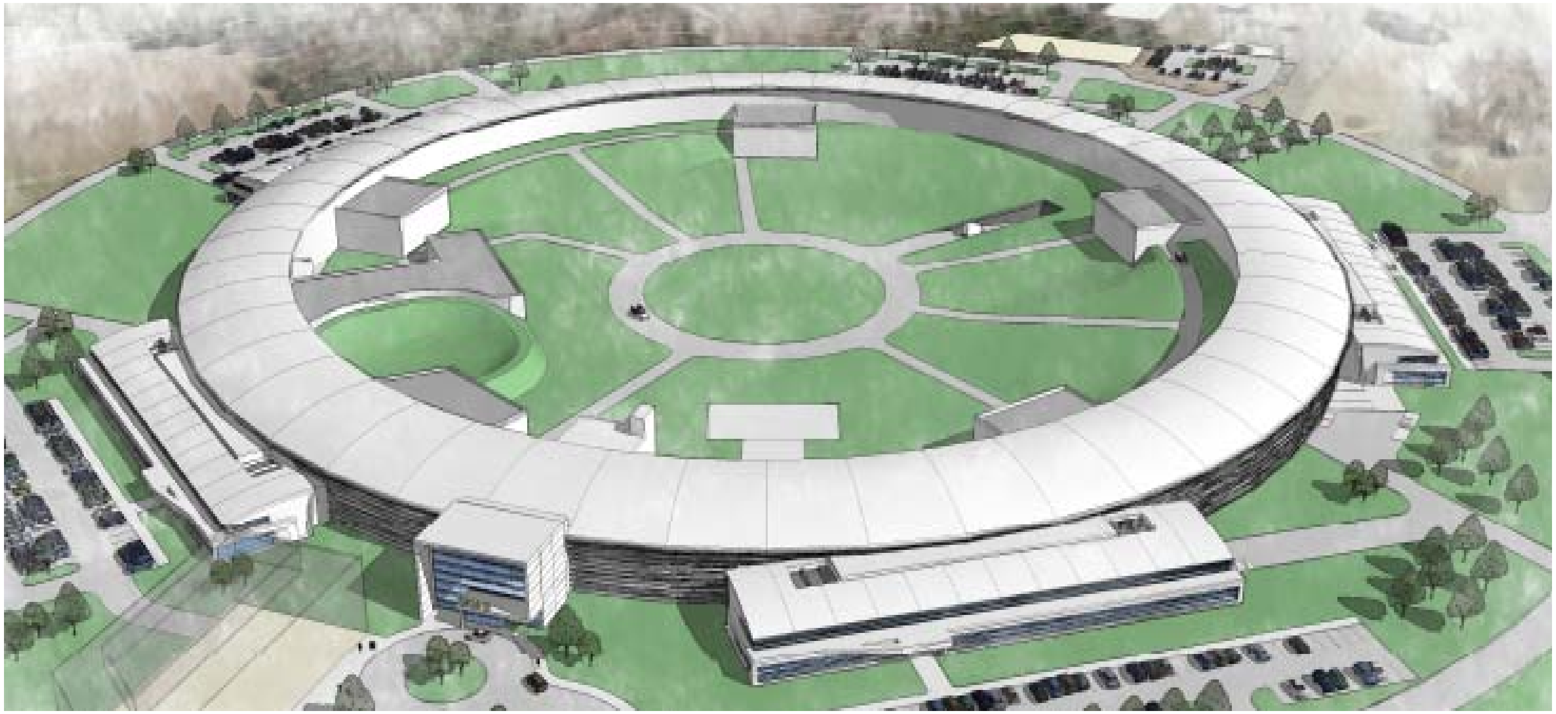
Vibrating Wire R&D for Alignment of Multipole Magnets in NSLS-II



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Animesh Jain for the NSLS-II magnet team

Office of Science
U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY
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Introduction

- For optimum performance, the magnetic axes of quadrupoles and sextupoles in NSLS-II should be aligned to better than ±30 microns.
- Optical survey accuracy (~50 microns) is inadequate to achieve the required tolerance.
- It is difficult, and expensive, to maintain the required machining and assembly tolerances in a long support structure (~5 m) holding several magnets.
- It is desirable to achieve the required alignment using direct magnetic measurements in a string of magnets.

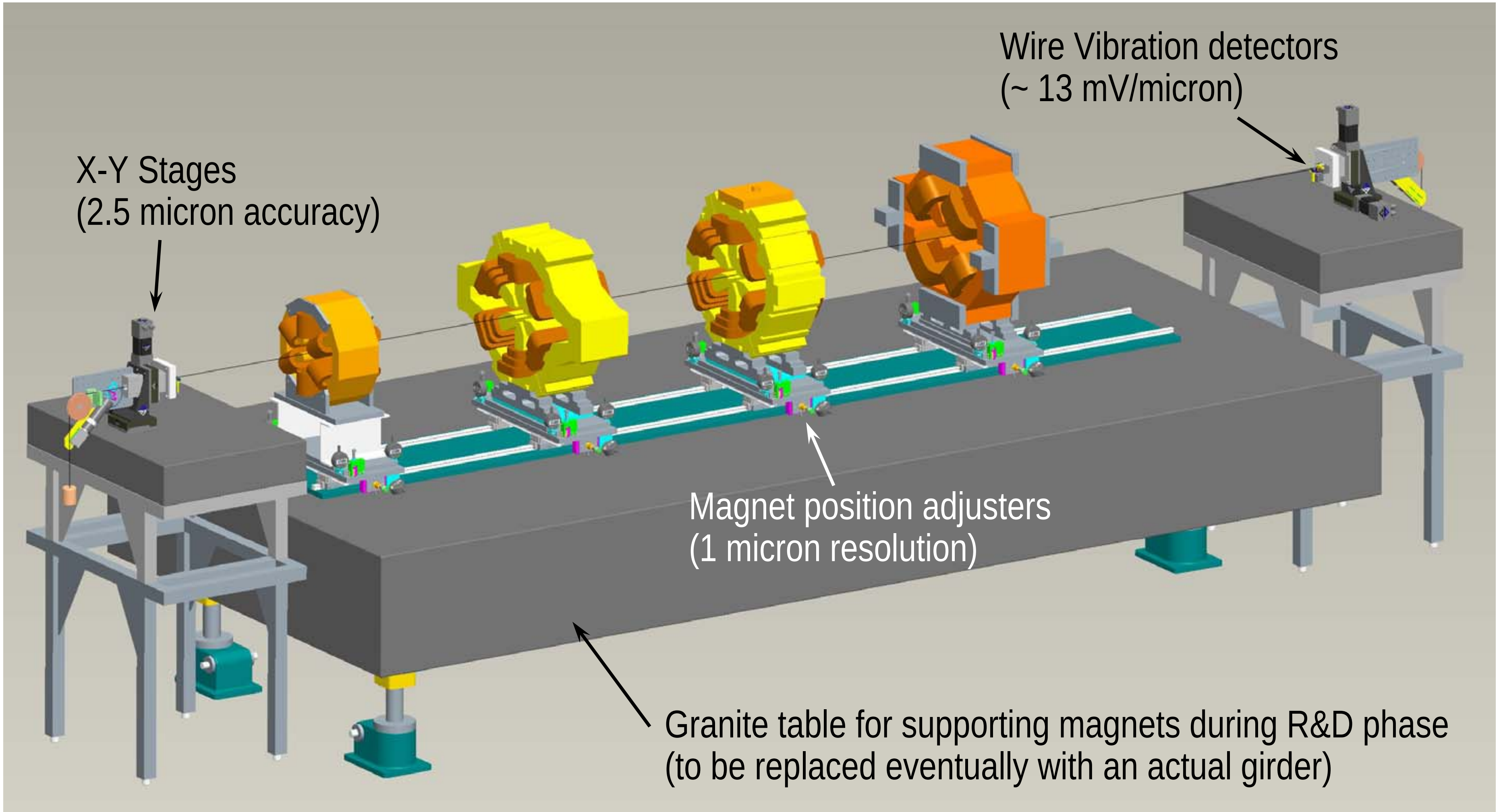
Magnet Alignment R&D

- Several magnets, including multipoles and corrector dipoles, will be installed on a girder ~5-6 m long.
- Based on the accuracy required, and the overall length of the girders, the vibrating wire technique developed at Cornell was deemed most appropriate for this task.
- An R&D program was initiated to develop the technique at BNL and demonstrate the required accuracy.
- Preliminary work was carried out using a temporary setup with help from Cornell and staff from NSLS.
- A new R&D setup was designed and is now operational.

The Vibrating Wire Technique: Basics

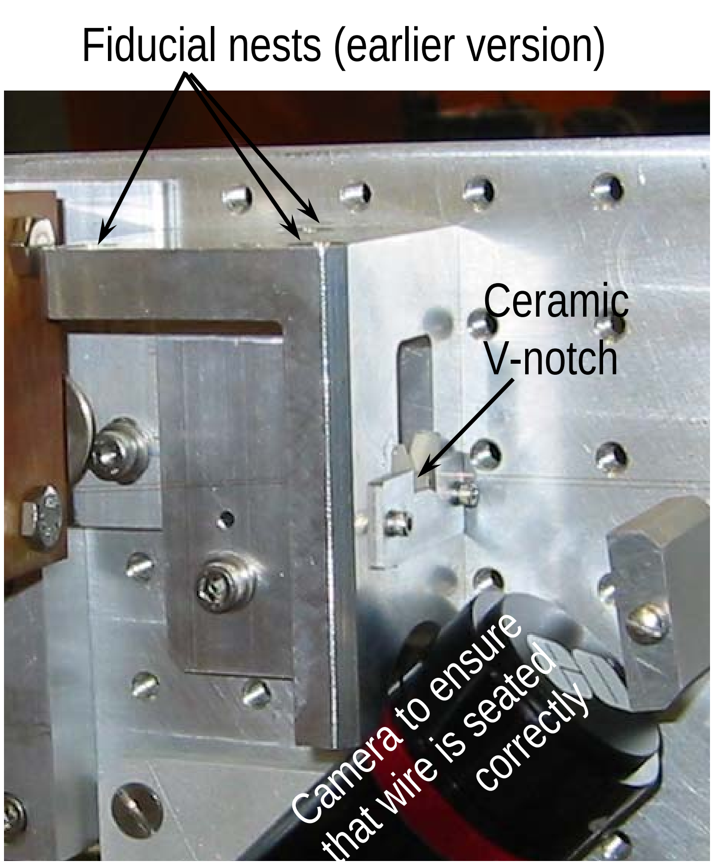
- In this technique, an AC current is passed through a wire stretched axially in the magnet.
- Any transverse field at the wire location exerts a periodic force on the wire, thus exciting vibrations.
- The vibrations are enhanced if the driving frequency is close to one of the resonant frequencies, giving high sensitivity.
- The vibration amplitudes are studied as a function of wire position to determine the transverse field profile, from which the magnetic axis can be derived.
- Vibration amplitudes measured at many resonant modes can also give the axial distribution of field along the wire.

