# Automated in-situ optimisation of bimorph mirrors at Diamond Light Source

**John P. Sutter, Simon Alcock, Kawal Sawhney**
Diamond Light Source

Bimorph mirror:

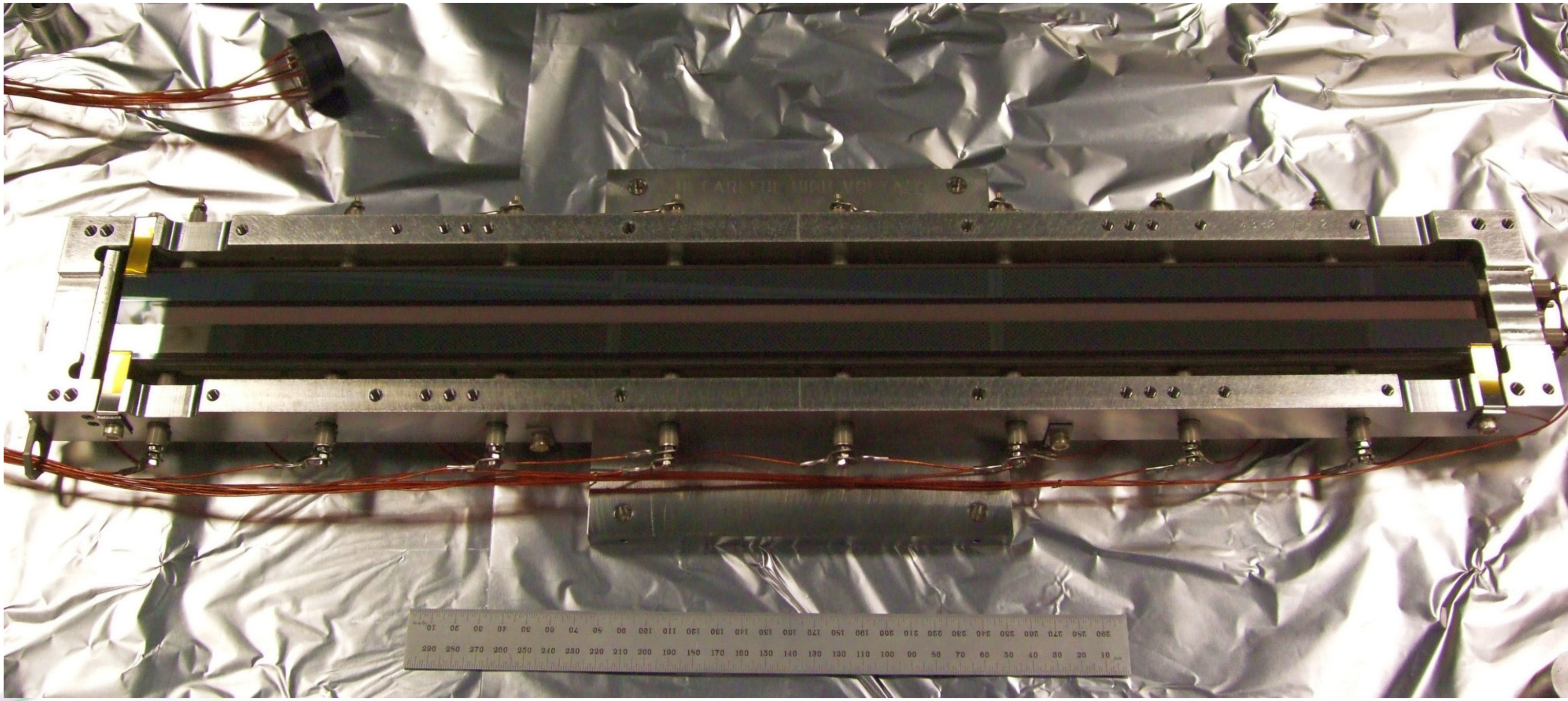
Mirror composed of two piezoelectric layers:
-Series of electrodes deposited on layer surfaces
-Precisely ground and highly polished silica layer on top surface
-Heavy metal coatings (Pt, Rh, Pd) on silica layer to increase reflectivity.

Routinely used to focus synchrotron beams at
-APS
-SOLEIL
-PETRA III
-Diamond Light Source:

- I02, I03, I04 (macromolecular crystallography)
- I07 (surfaces and interfaces)
- I19 (small-molecule single-crystal diffraction)
- I22 (non-crystalline diffraction)
- I24 (microfocus macromolecular crystallography)

diamond

# I02 VFM – 8 piezos



Bimorph mirrors have many electrodes (up to 32)

→ non-cylindrical (e.g. elliptical) figures well approximated

→ low spatial frequency roughness/slope error (period ≥ 20 mm) can also be corrected.

**But optimisation is also challenging:**

Measurement of slope errors must be
- portable
- reproducible
- accurate (error << 1 μrad)
- automated
- quick (< 2-3 hours).

