Precision Alignment of Multipoles on a Girder for NSLS-II*

Animesh Jain
Superconducting Magnet Division
Brookhaven National Laboratory, Upton, NY 11973

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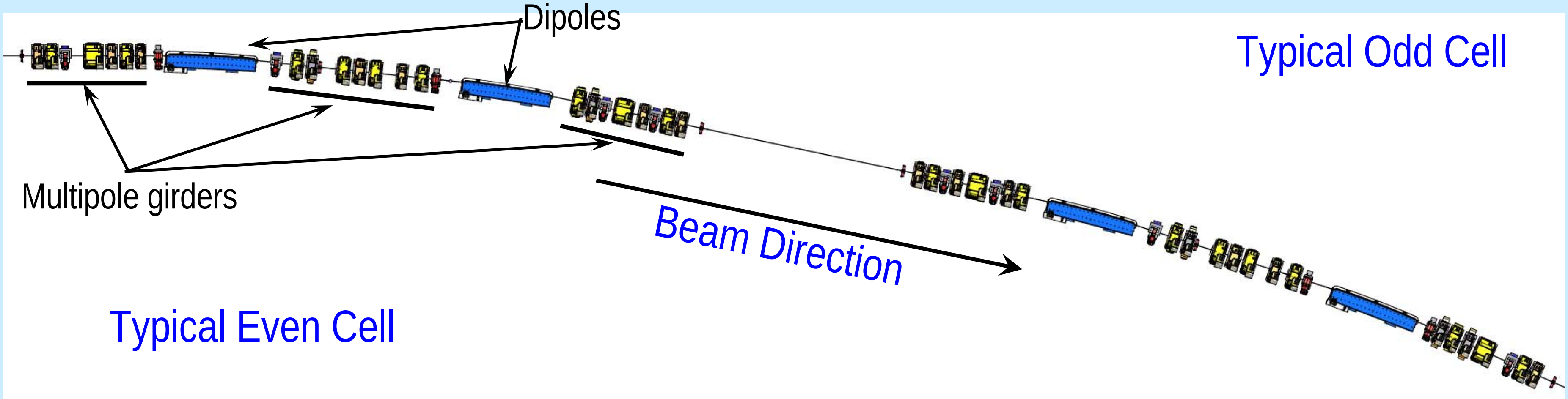
Introduction

- The National Synchrotron Light Source-II (NSLS-II) is a new light source presently under construction at Brookhaven National Laboratory (BNL).
- The magnets needed for the storage ring of NSLS-II are currently being produced by various manufacturers located around the world (7 vendors in 6 countries, 4 continents).
- The multipole magnets (quadrupoles and sextupoles) in the storage ring must be aligned to each other within tight tolerances (better than 30 microns).
- This talk describes the alignment procedure being followed for the multipoles in NSLS-II, and the current status of this work.

Lattice Layout



- The storage ring consists of 30 cells, each containing six girders with one or more magnets mounted on each girder.
- Three of the girders in each cell contain either 6 or 7 multipole magnets, along with two slow orbit correctors, on each girder.
- The multipoles on a common girder need to be aligned to each other to better than ±30 microns. This is difficult to achieve by survey alone.
- The girder-to-girder alignment needs to be better than ±100 microns, and is achievable by survey.

List of Magnets in NSLS-II Storage Ring

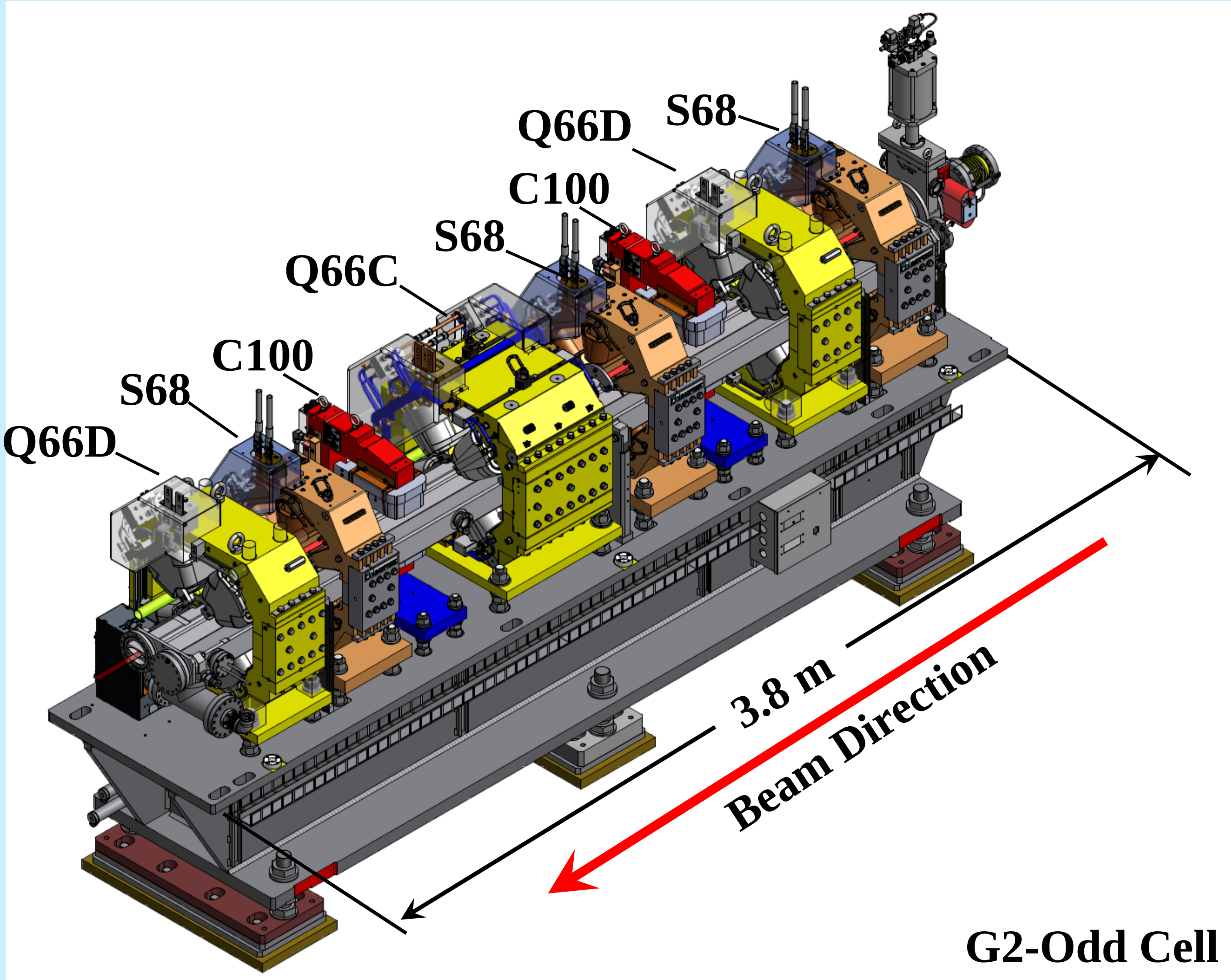
Short Name	Description	Quantity	Vendor	Integ. Strength[1]
Q66A	66 mm Single Coil Short Quadrupole	30	A	2.75 Tesla
Q66B	66 mm Single Coil Short "Wide" Quadrupole	30	A	2.75 Tesla
Q66C	66 mm Double Coil Long Quadrupole	30	A	8.80 Tesla
Q66C'	66 mm Double Coil Long Quadrupole (Kinked)	30	A	8.80 Tesla
Q66D	66 mm Double Coil Short Quadrupole	90	B	5.50 Tesla
Q66E	66 mm Double Coil Short "Wide" Quadrupole	30	B	5.50 Tesla
Q90	90 mm Aperture Quadrupole	60	C	3.79 Tesla
S76	76 mm Aperture Sextupole	30	C	100 Tesla/m
S68	68 mm Aperture Sextupole	165	D	80 Tesla/m
S68W	68 mm Aperture "Wide" Sextupole	75	E	80 Tesla/m
D35	35 mm Aperture Bending Dipole	54	C	1.048 Tesla.m
D90	90 mm Aperture Bending Dipole	6	C	1.048 Tesla.m
C100	100 mm Aperture Dipole Correctors	90	F	0.0082 T.m
C101	100 mm Aperture Correctors with Skew Quad	30	F	0.086 Tesla[2]
C156	156 mm Aperture Correctors	60	F	0.0082 T.m (VF) 0.0092 T.m (HF)
	Fast Orbit Correctors	60	G	