Vibrating Wire R&D Setup at BNL

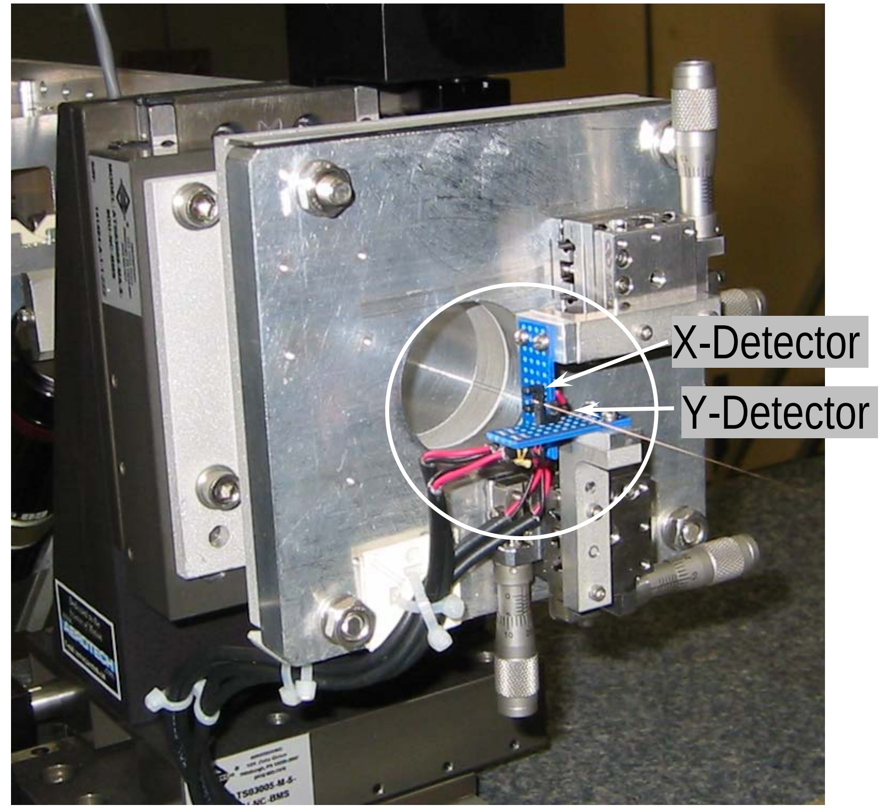


Unique feature: Vibration sensors are installed on both ends, giving two simultaneous measurements

Vibrating Wire R&D Setup: Wire Ends & Sensors



Wire Ends Details

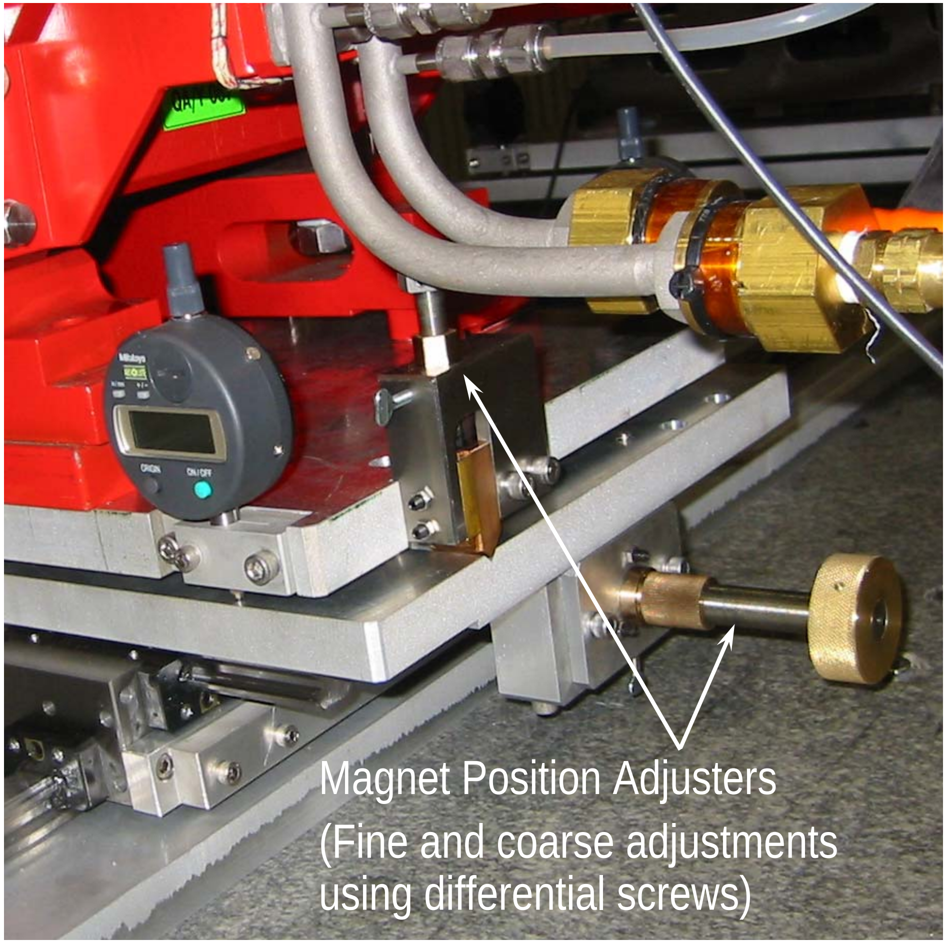


Wire Vibration Sensors

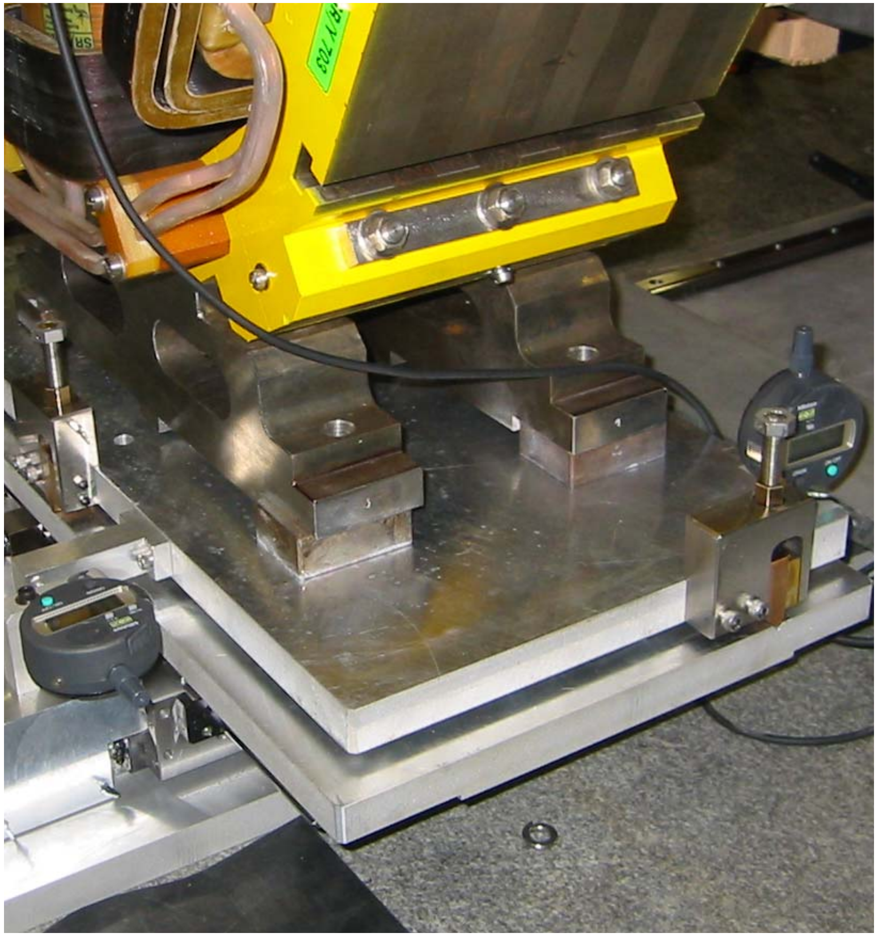
Fiducials relate the wire ends to the overall girder coordinate system.

New version has 4 fiducials

Vibrating Wire R&D Setup: Manual Magnet Movers



First version with stainless steel parts did not work very smoothly. New version with Silicon-Bronze parts works well.

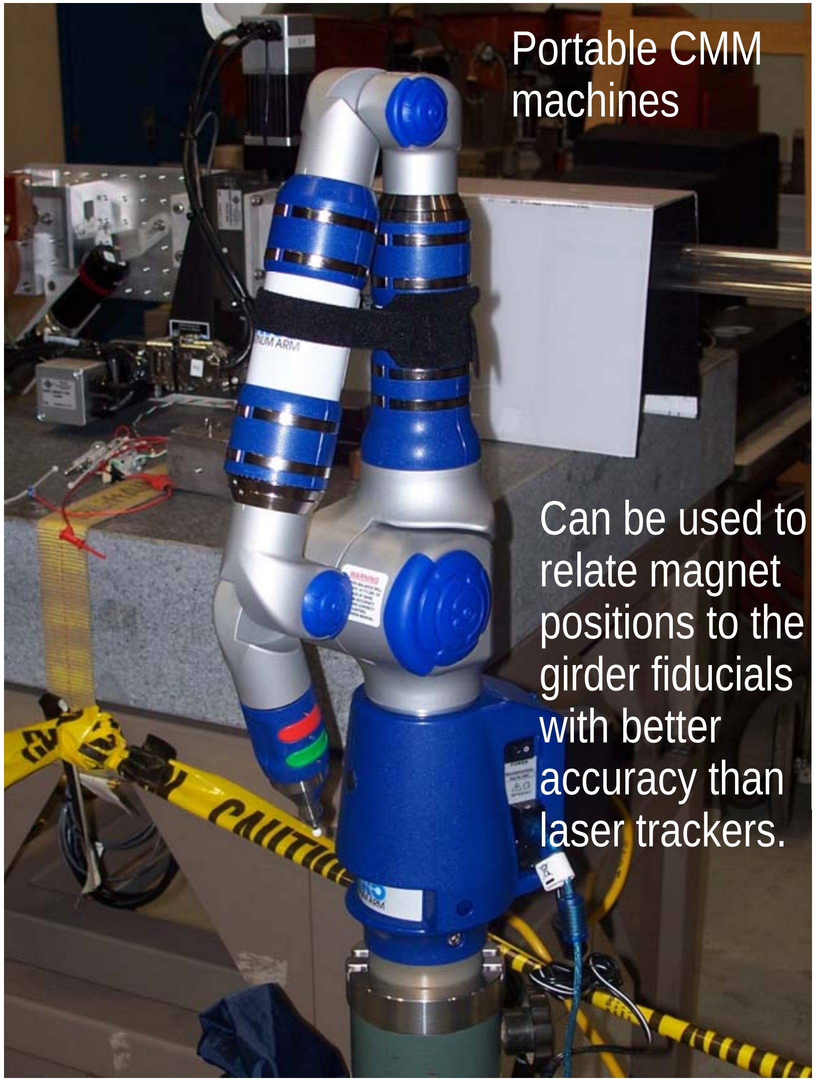


Dial indicators to monitor magnet motion. Mounting of horizontal indicators is now improved from an earlier version.