*Performed by pencil-beam method.*

*Calculation of electrode voltage corrections is done by the well-known interaction matrix method.*

**Ex-situ vs. in-situ:** both done at Diamond Light Source

<u>Ex-situ</u>: examination of mirror in metrology cleanroom lab (Diamond-NOM, Fizeau interferometer, micro-interferometer)
-Initial characterisation and optimisation
-Not dependent on synchrotron beam → saves scarce beamtime

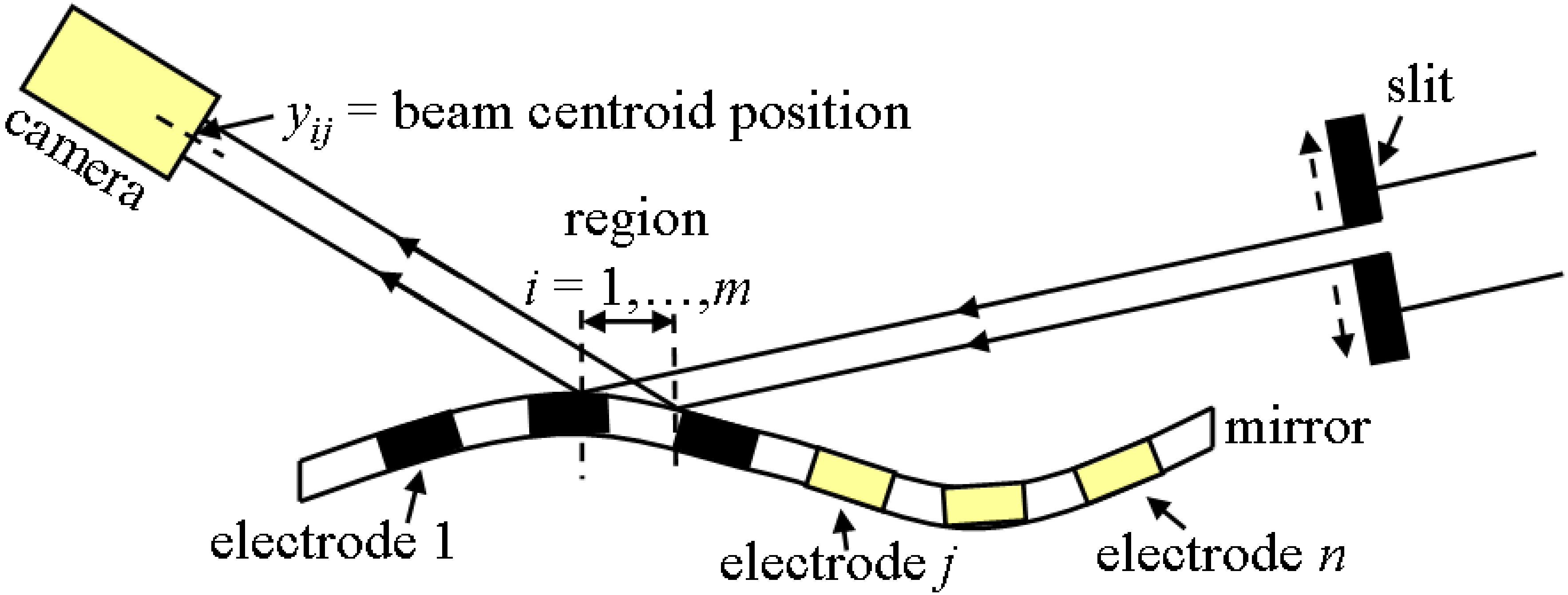
But beamline operating environment can differ greatly from controlled cleanroom:
-mounting strains
-ultra-high vacuum
-heat load imposed by incident beam.
→ <u>in-situ examination is also necessary.</u>

**<u>In-situ:</u> examination of mirror in its beamline, at its operating wavelength**

diamond

**Pencil-beam method:** application to synchrotron beamlines

O. Hignette, A. Freund & E. Chinchio, *SPIE Proc.* **3152**, 188-199 (1997)




Upstream slit reduced to 10-20 μm

→ only small area (several mm) of mirror are illuminated at a time

Camera measures reflected beam position $y_{ij}$ from $i$th section in $j$th scan.

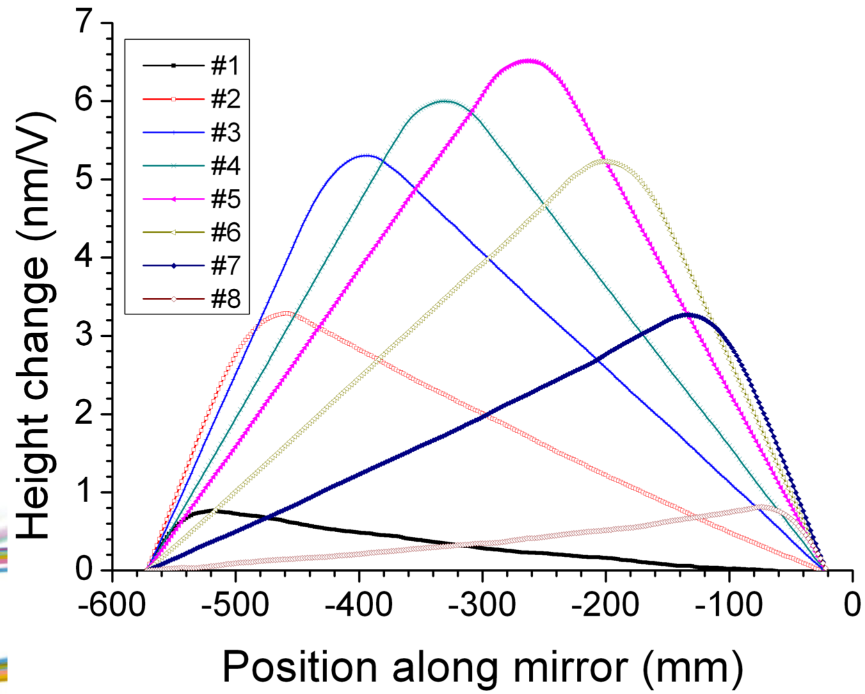
No less than 2-3 points scanned per electrode.