Total number of magnets in storage ring = 870

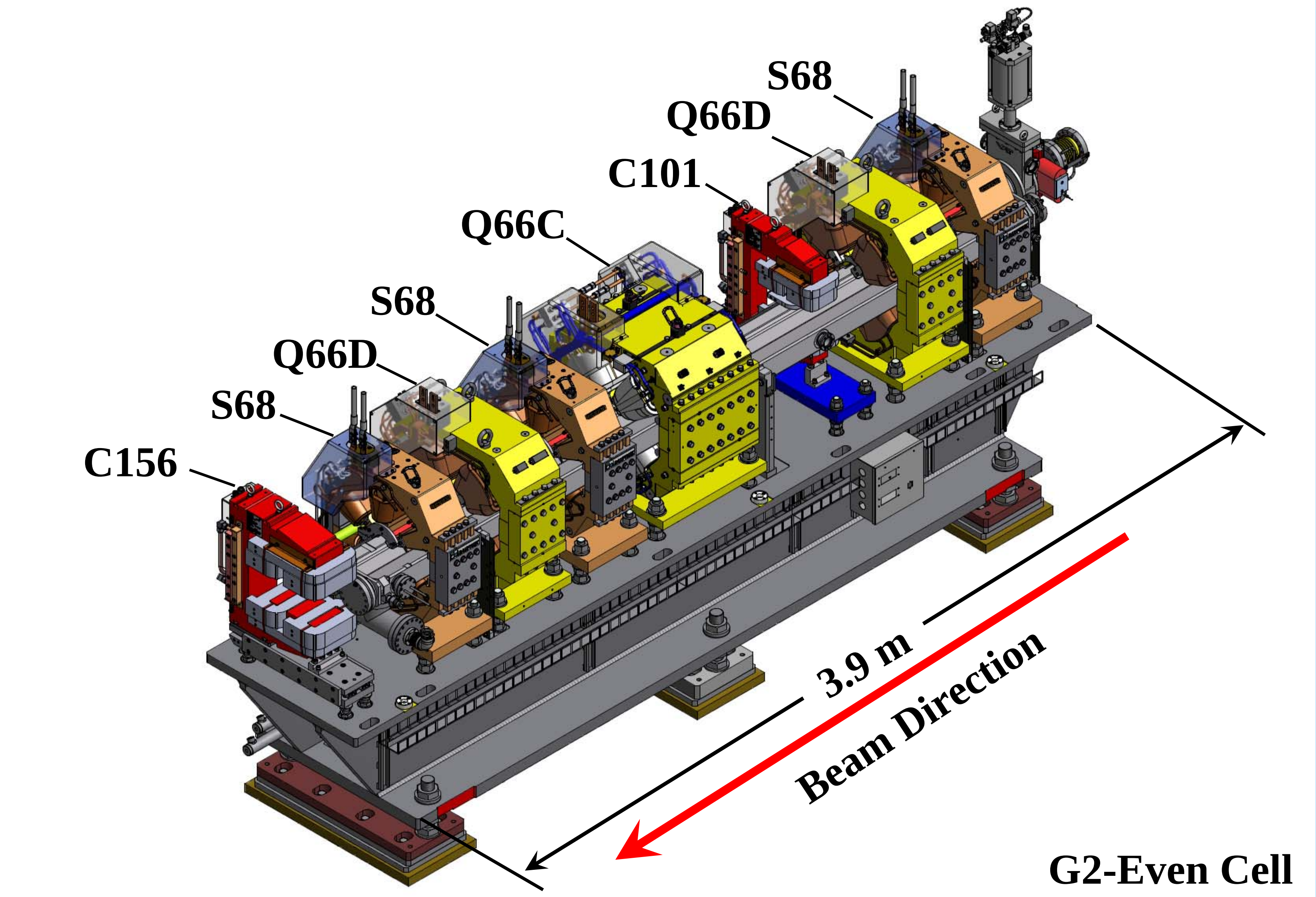
(1) Integrated strength is defined as Int(B.dl) for dipoles, Int(B'.dl) for quads, and Int(B".dl) for sextupoles

(2) Strength listed is of the skew quadrupole; the dipole correctors have the same strengths as in C100