Survey Equipment

Laser Trackers

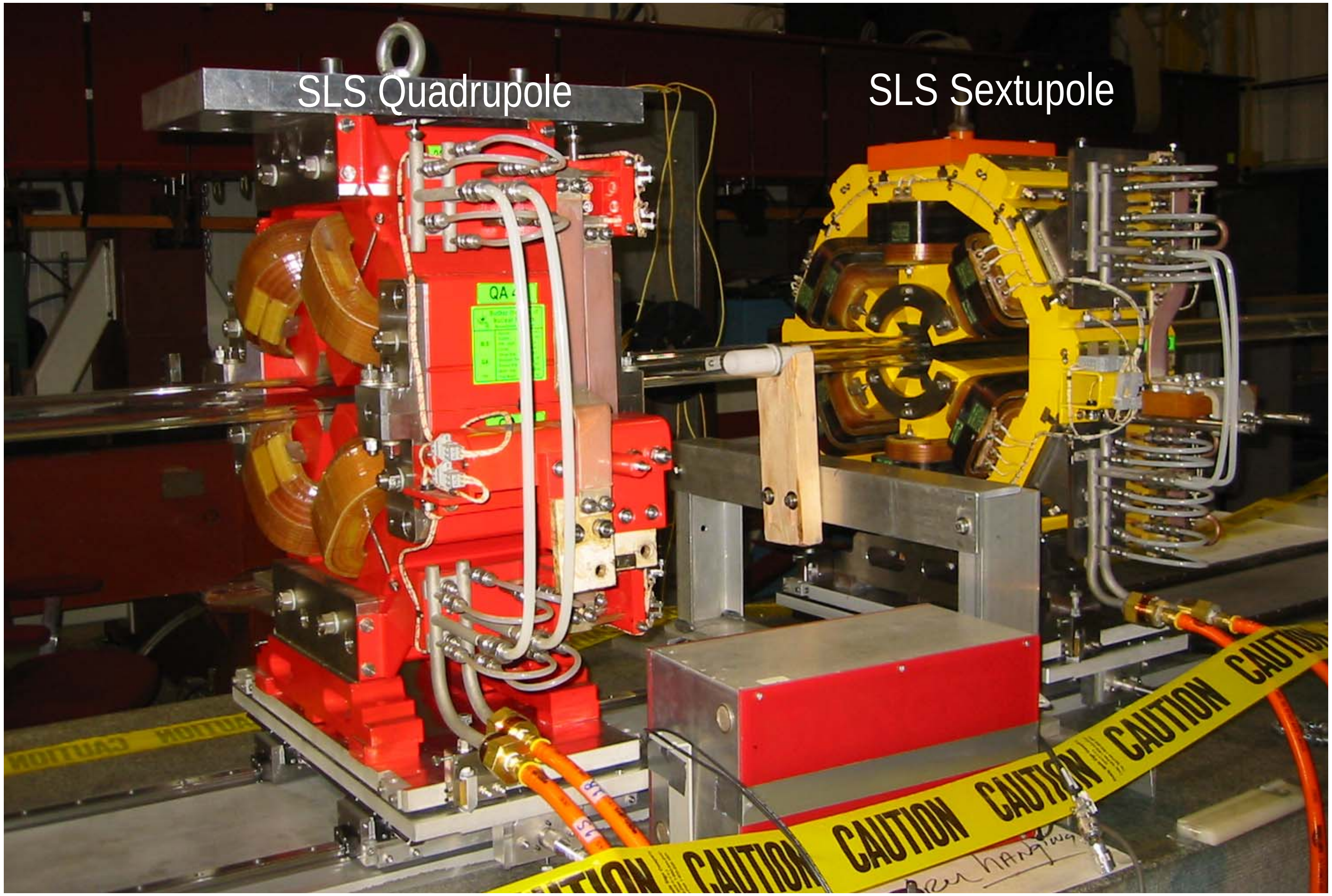
To be used for survey of girder and wire fiducials.



Portable CMM machines

Can be used to relate magnet positions to the girder fiducials with better accuracy than laser trackers.

SLS Magnets in the Vibrating Wire Setup



SLS Quadrupole at 80 A:

$$\int_{-\infty}^{\infty} \frac{dB_y}{dx} dz = 3.19 \text{ T}$$

$$\frac{dB_y}{dx} = 13.8 \text{ T/m}$$

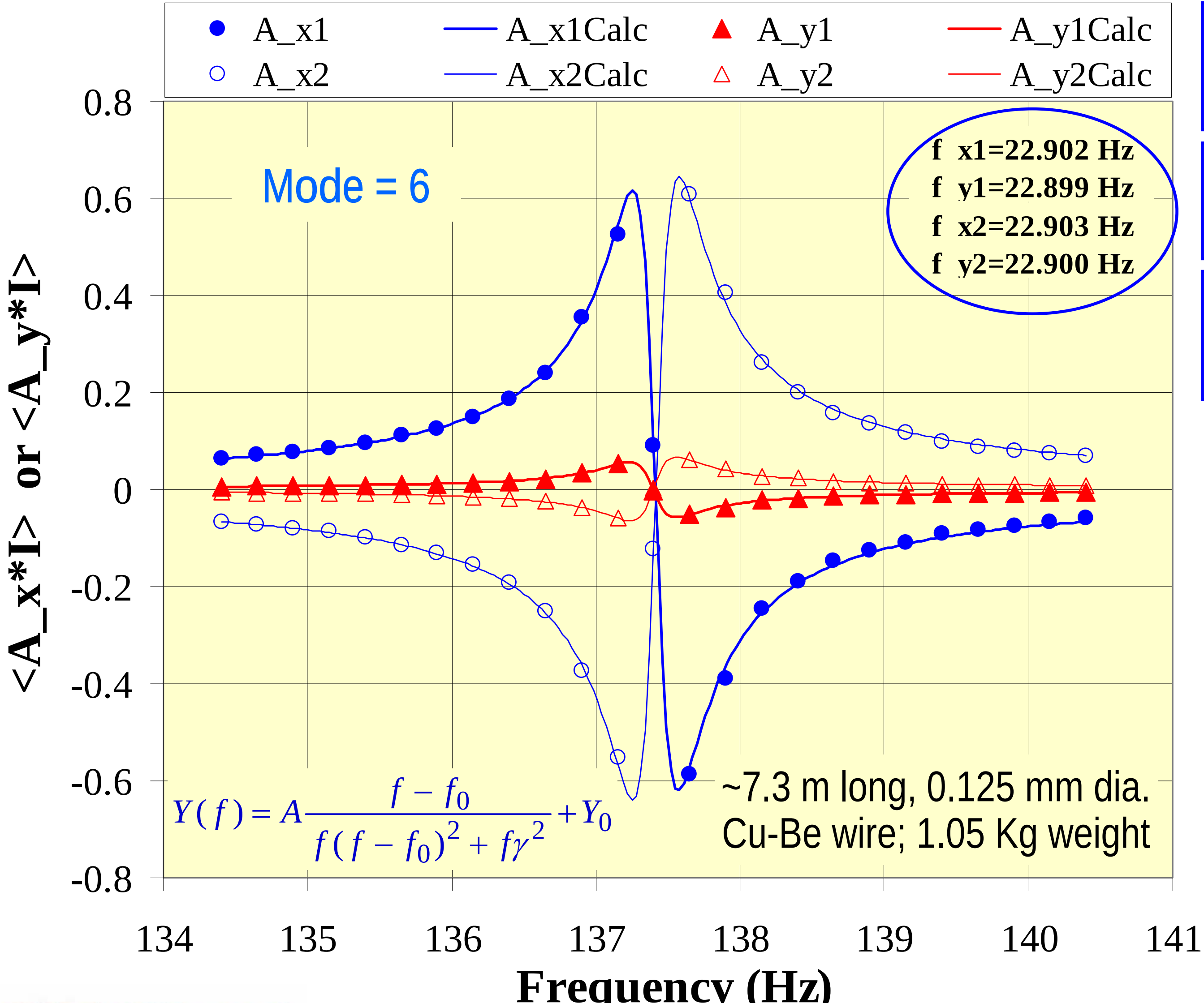
SLS Sextupole at 80 A:

$$\int_{-\infty}^{\infty} \frac{d^2B_y}{dx^2} dz = 94.2 \text{ T/m}$$

$$\frac{d^2B_y}{dx^2} = 430 \text{ T/m}^2$$

Magnets can be run at currents up to 140 A, but saturation begins at ~80 A

Resonant Frequency and Wire Sag



$$f_0 = \frac{1}{2L}\sqrt{\frac{T}{m_\ell}}$$

T = Tension
L = Length
m_ℓ = mass per unit length

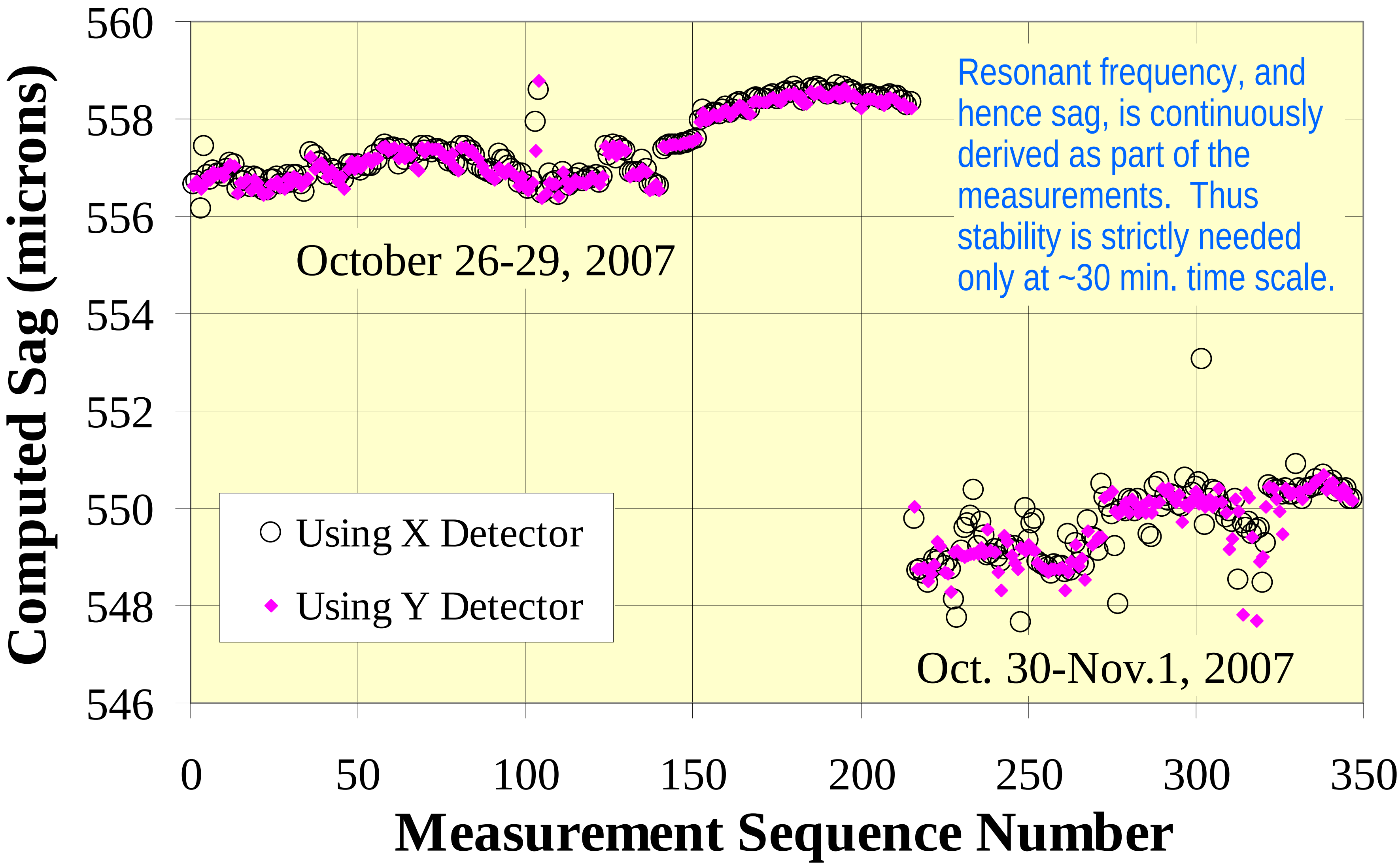
$$Sag = \frac{m_\ell g L^2}{8T}$$

$$Sag = \frac{g}{32 f_0^2}$$

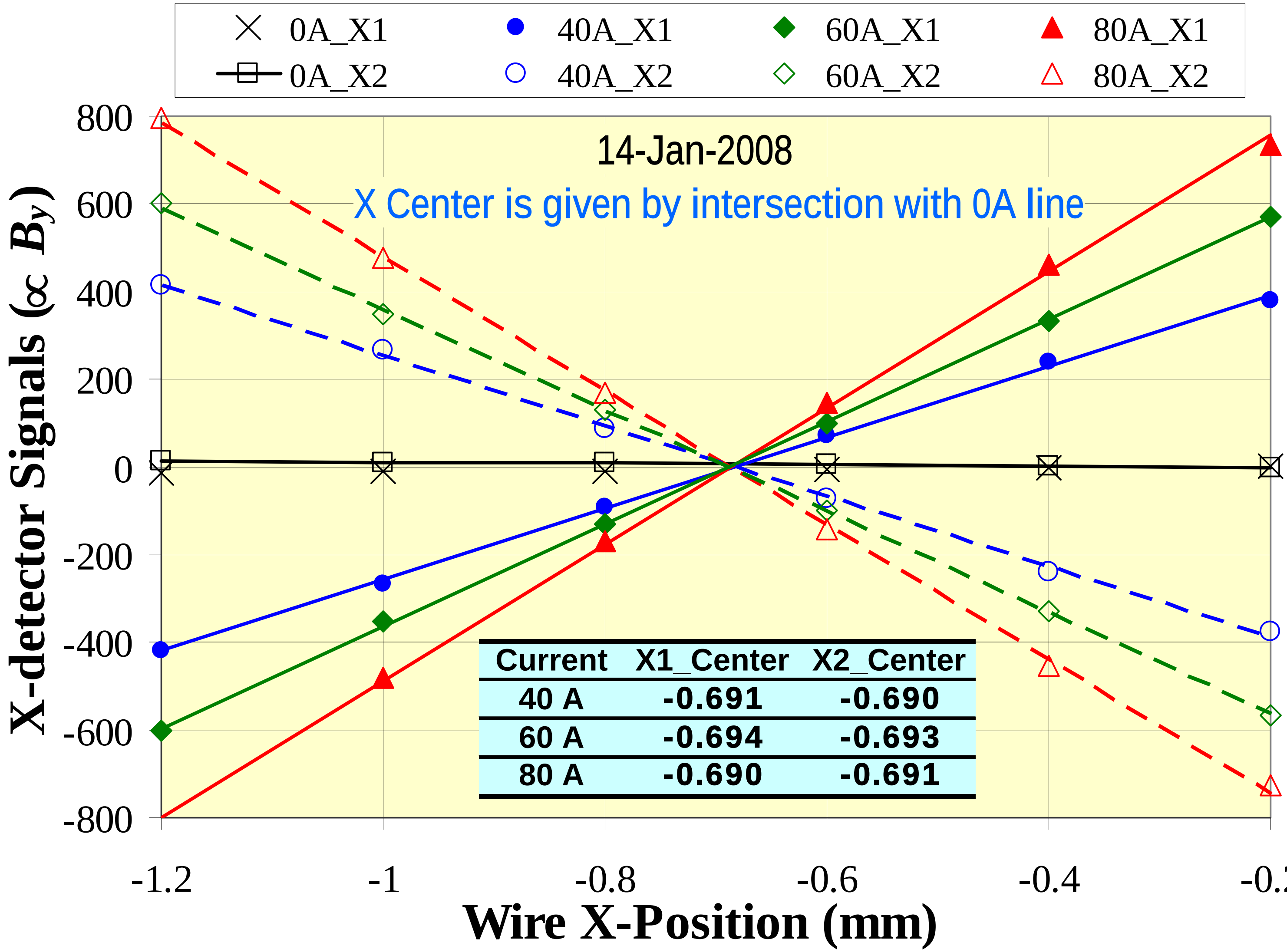
Correction for large wire sag (~550-600 microns for ~7.3 m length) is very important, which in turn requires a very precise knowlege of resonant frequency.

$\pm$0.02 Hz $\Rightarrow$ $\pm$ 1 micron

Stability of Wire Sag Over Several Days

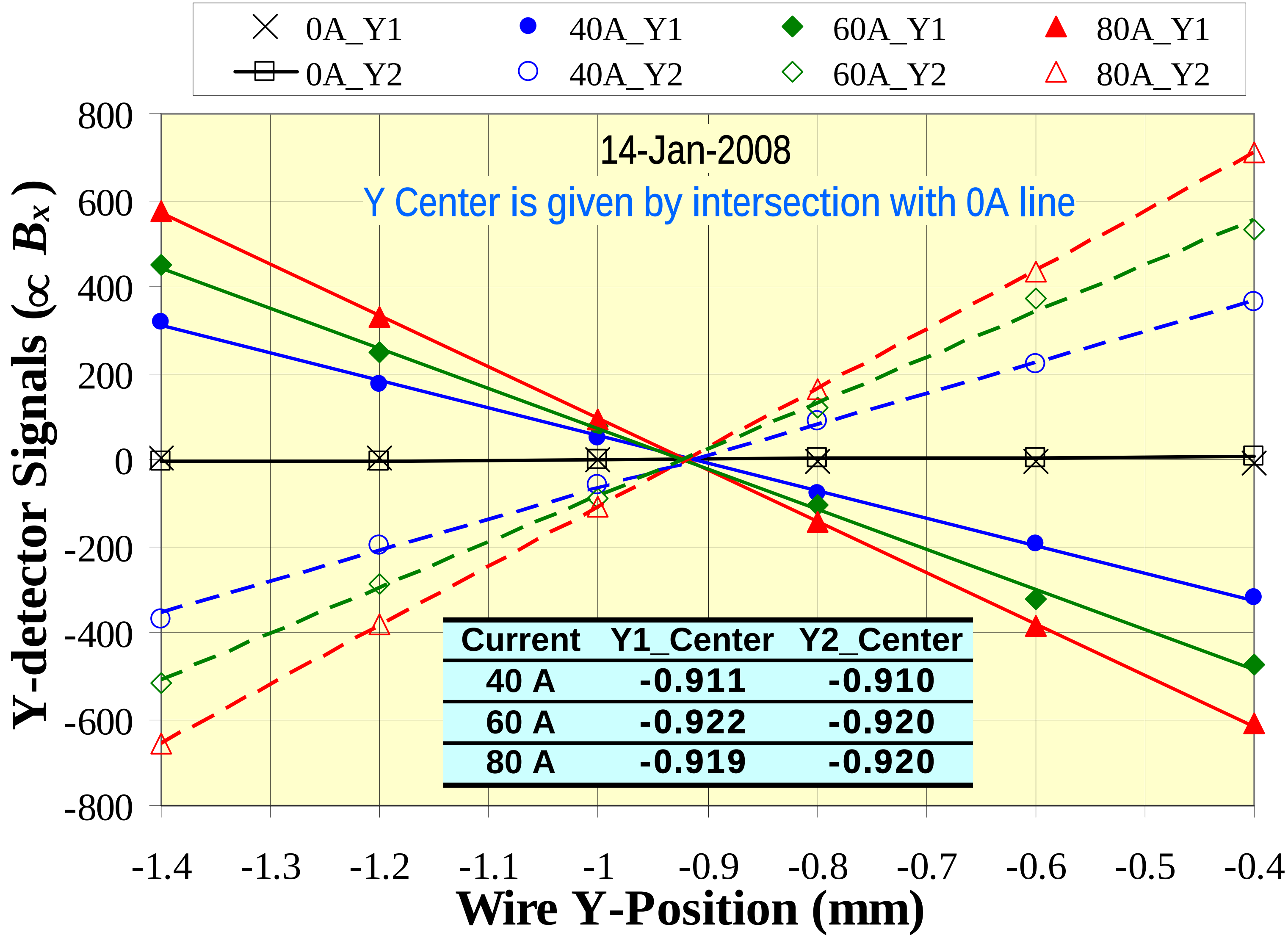


Quadrupole Measurements: Horizontal Scans

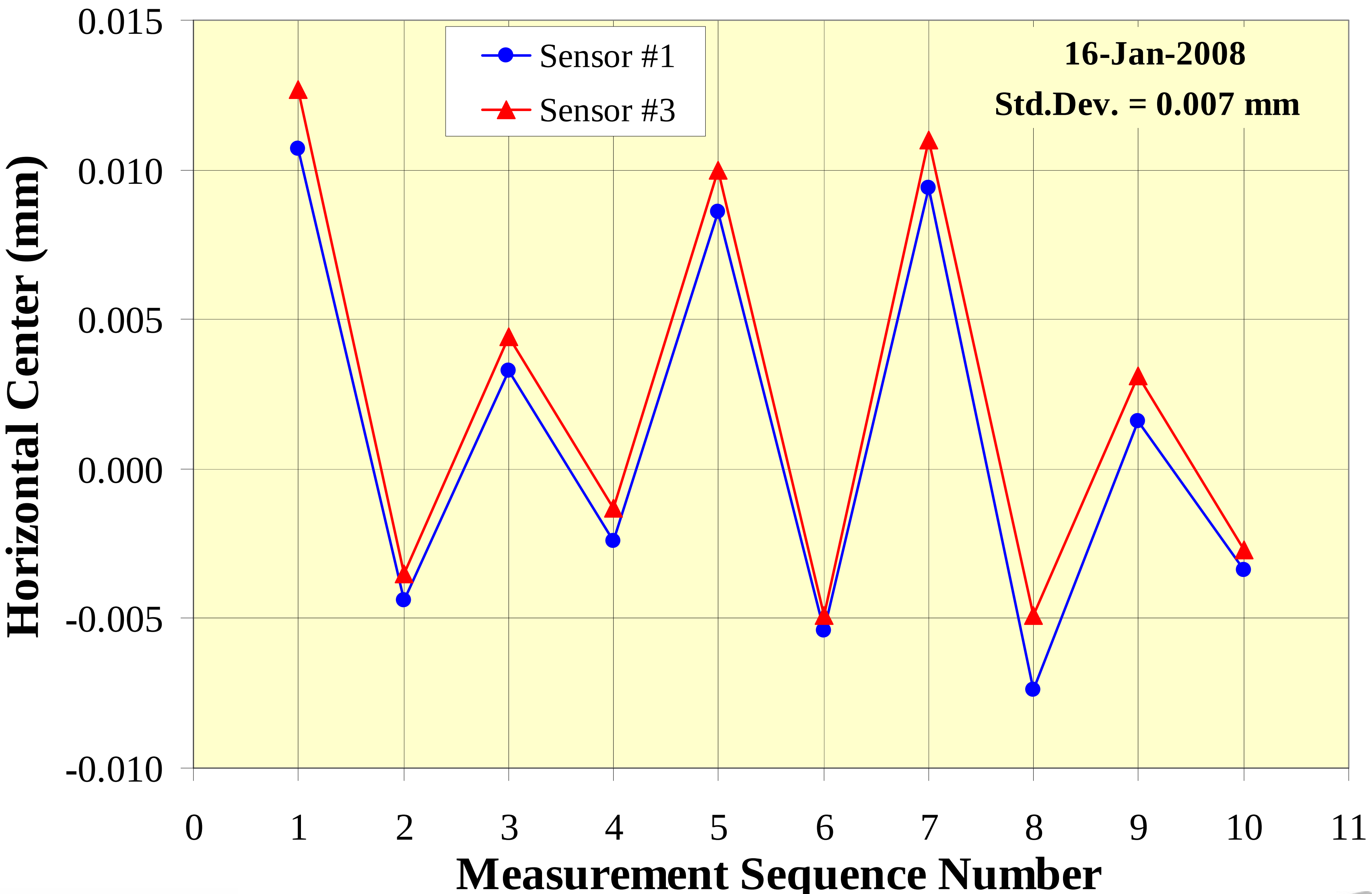


Current	X1_Center	X2_Center
40 A	-0.691	-0.690
60 A	-0.694	-0.693
80 A	-0.690	-0.691