diamond

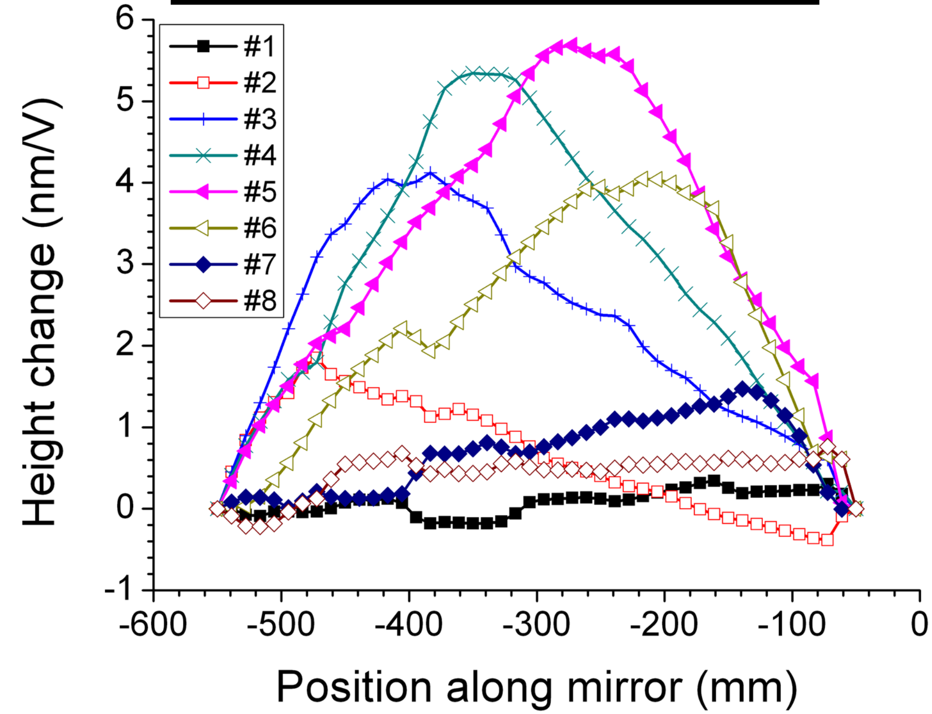
Piezo response functions: change in mirror figure per 1 V change of voltage to given electrode

*Example: I04 vertical focusing mirror (VFM): 8 electrodes*

Ex-situ on Diamond-NOM




In-situ on beamline I04




Noisier in-situ height measurement due to coarser slope error scan → finer scans would better smooth out measurement noise.

**Interaction matrix *H*: Shows each actuator's effect on figure.**

Begin collection of scans

Run pencil-beam scan

Increment scan counter $k$ by 1

Is scan counter $k \leq$ number of electrodes?

YES

Increment $k$th electrode voltage by $v$

NO

Scan collection completed

$$H_{ij} = (y_{i,j+1} - y_{ij})/v$$

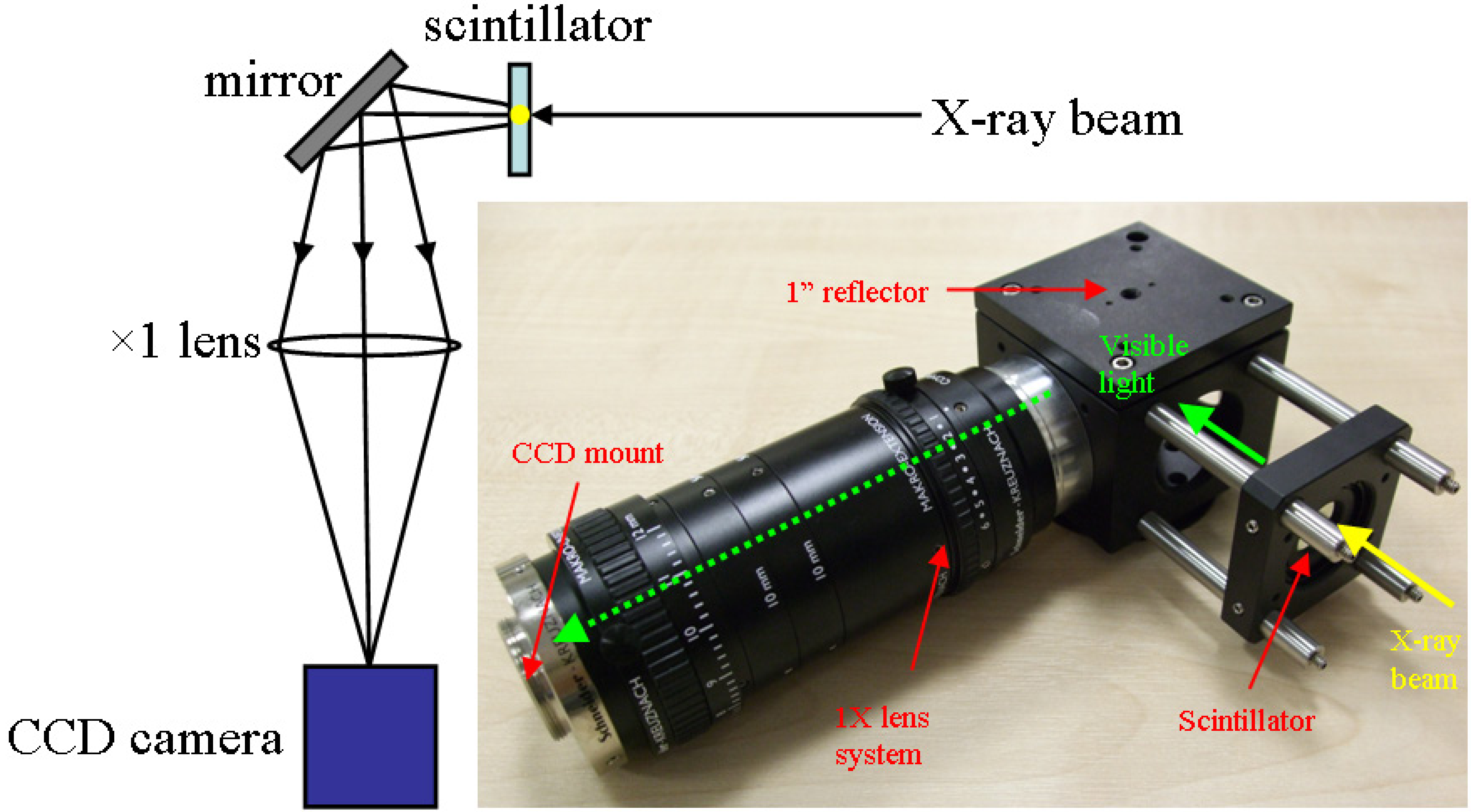
Vector $Y$: $Y_i$ = correction to reflected beam position from $i$th point