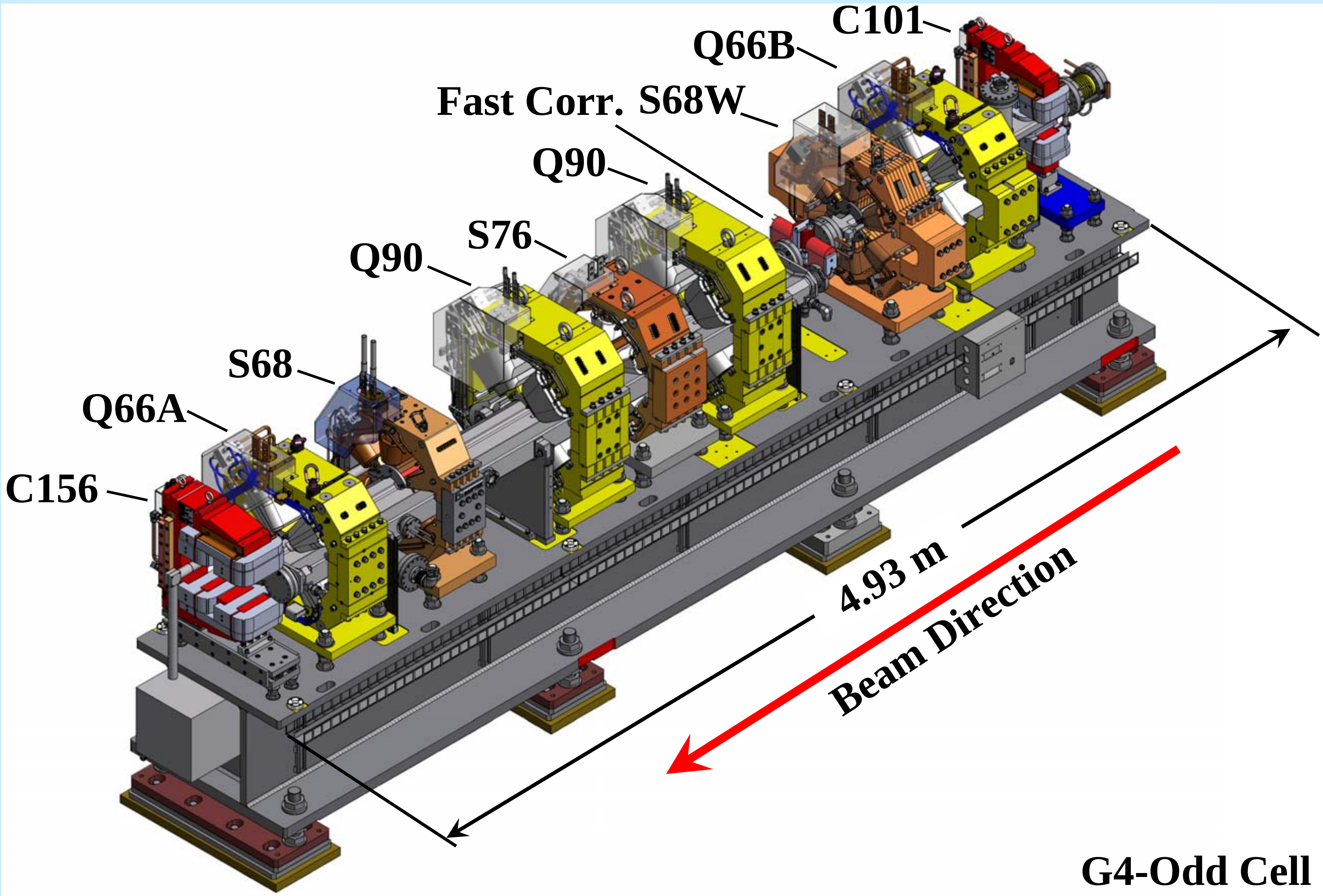
Magnets on Girders in NSLS-II



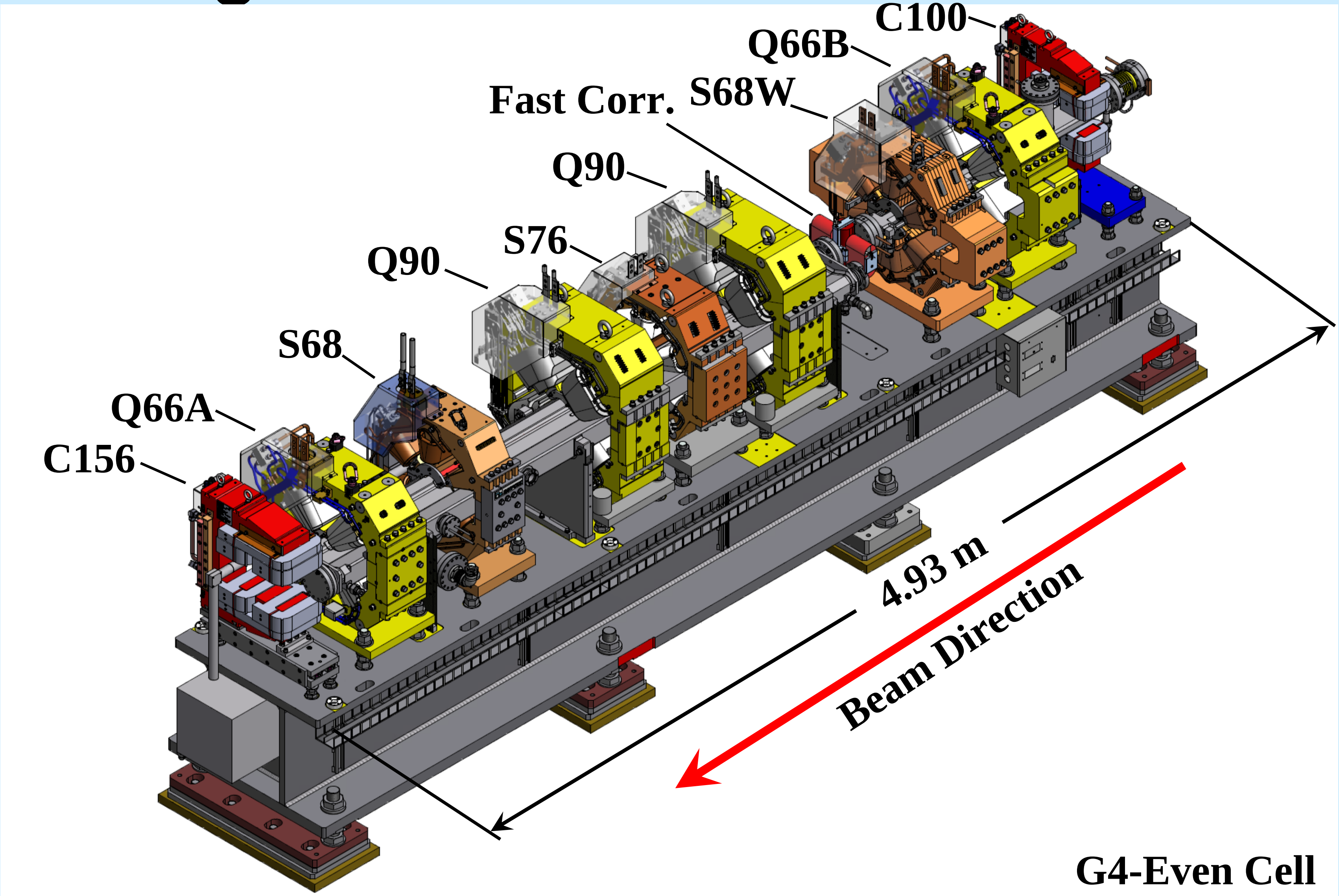
Magnets on Girders in NSLS-II



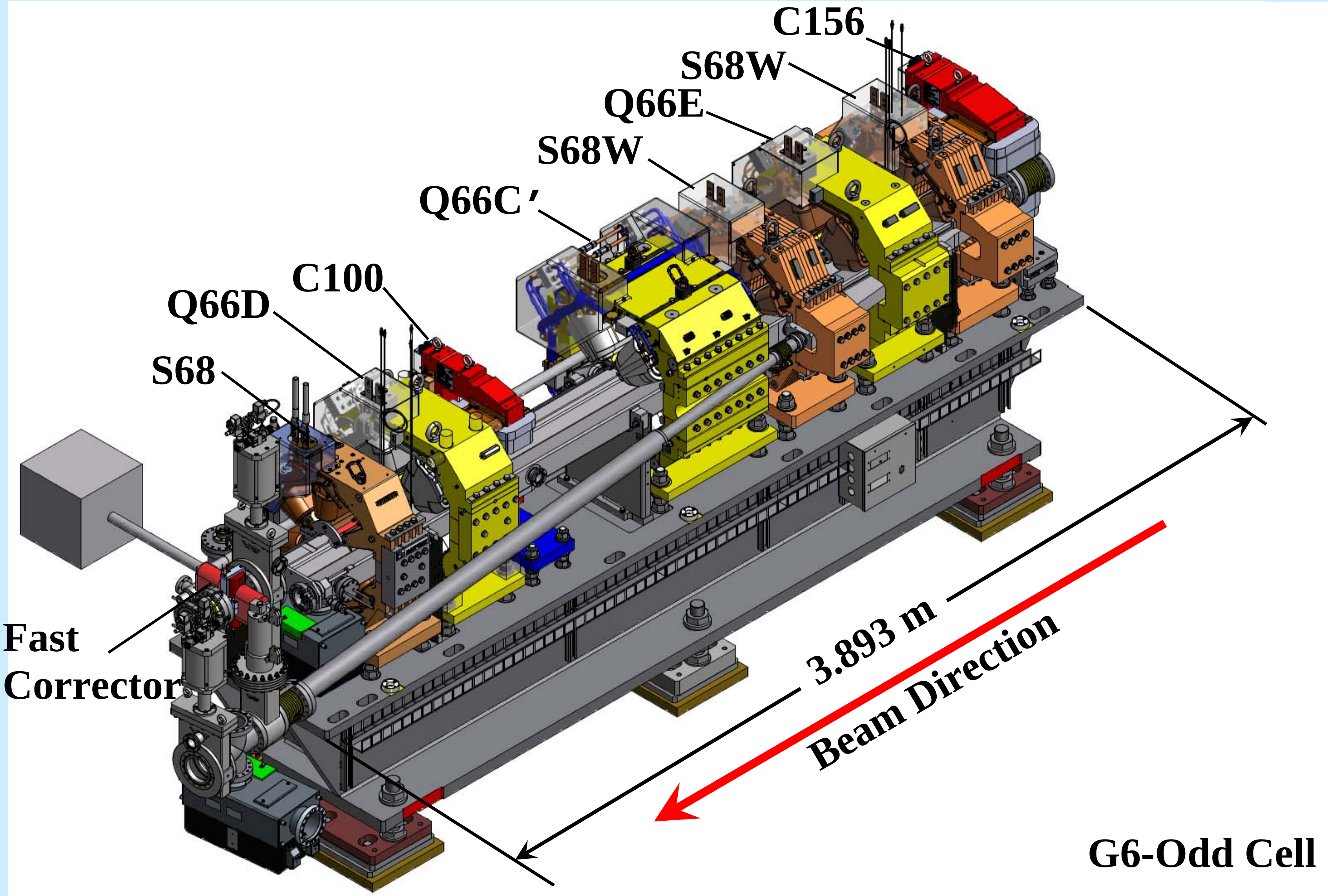
Magnets on Girders in NSLS-II



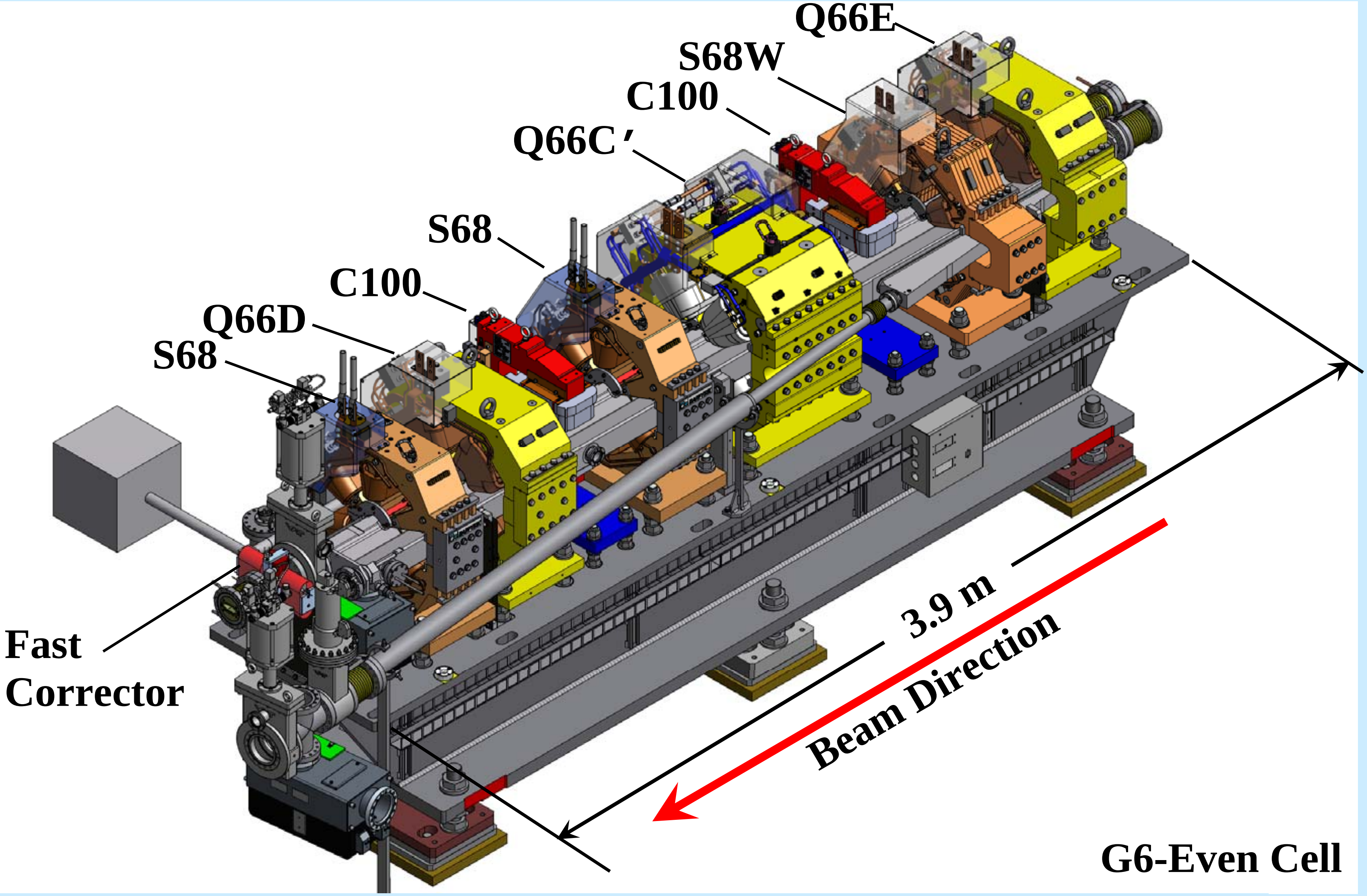
Magnets on Girders in NSLS-II



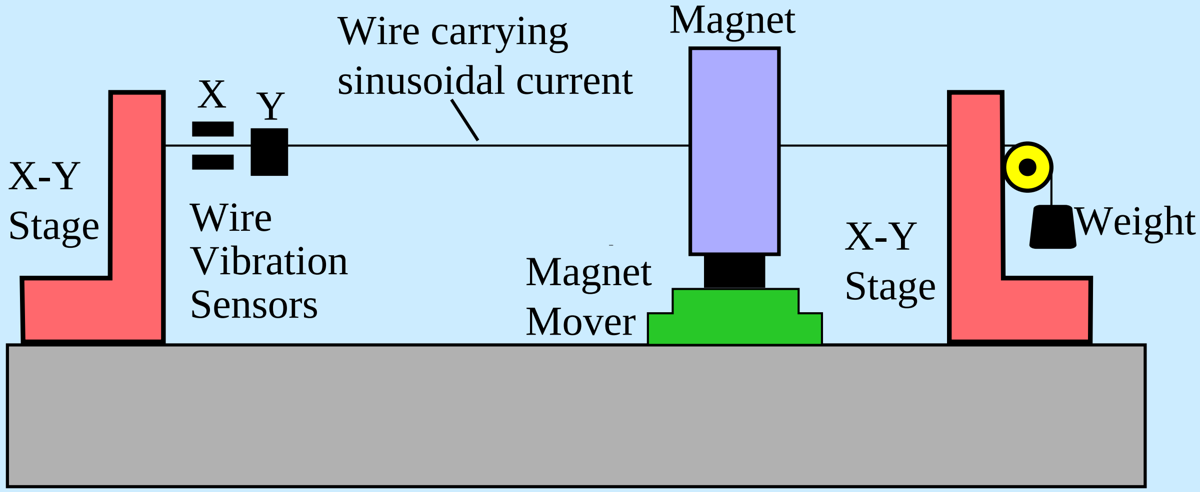
Magnets on Girders in NSLS-II



Magnets on Girders in NSLS-II



The Vibrating Wire Technique: Basics



- 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 offset to determine the transverse field profile, from which the magnetic axis can be derived.
- Resonant mode must be chosen carefully to match magnet axial position.

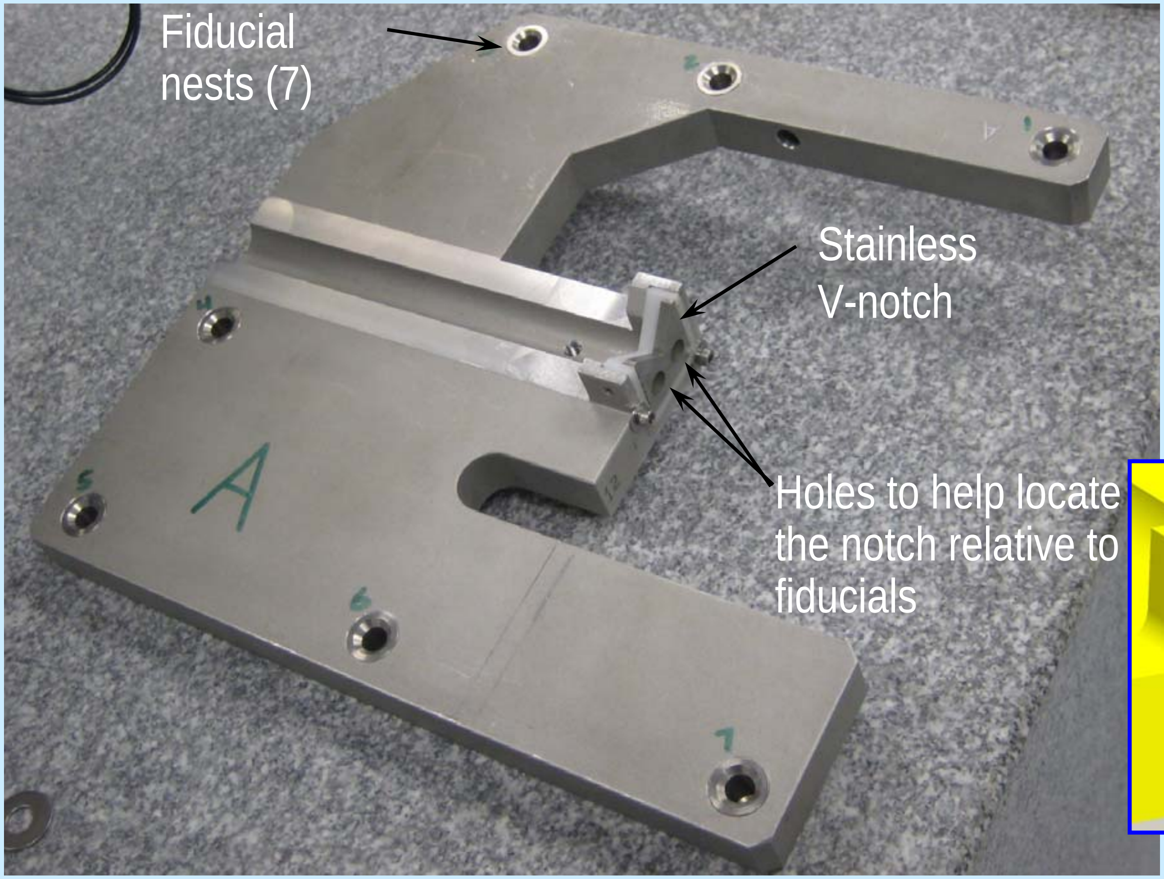
Steps Involved in Alignment