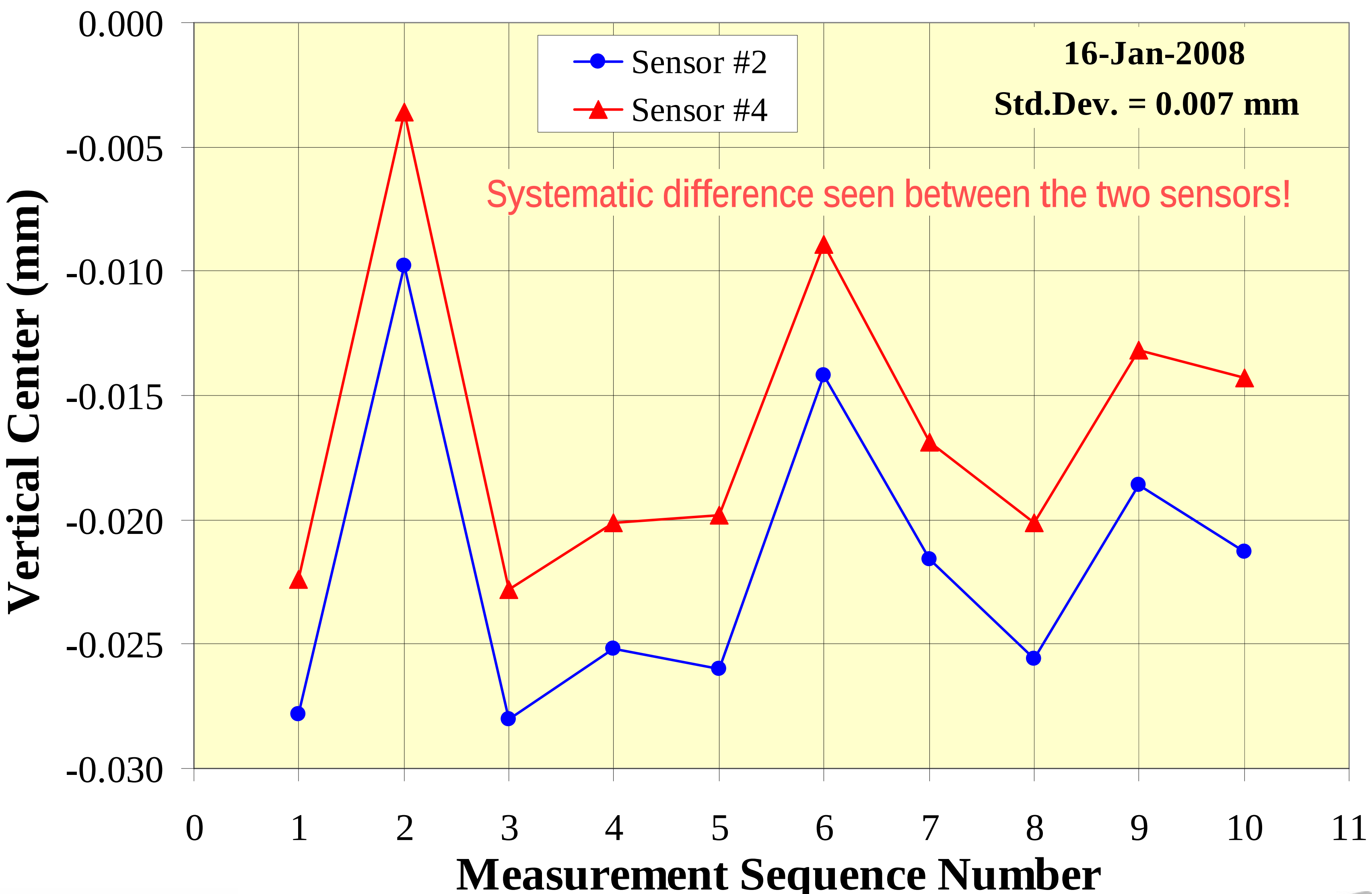
Quadrupole Measurements: Vertical Scans



Quadrupole Measurements Reproducibility



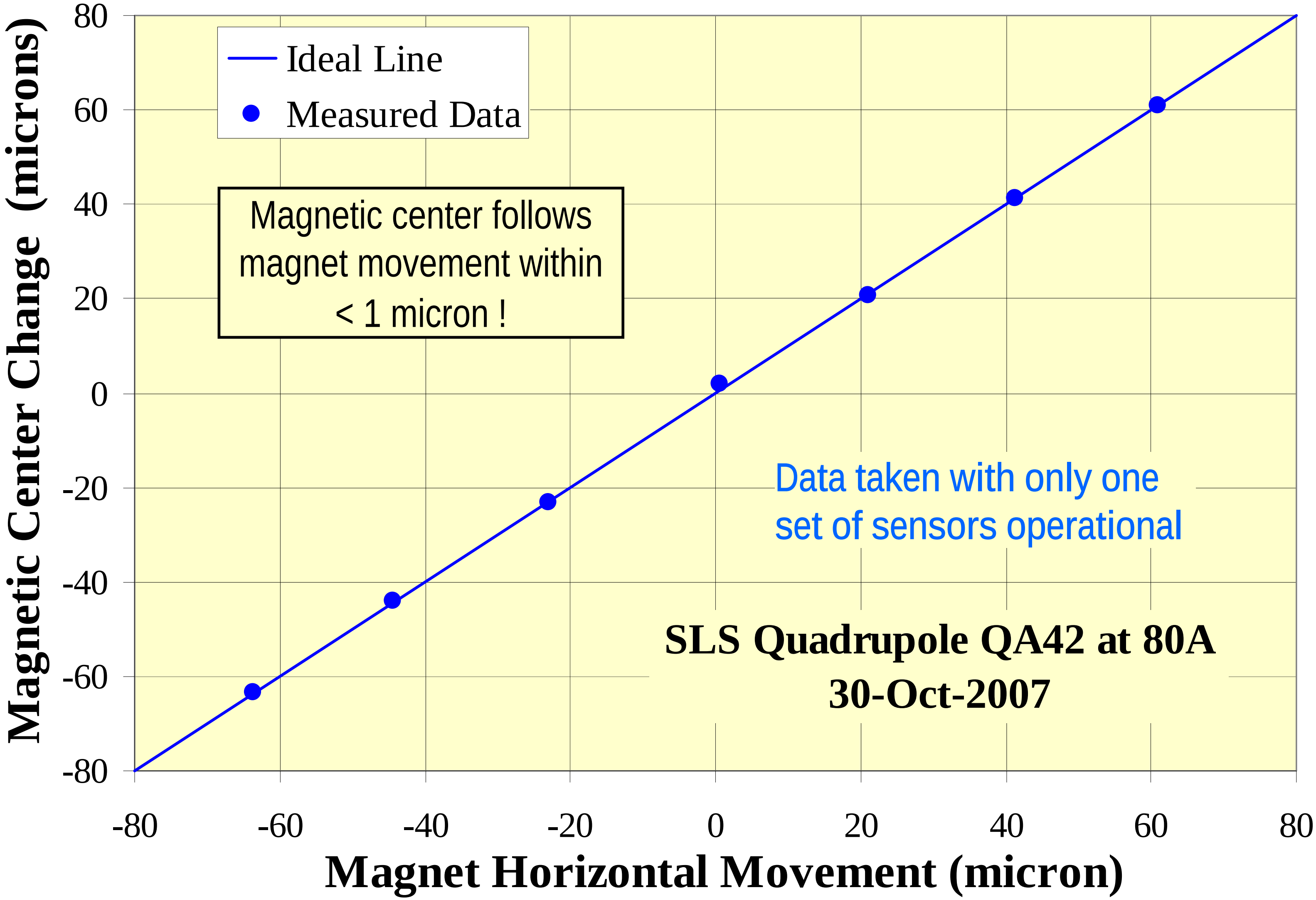
Quadrupole Measurements Reproducibility



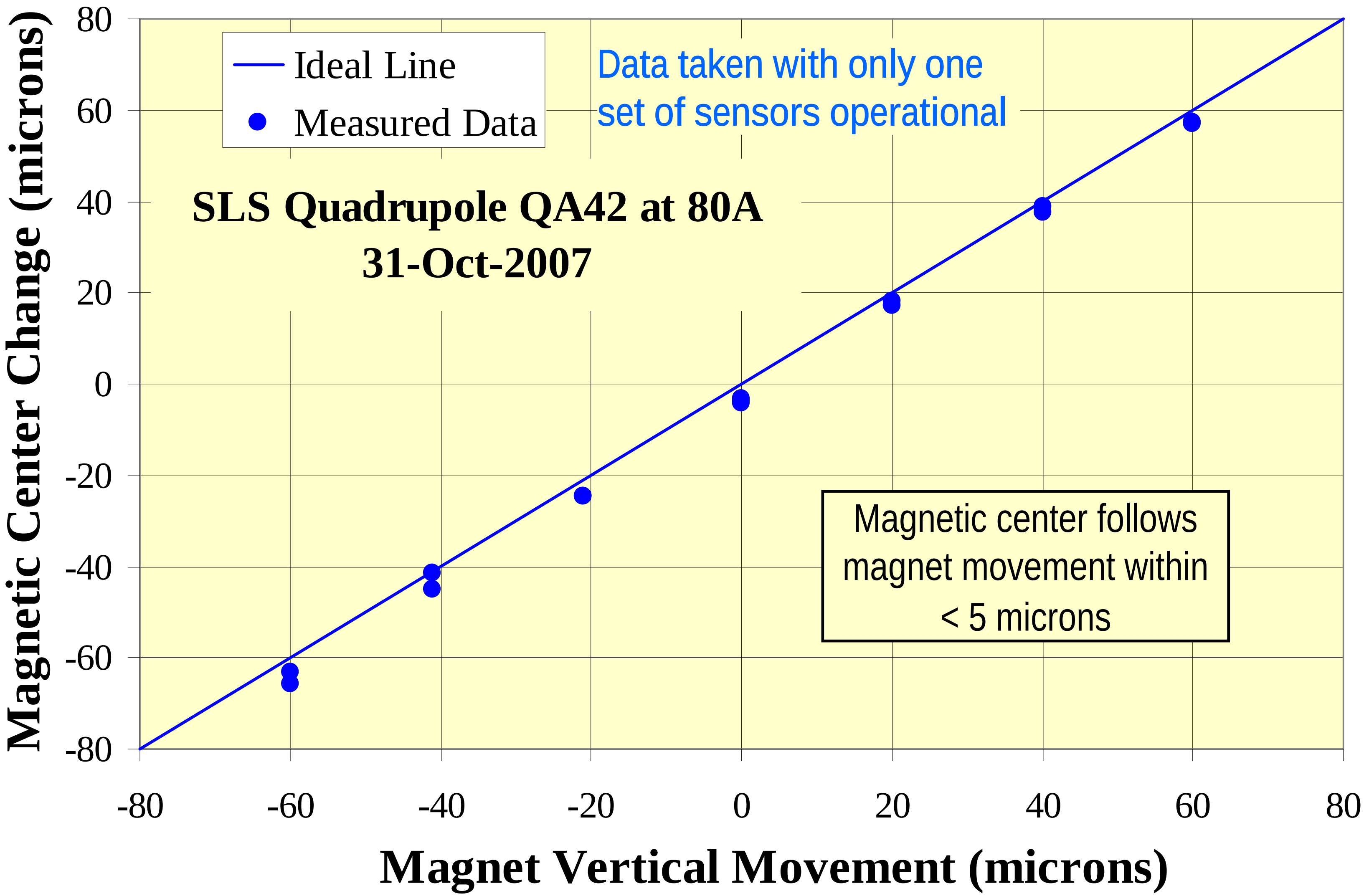
Study of Measurement Resolution: Concept

- Measurements have been made in a SLS quadrupole and a SLS sextupole to study the measurement resolution achievable in each case.
- Magnetic center was first measured in the as-installed position of the magnet using vibrating wire technique.
- The magnet was then moved either horizontally or vertically by a known amount, as monitored by dial indicators.
- Vibrating wire measurements were made again and the results compared against dial indicators.