Vector $V$: $V_j$ = voltage correction for $j$th electrode

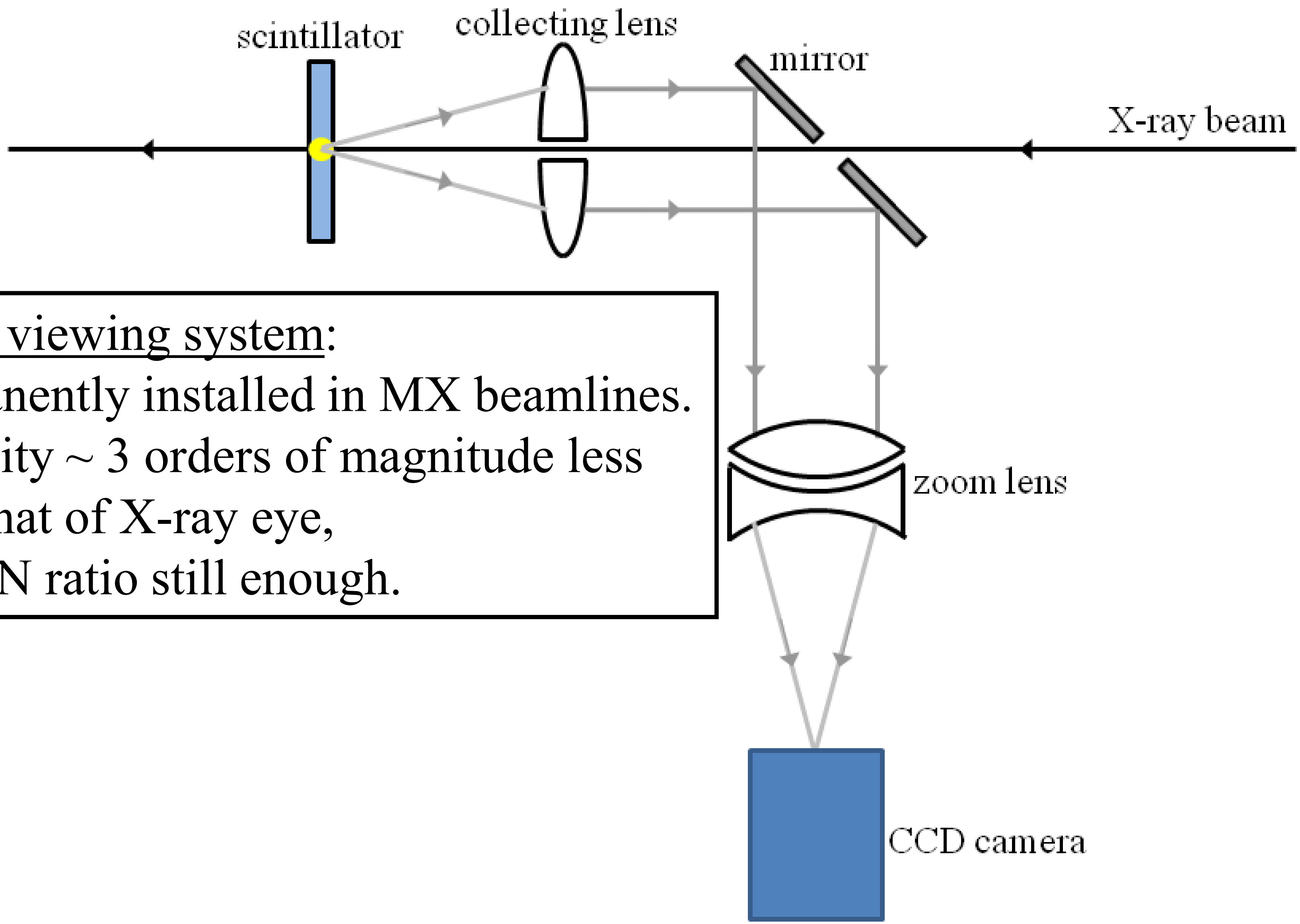
Shortest length least squares solution: $V = H^{\dagger} Y$

