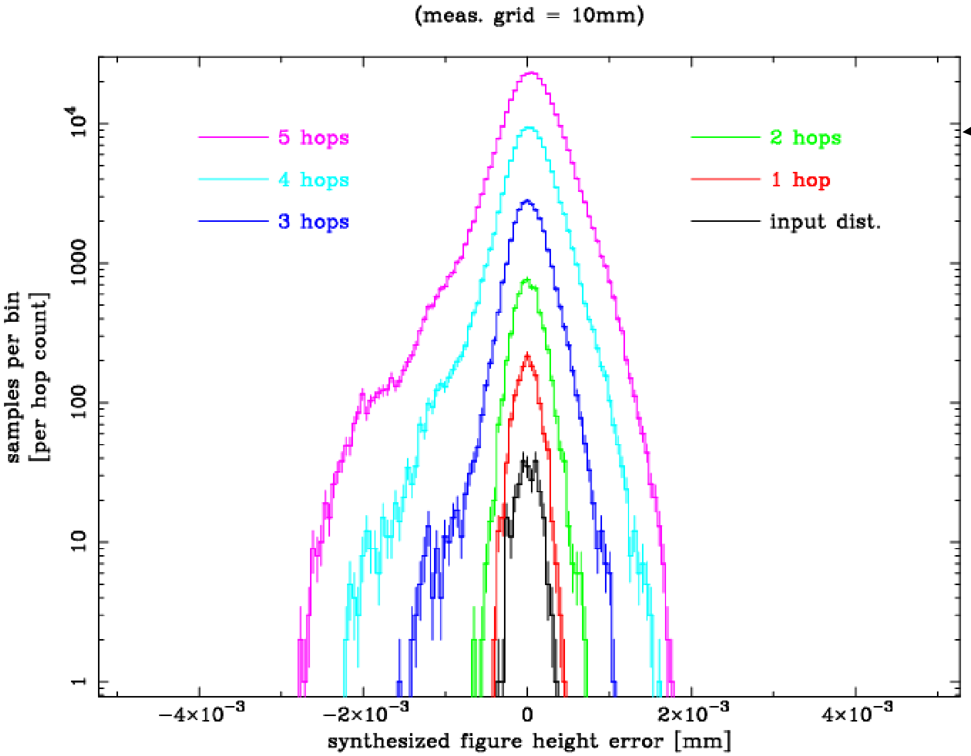




Current systematic limit:
5% of P-V requirement

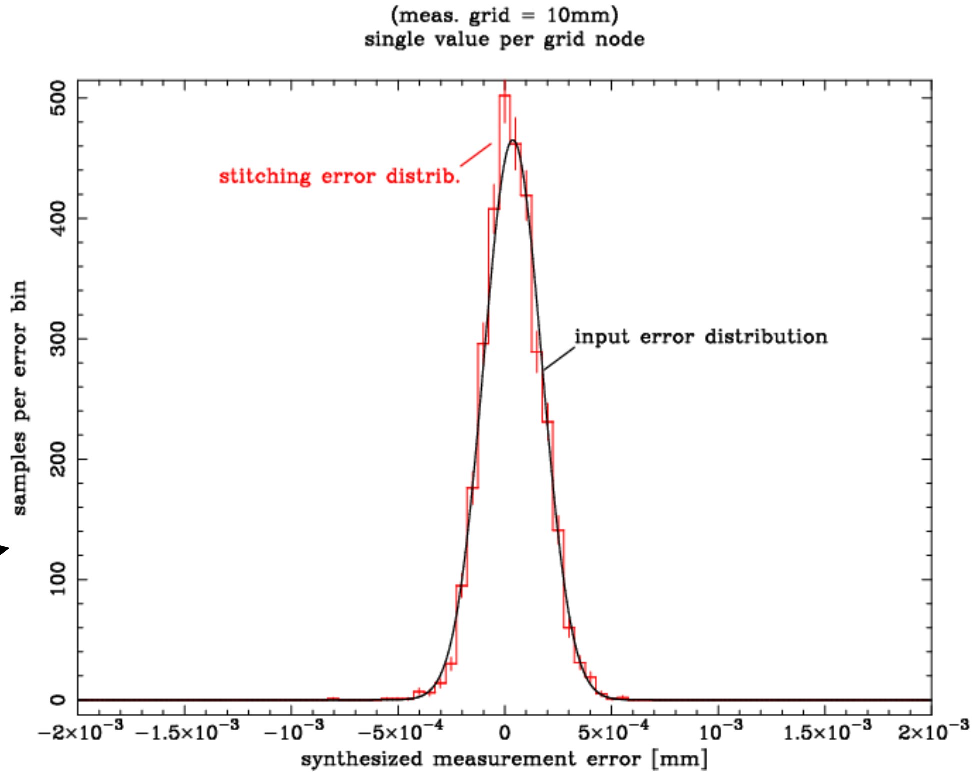


Stitching algorithm, using apparent differential metrology error distribution



Error degradation with increased intermediate references (“hops”)

Single value per measurement grid node (average available computations):
Input error distribution nearly recovered.



=> Should work fine for measuring environmental grid distortion and initial ball arrangement

Metrology Summary

- R&D activities address specific needs for integration and testing of the assembled FP
  - Development of tools and methodology for acquiring feedback in a rapid fashion during integration
  - Tested means for measuring FP surfaces under representative conditions (through vacuum barrier). Typically ~250 nm repeatability is achieved for this
  - Materials and surface preparations are still under investigation in attempt to minimize differential wear and to formulate an environmental exposure budget

Backup Slides

- None