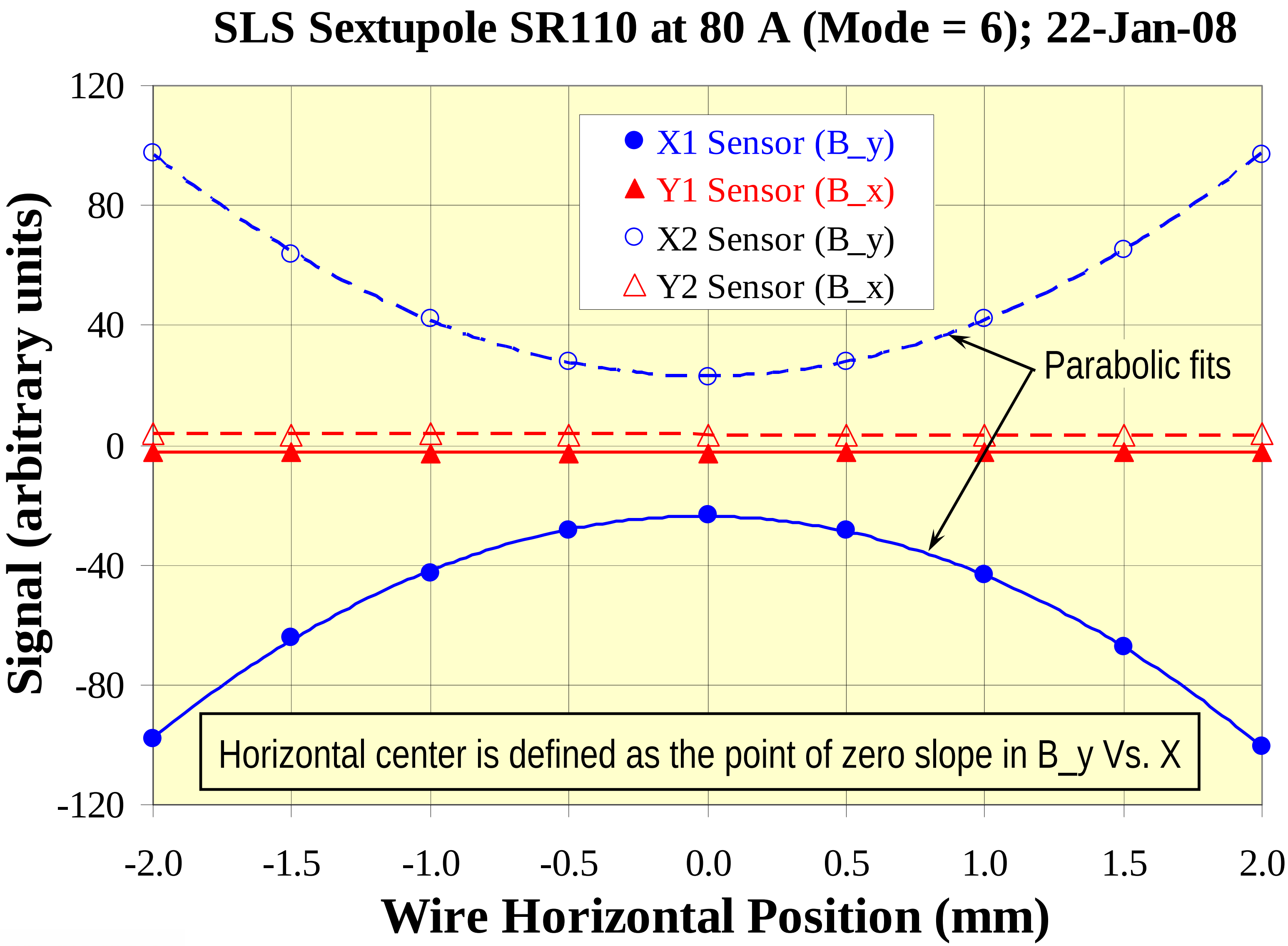
Correlation with Magnet Moves (Quad; Horiz.)



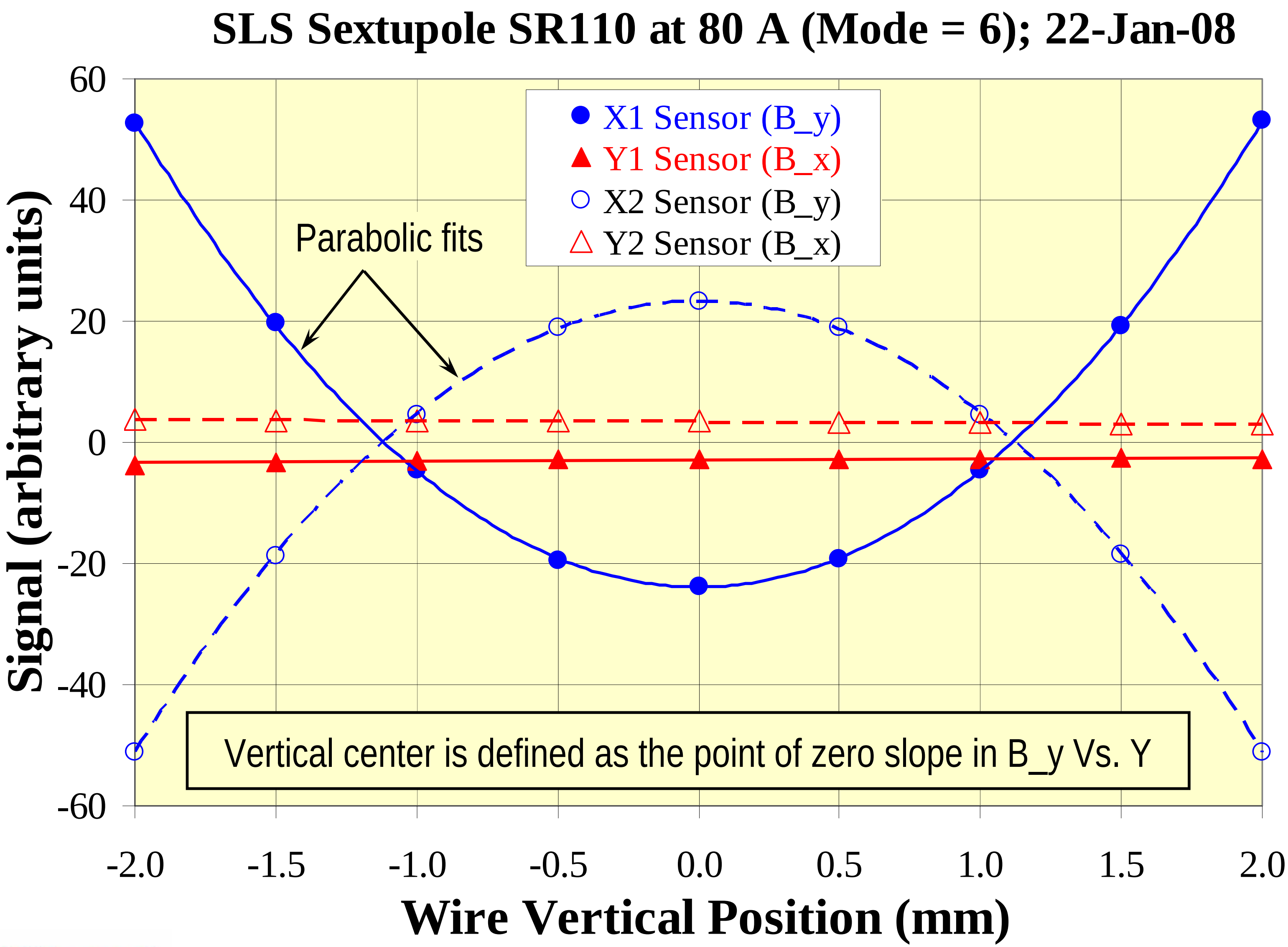
Correlation with Magnet Moves (Quad; Vertical)