$H^{\dagger}$ = Moore-Penrose pseudoinverse of $H$

# Types of X-ray cameras used at Diamond Light Source: X-ray eye




Small, portable camera with 4.65 μm/pixel, 90% integrated line spread function = 4.65/6.35 μm




Inline viewing system:
permanently installed in MX beamlines.
Intensity ~ 3 orders of magnitude less
than that of X-ray eye,
but S/N ratio still enough.

diamond

**Beamline controls:** *done in-house by our own Controls and Data Acquisition groups*

Beamline motors and X-ray camera control: **EPICS**

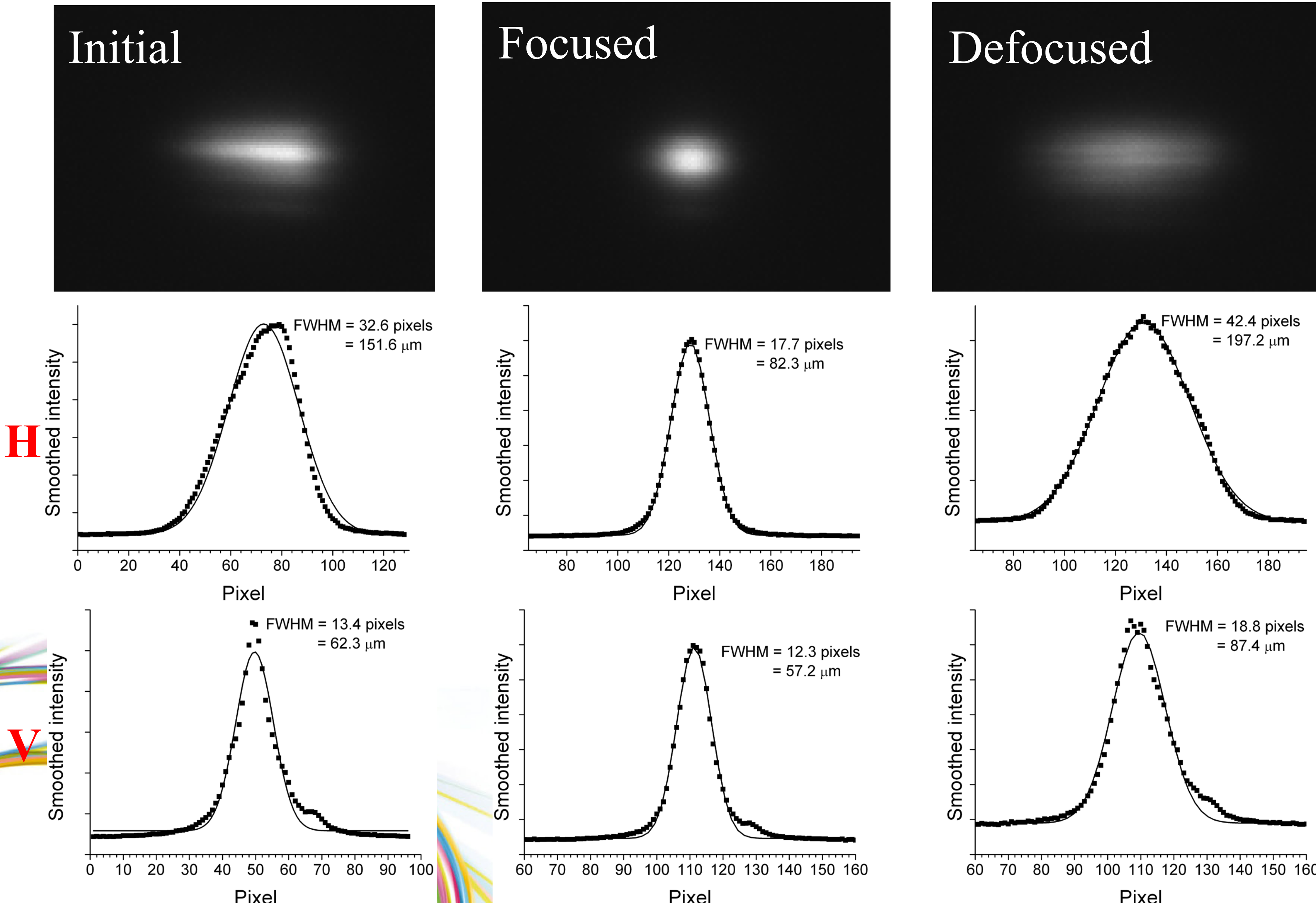
X-ray camera image collection: **EPICS & Firewire**