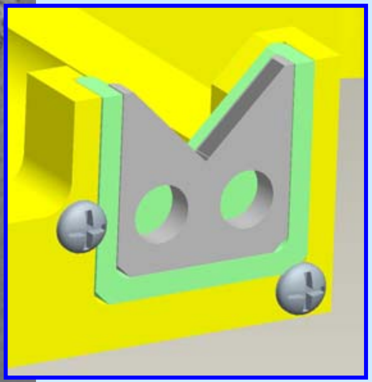
- Prealign the magnets on a girder using survey. Set the roll angles.
- Split the magnets, install and align the vacuum chamber.
- Move girder to temperature controlled test room and allow to stabilize.
- Determine magnetic axis of all elements on the girder relative to the wire frame.
- Pick a "best fit" line and move all magnets to this line.
- Secure magnets to the girder (270 N.m) without disturbing the alignment.
- Verify alignment after securing the magnets.
- Characterize the magnet and girder positions, *including the vertical profile of the girder*, in space using survey. (Ten tracker positions are used to get <±10 μm.)
- Realign the vacuum chamber, if necessary.
- Install the girder in the machine using survey data taken in the alignment stand, and reproduce the girder profile.

Salient Features of the Vibrating Wire System

- Temperature controlled environment (±0.05 C)
- Aerotech ATS03005 stages for wire movement
(0.1 micron resolution; 2.5 micron over 25 mm accuracy).
- Wire ends are defined by stainless steel V-notches.
- Set of 7 fiducials on each V-notch holder to locate the notches.
- A pair of X-Y wire vibration sensors at each end of the wire.
Allows two independent, simultaneous measurements for data verification and redundancy.
- Fully automated acquisition and analysis software with scripting support for flexibility in experiment control. Standard scripts are being developed for each girder type, as we go along.