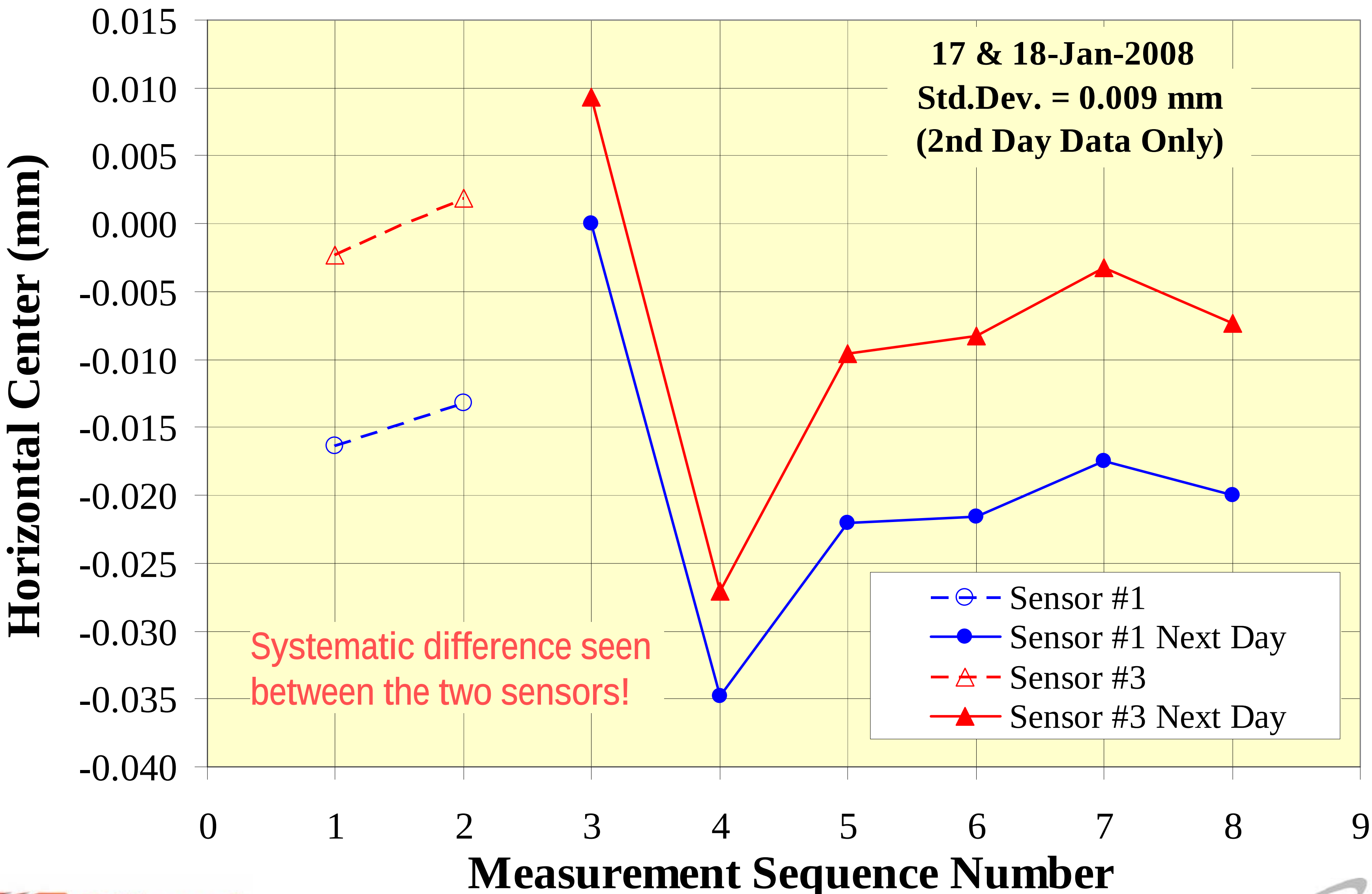
Sextupole Measurements: Horizontal Scan



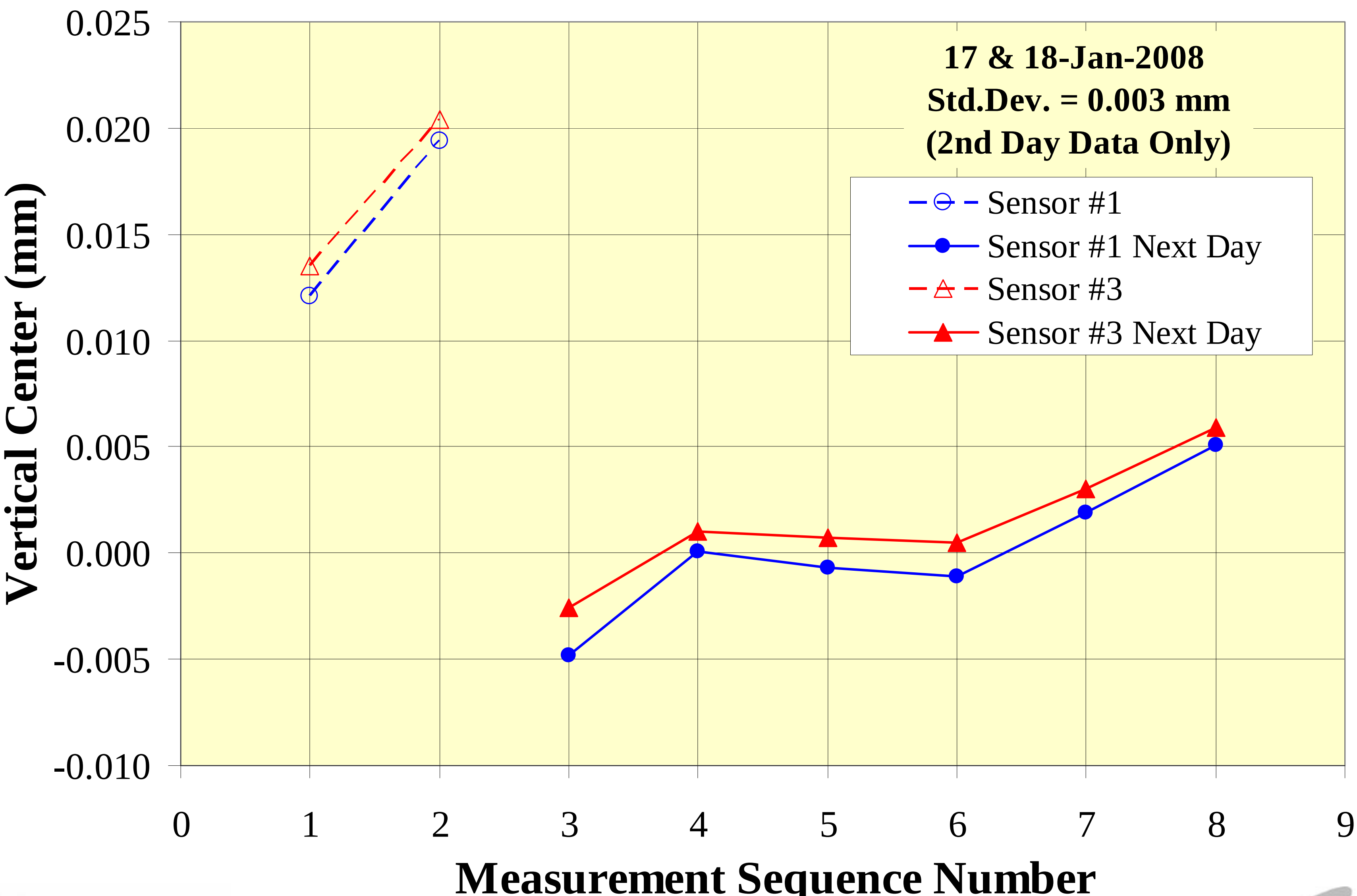
Sextupole Measurements: Vertical Scan



Sextupole Measurement Reproducibility



Sextupole Measurement Reproducibility



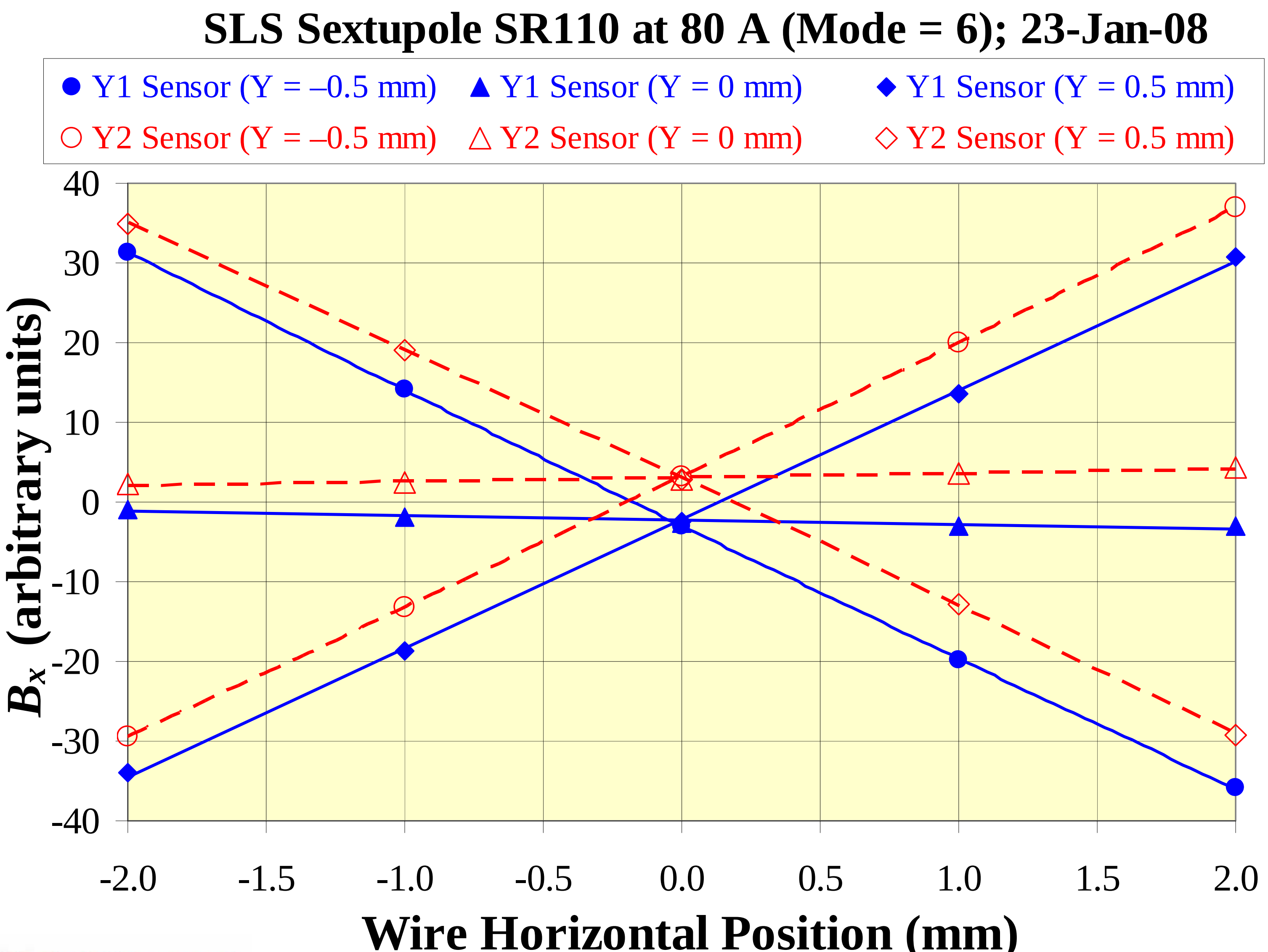
Sextupole Measurements Using B_x Instead of B_y

- Obtaining centers from B_y vs. X and B_y vs. Y plots uses only one set of sensors, and requires quadratic fits.
- One could also use scans of B_x vs. X (or Y) for various values of Y (or X). These plots are expected to be linear with slopes proportional to offsets in Y (or X) direction.
- Doing three such scans allows to obtain centers from both B_x and B_y data. With 2 sets of sensors, one gets four values of magnetic center.

$$B_y = B_3\left[\frac{(x-x_0)^2-(y-y_0)^2}{R_{ref}^2}\right]$$

$$B_x = 2B_3\left[\frac{(x-x_0)(y-y_0)}{R_{ref}^2}\right]$$

Sextupole Measurements: B_x vs. X Scans



Vertical center is defined as the point where B_x Vs. X has zero slope.

Comparison of Sextupole Data Using B_x and B_y

SLS Sextupole at 80 A (23-Jan-2008)

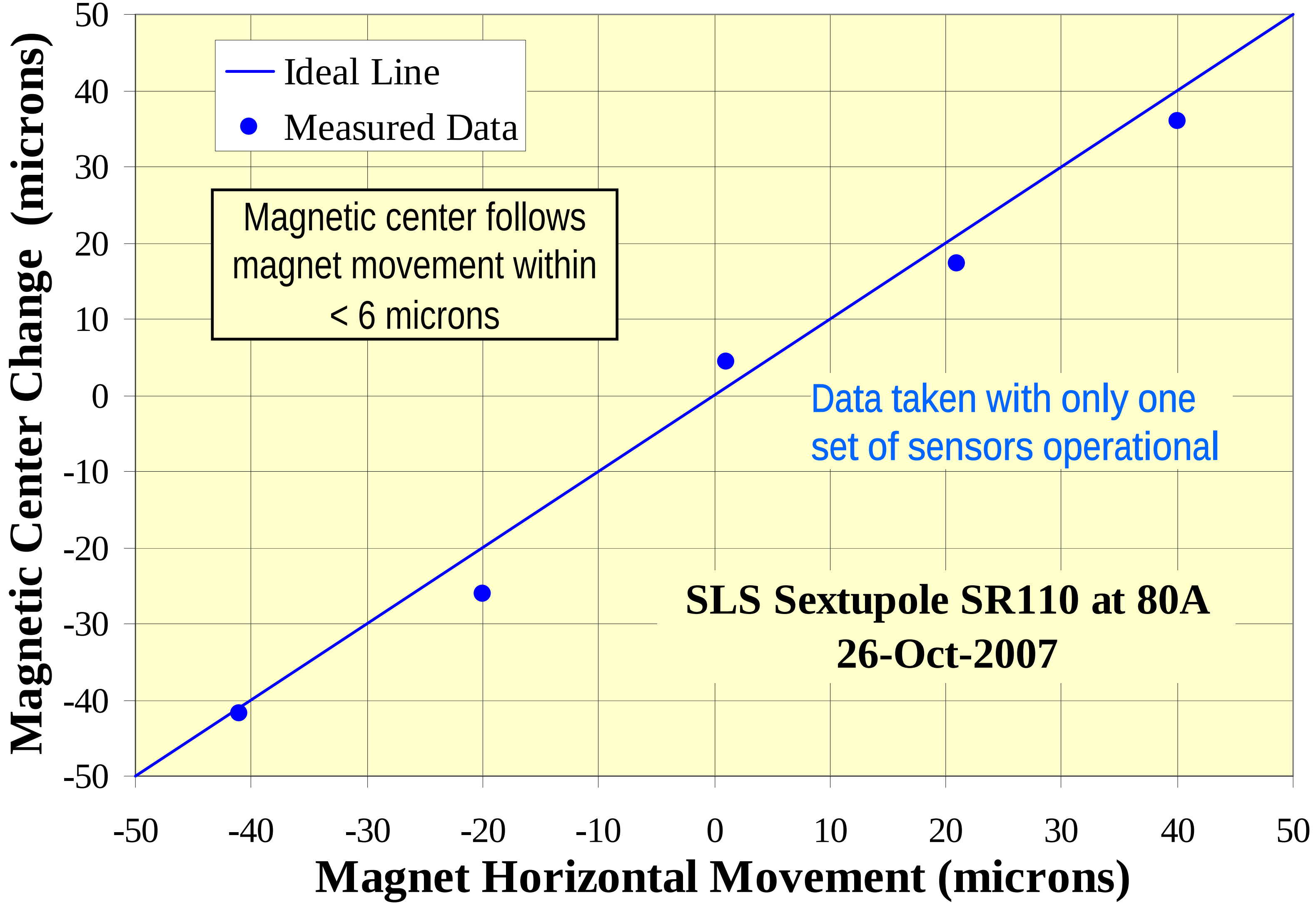
Quantity	Sensors Used	B_x Data		B_y Data	
		Mode=6	Mode=8	Mode=6	Mode=8
X_Center (micron)	Pulley End	-11	-25	6	-8
	Fixed End	-11	-24	-11	-25
Y_Center (micron)	Pulley End	12	-3	-2	-3
	Fixed End	12	-2	1	2