Pencil-beam scan setup and execution: **Generic Data Acquisition (GDA)**

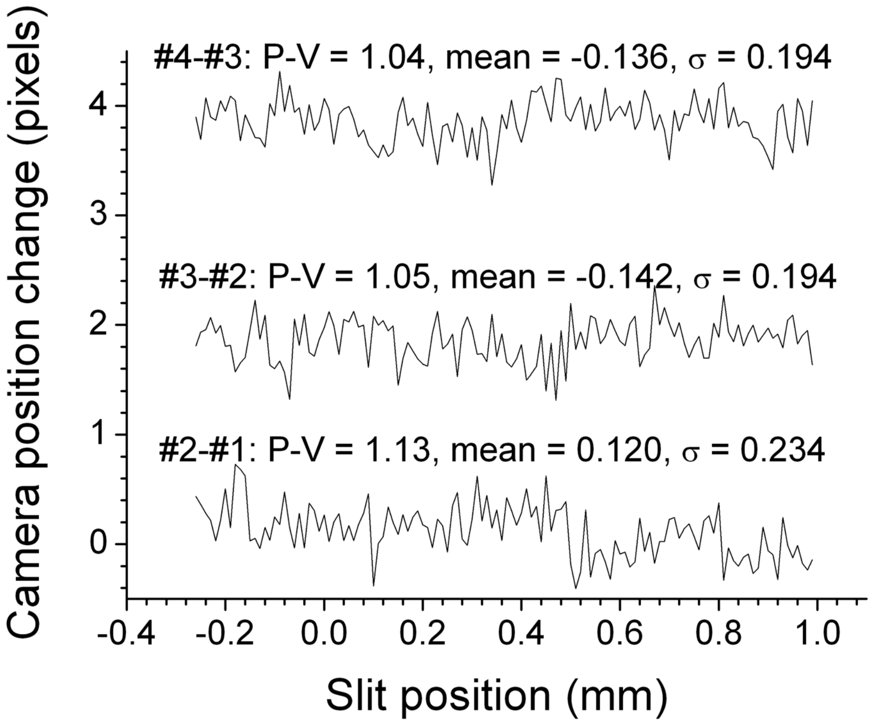
Image processing to extract reflected beam positions: **Jython script *peak2d***

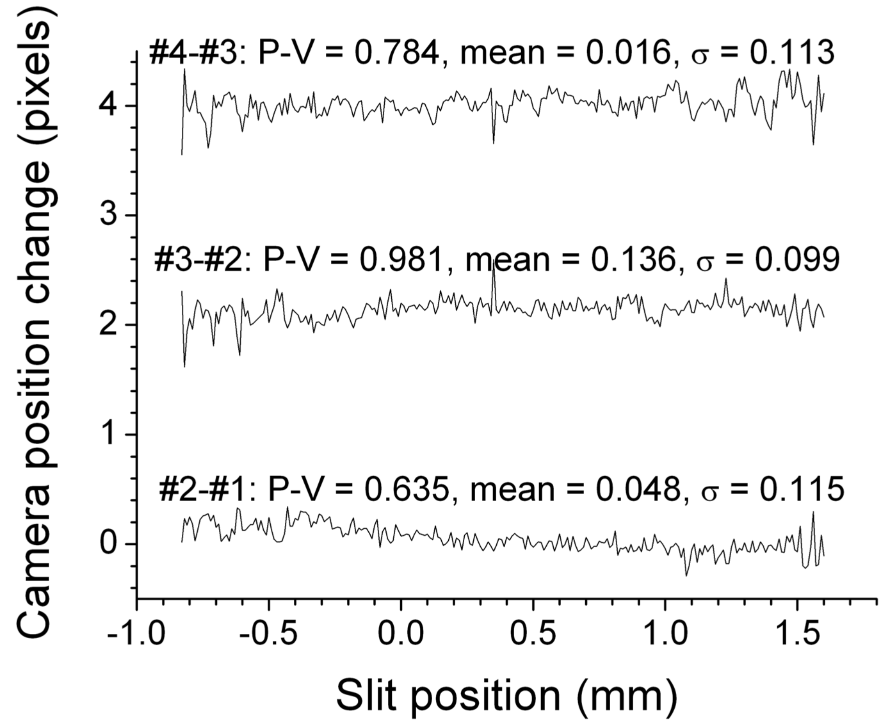
Inversion of interaction matrix to derive voltage corrections: **Jython script using inbuilt linear algebra routines**

# Ability to focus/defocus beam in-situ: *I19*



## Repeatability: *I19: 4 consecutive slit scans in same direction*




VFM: taken at 7 m →
1 pixel = 0.33 μrad slope error

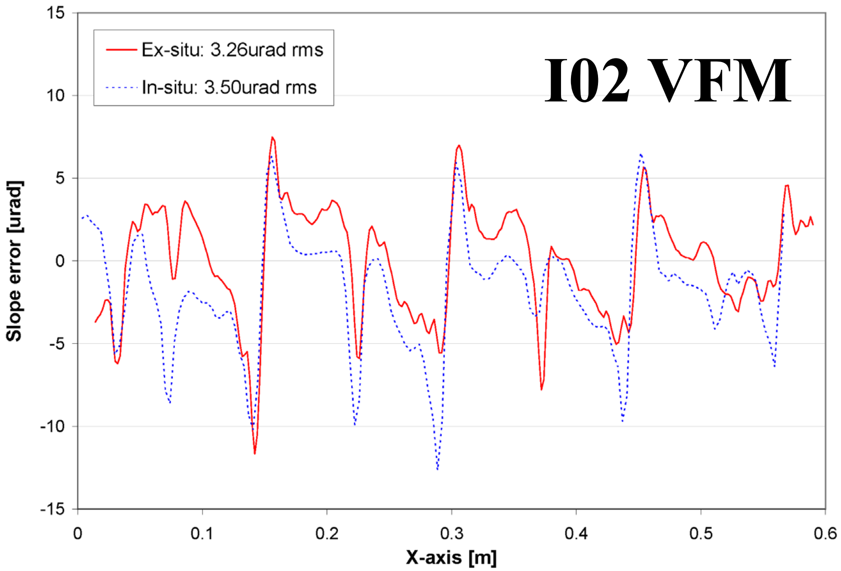
HFM: taken at 6 m →
1 pixel = 0.39 μrad slope error