Wire End Support (V-notch)

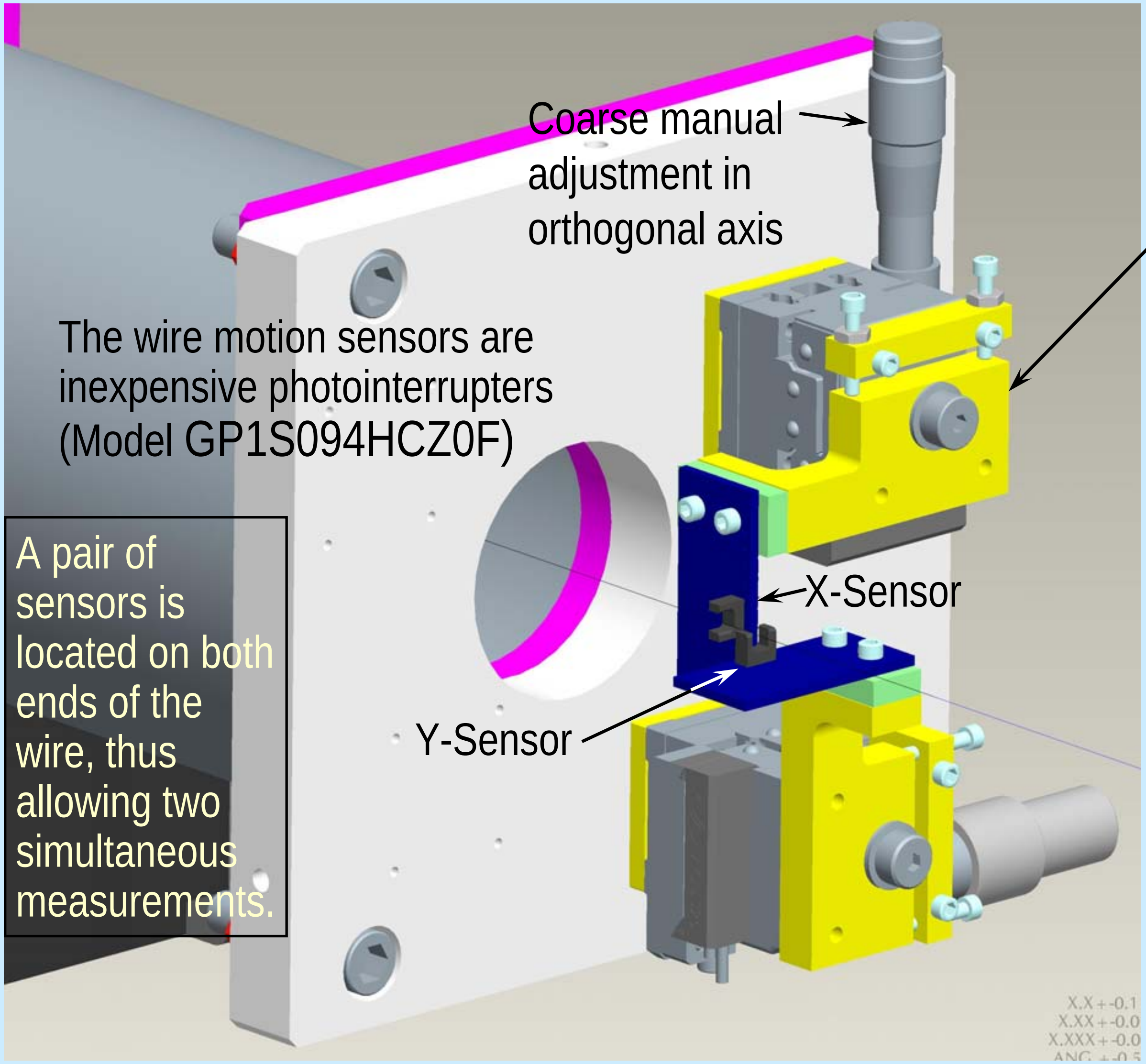




Fiducials relate the wire ends to the overall girder coordinate system.

A V-notch with radius much smaller than the wire was chosen.
The wire position is thus insensitive to the actual radius of the V-notch.