B_x data from the two sensors show better consistency.
Systematic differences between results using two different modes are significant.

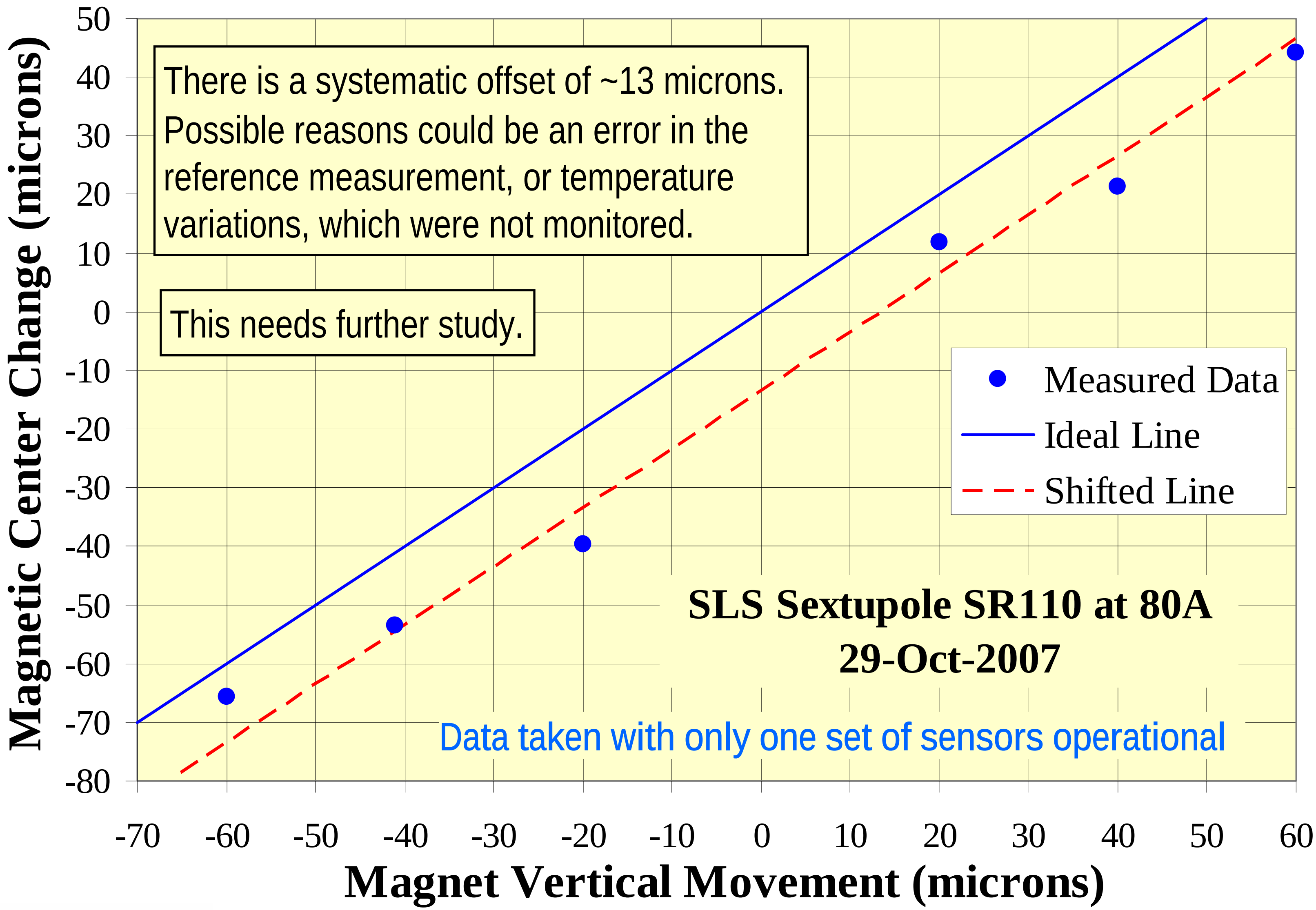
Issue of Background Fields in Sextupole Meas.

- There is a significant quadrupole background field from quadrupole magnet(s) even when these are unpowered.
- Based on rotating coil data, the remnant integrated quadrupole field is ~0.02 T in the SLS quadrupole.
- For a sextupole with integral field of 94.2 T/m at 80A, this could amount to a change in horizontal center by hundreds of microns, depending on quad position and mode used.
- The vertical center measurement is not affected because B_y (or B_x) is independent of y (or x) in a quadrupole field.
- Corrections must be made for this background field.

Correlation with Magnet Moves (Sextupole; Horiz.)



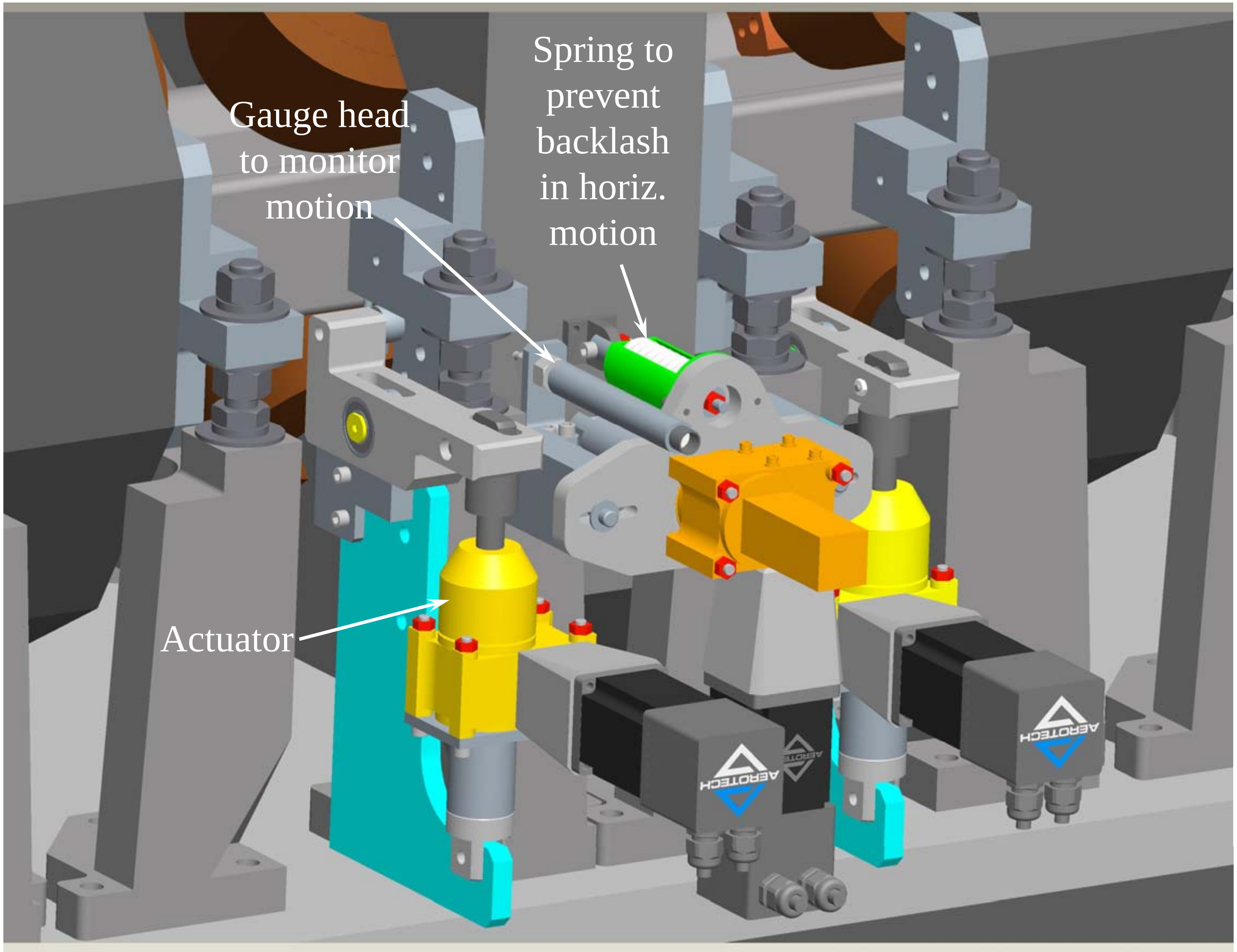
Correlation with Magnet Moves (Sextupole; Vertical)



Procedure for Multipole Alignment on a Girder

- Install magnets on a girder, install vacuum chamber, and carry out a rough alignment.
- Set up girder on a vibrating wire test stand in a temperature controlled environment, and wait for steady temperature.
- Determine center of each magnet relative to the wire coordinates. Move the magnets to locate the magnetic centers on a line joining the two end points of the wire.
- Lock the magnets in place, while monitoring the magnet positions using displacement gauges.
- Survey the wire ends, and all girder and magnet fiducials (?) using laser trackers and portable CMM machines.

Magnet Movers for Alignment on a Girder



Magnet movers will be installed on the girder, and then removed after the magnets are aligned and locked in place.

A test was performed to demonstrate ability to easily lock a magnet in place within 5-10 microns.

Future Work

- Study (and improve) the absolute accuracy of the measurements (better than ~10 microns desirable).
- Resolve various inconsistencies in detector responses.
- Survey of wire end V-notches relative to fiducials on test stand.
- Prototypes for motorized magnet movers.
- Integrate various components of hardware and software needed for measurements into a single, fully automated system for multipole alignment on a girder.

Conclusions

- A new vibrating wire R&D system has been designed, built and assembled.
- The R&D system has been used to measure a quadrupole and a sextupole received on loan from the Swiss Light Source.
- Unique feature of dual sensors allows extensive checks of consistency and systematic accuracy.
- Good correlation between magnet position and magnetic center has been shown (well within the required tolerance) for both quadrupole and sextupole magnets.
- Work is underway to further improve the accuracy of the system, and to automate the entire measurement and alignment sequence.

Acknowlegements

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Swiss Light Source