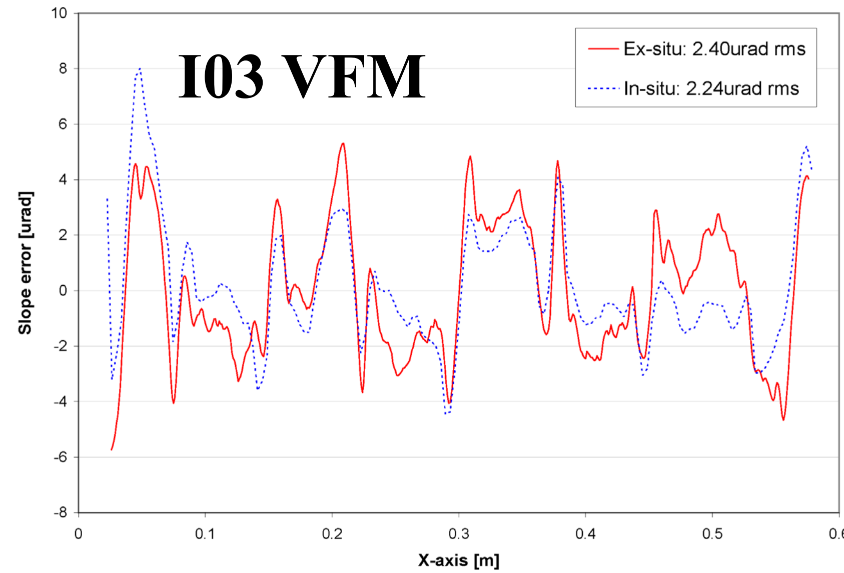
Successive plots shifted by intervals of 2.