Wire Vibration Sensors

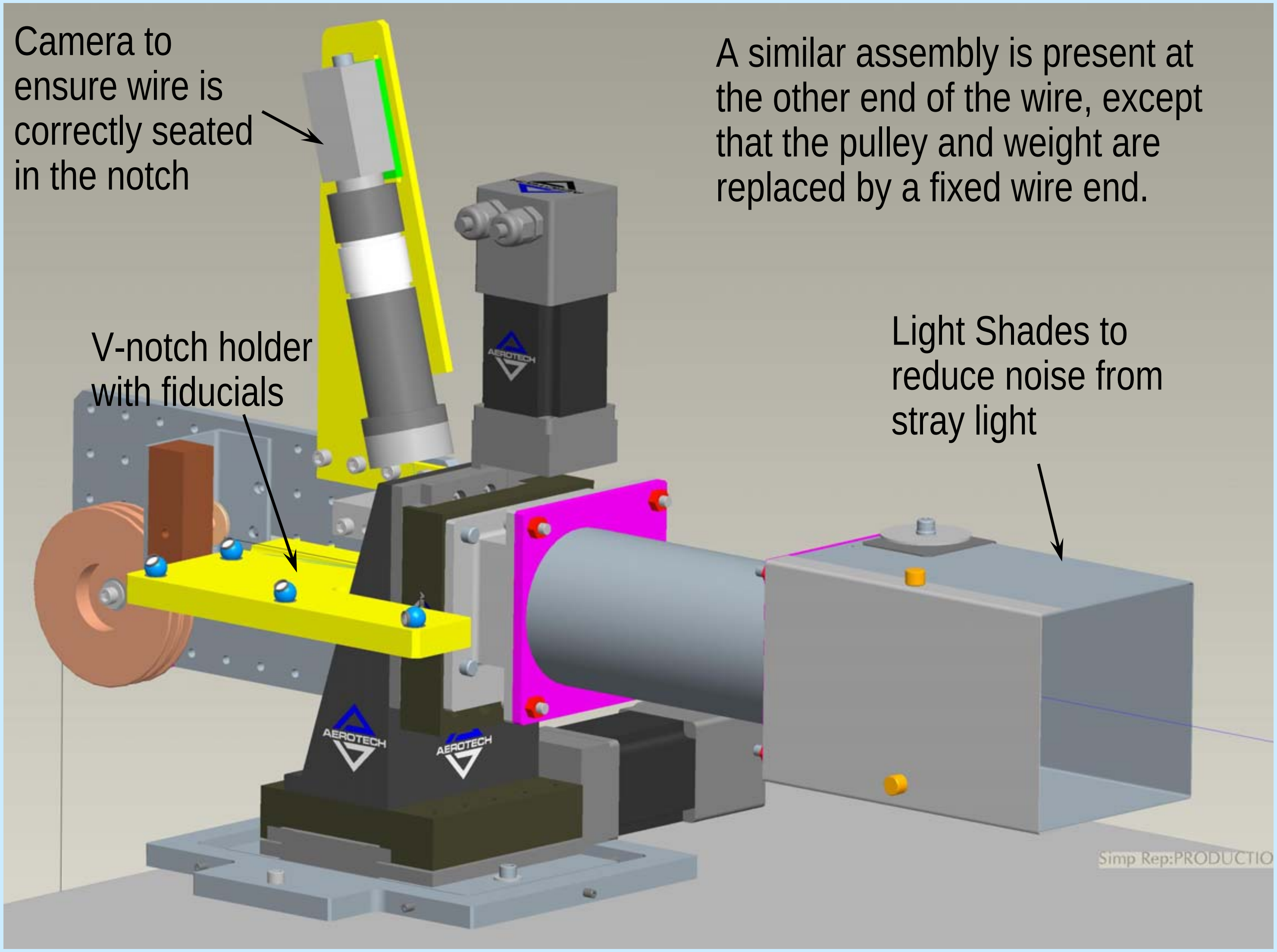


Fine, automated adjustment along measurement axis using piezo stages

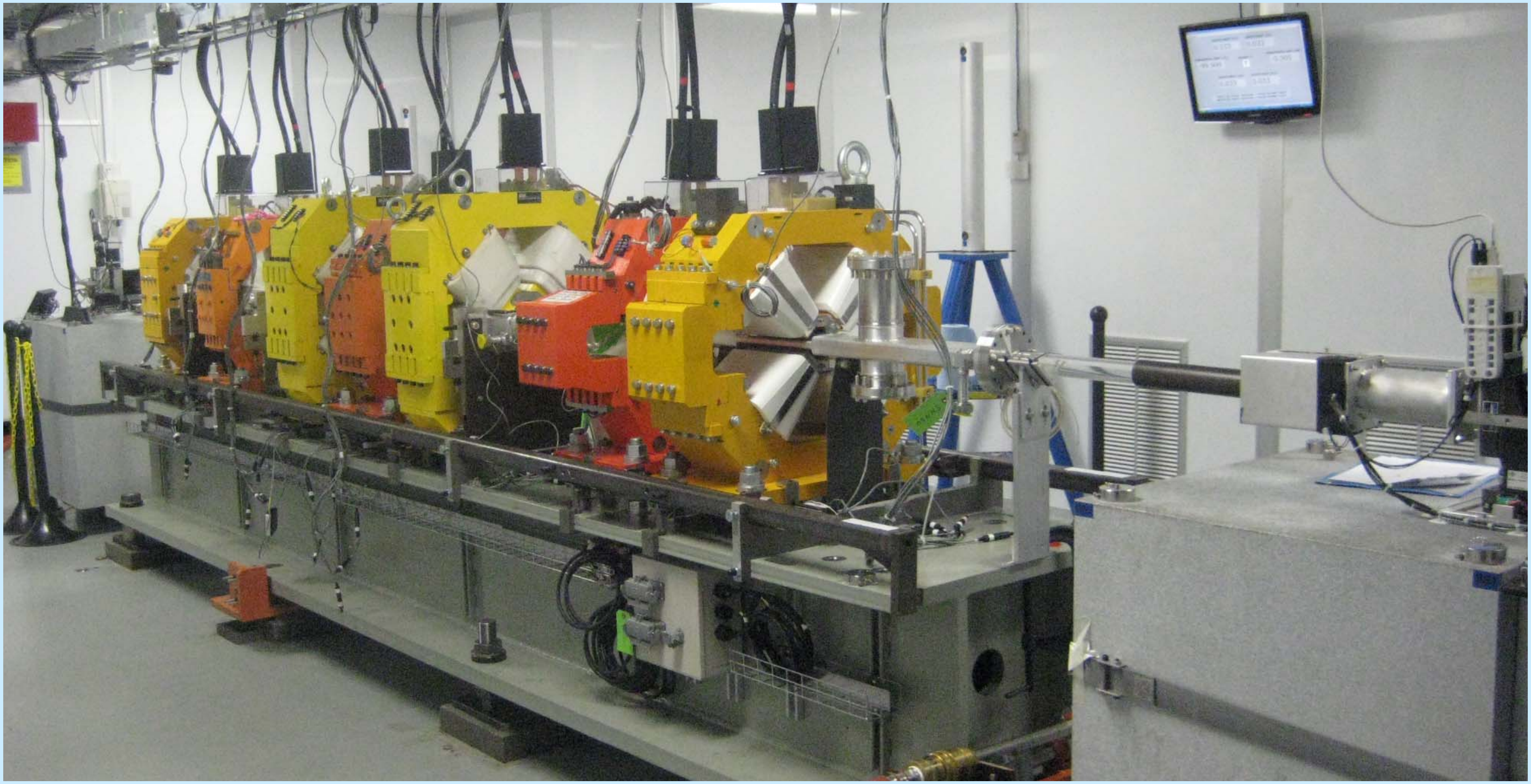
As the wire is moved horizontally or vertically, the position of the wire relative to the sensor changes slightly (~ a few microns) due to imperfections in the stage motion. This causes a change in the operating point of the sensor.

An automated piezo stage was added to keep the wire "centered" in the sensors during a scan.