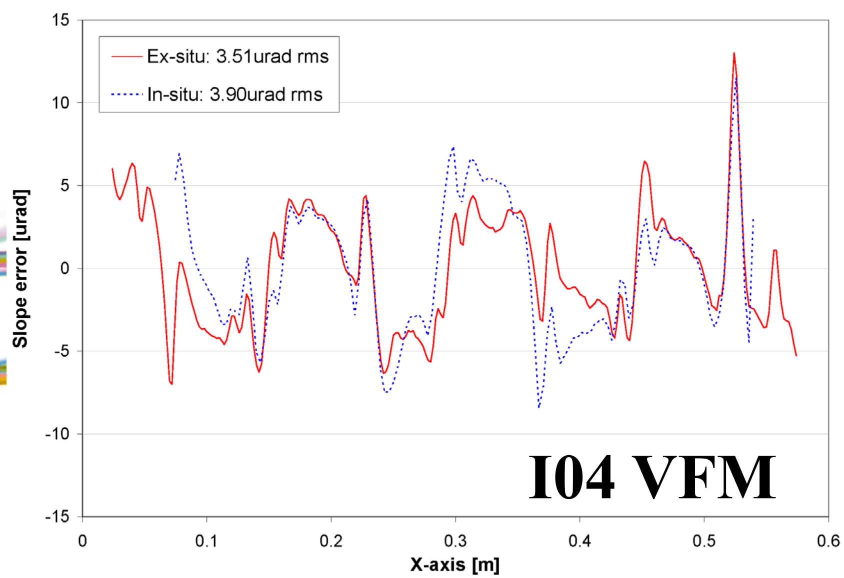
P-V = peak-to-valley difference

σ = standard deviation of difference

# Agreement of in-situ with ex-situ measurements



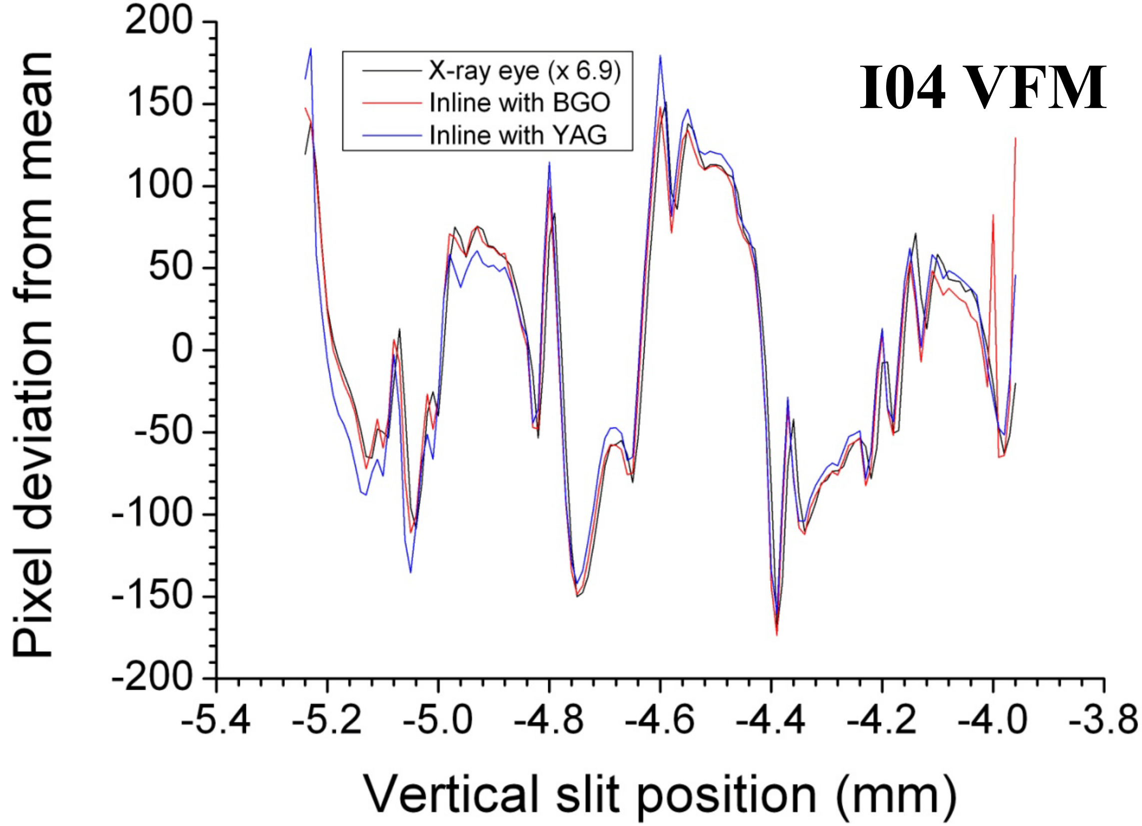

**Ex-situ: from Diamond-NOM**

Sharp jumps in slope error due to surface damage —
cause being investigated.

**Good agreement in slope error for 3 independent mirrors!**

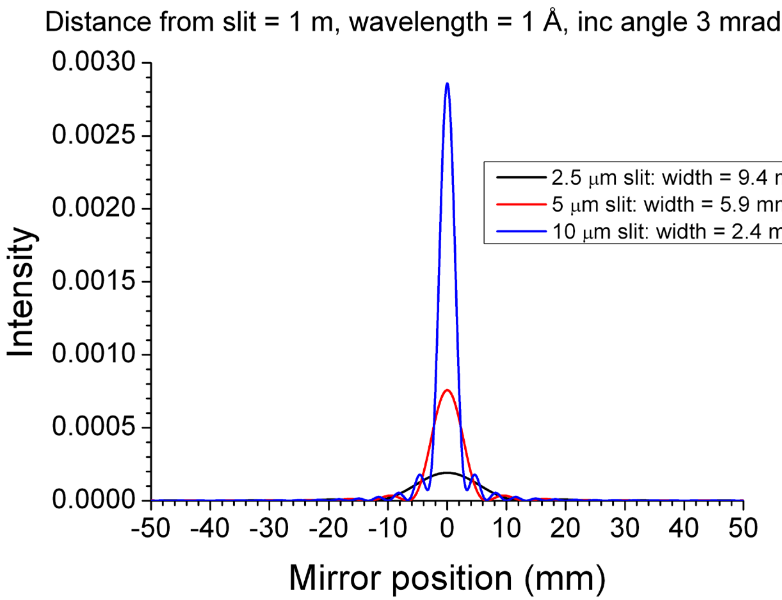
diamond

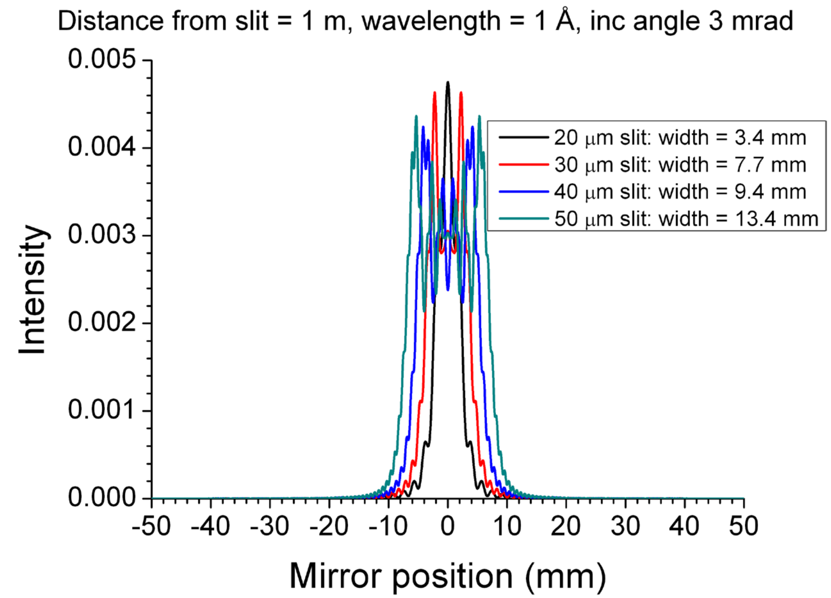
# Agreement of X-ray eye and inline viewing system




**Pencil beam technique is independent of the camera.**

# Diffraction from incident beam slit sets the ultimate spatial resolution of the pencil-beam scan.




1-D Fresnel diffraction patterns of a rectangular slit

Best spatial resolution obtained at ~10 μm slit width.

Narrower slits actually increase the footprint!

diamond

# Conclusions

An automated procedure has been used at Diamond Light Source to optimise bimorph mirrors quickly and easily.

This procedure is repeatable to within ~0.1 camera pixels, or ~0.1 μrad with camera at 6 m from mirror.

It yields measurements that agree well with those taken ex-situ with the Diamond-NOM.

It permits both focusing and deliberate defocusing of X-ray beam.

Diffraction limits the ultimate spatial resolution that can be achieved by reducing the incident beam slit width.

diamond

# This automated method is not confined to hard X-ray bimorph mirrors!

Ex. Diamond I20 collimating mirror
- Curved using mechanical benders
- Gravitational sag compensated by 2 prop loads
- Pencil beam scans used to adjust both curvature and sag.

Pencil-beam scans of slope error are similar to calculations of elastic bending of beams.

## Acknowledgments

Diamond Light Source Controls:

Ronaldo Mercado

James O'Hea

Nick Rees

Diamond Light Source Data Acquisition:

Chris Coles

Paul Gibbons

Rob Walton