Complete Wire Mover Assembly



A Girder Under Test



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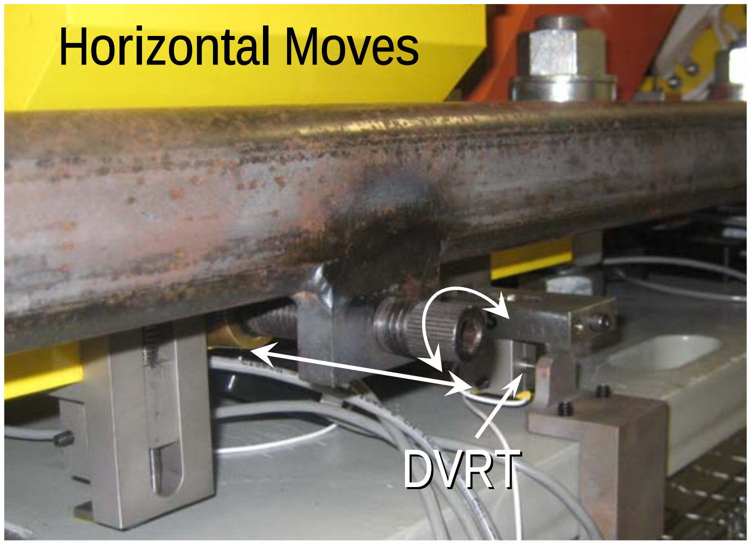
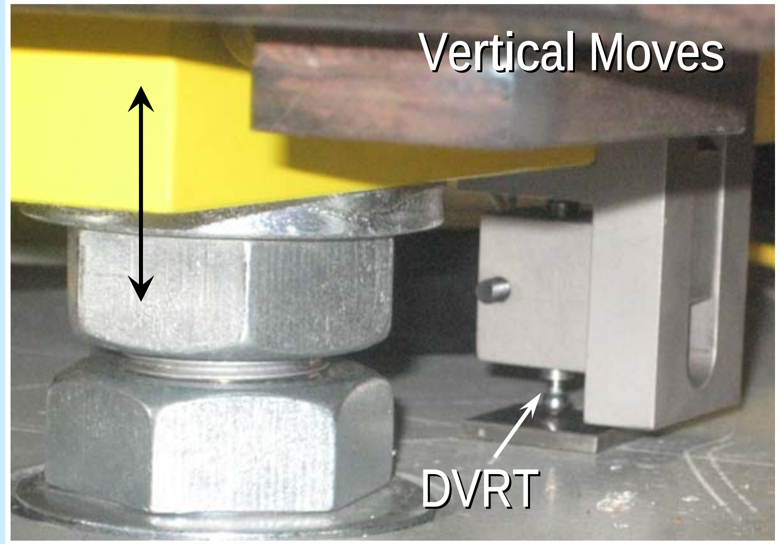
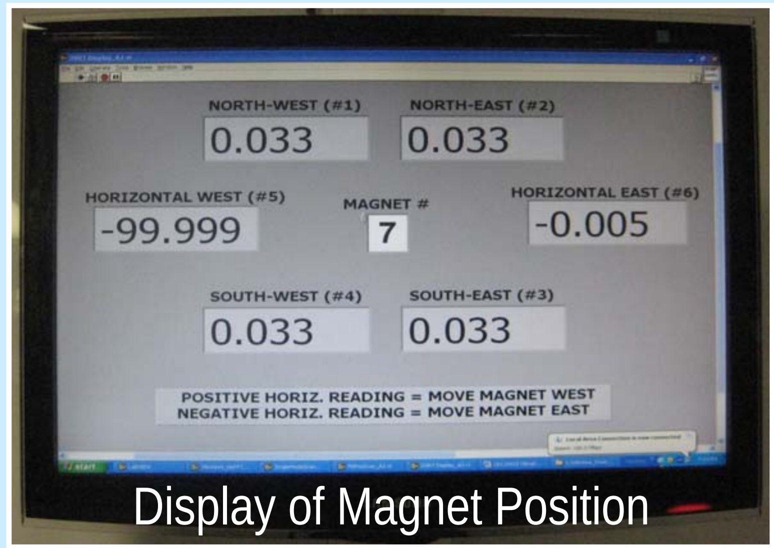
Moving Magnets to Desired Position

- Each magnet sits on a thick base plate, mounted to the girder using four bolts.
- A set of four vertical displacement sensors (DVRTs) is attached to the four corners of the base plate. These allow monitoring of the vertical position, and also help in controlling roll and pitch of the magnet.
- One horizontal displacement sensor is also mounted to the base plate. This does not allow monitoring of yaw. The yaw is maintained by yaw preventers present in a temporary fixture on the girder. (Ideally, sensor should be located at midplane.)
- The displacement sensors are initialized to the magnet position relative to the chosen "best-fit" line, based on vibrating wire measurements. The vertical and horizontal positions of one selected magnet at a time are displayed in real time on large monitor screens on the walls on both sides of the girder.
- Magnets are moved manually using mounting nuts for the vertical adjustment and a pair of adjustment screws in the temporary fixture for horizontal adjustment. *This has to be done in small torque increments and in small moves at a time*.

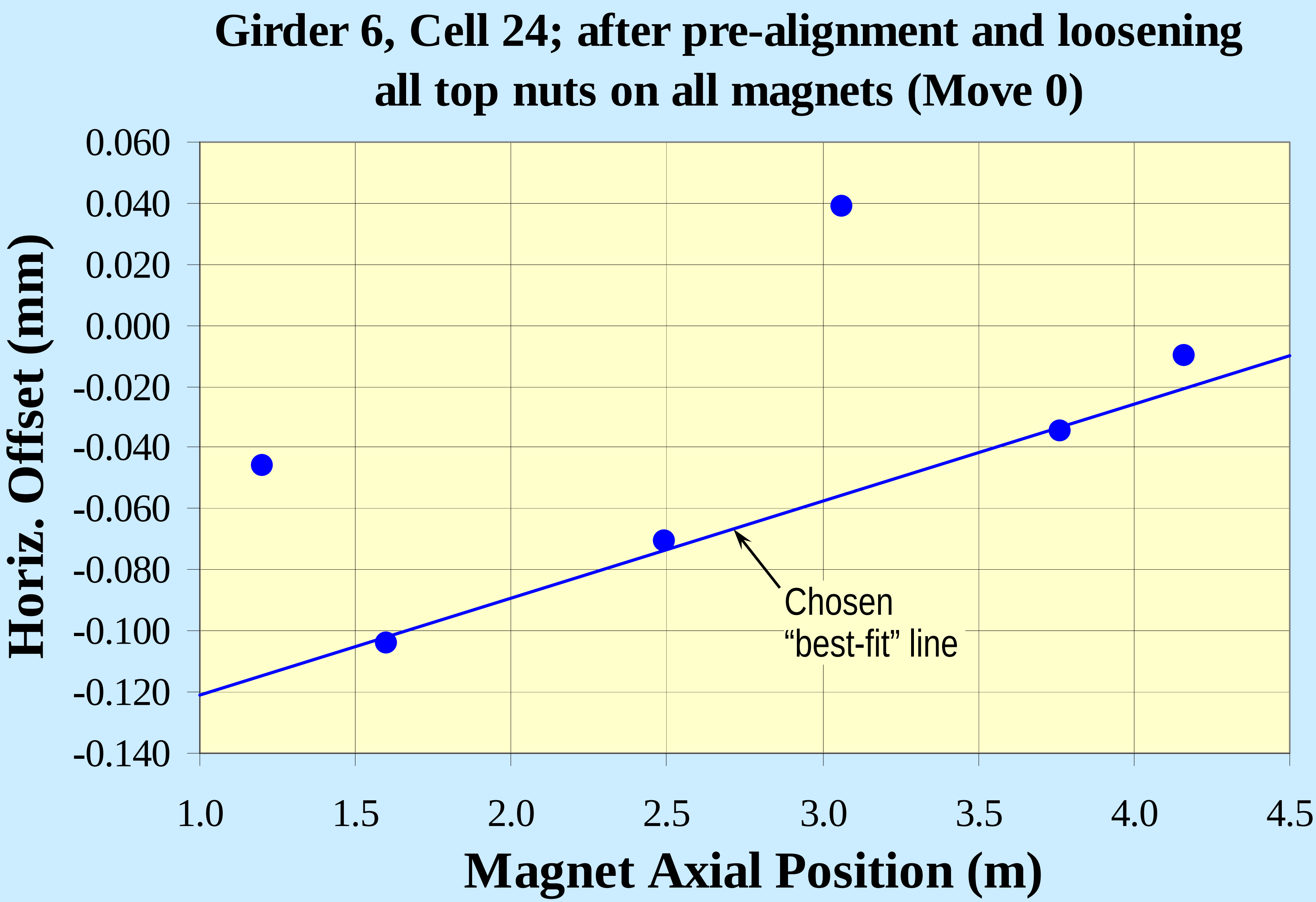
Adjusting Magnet Position



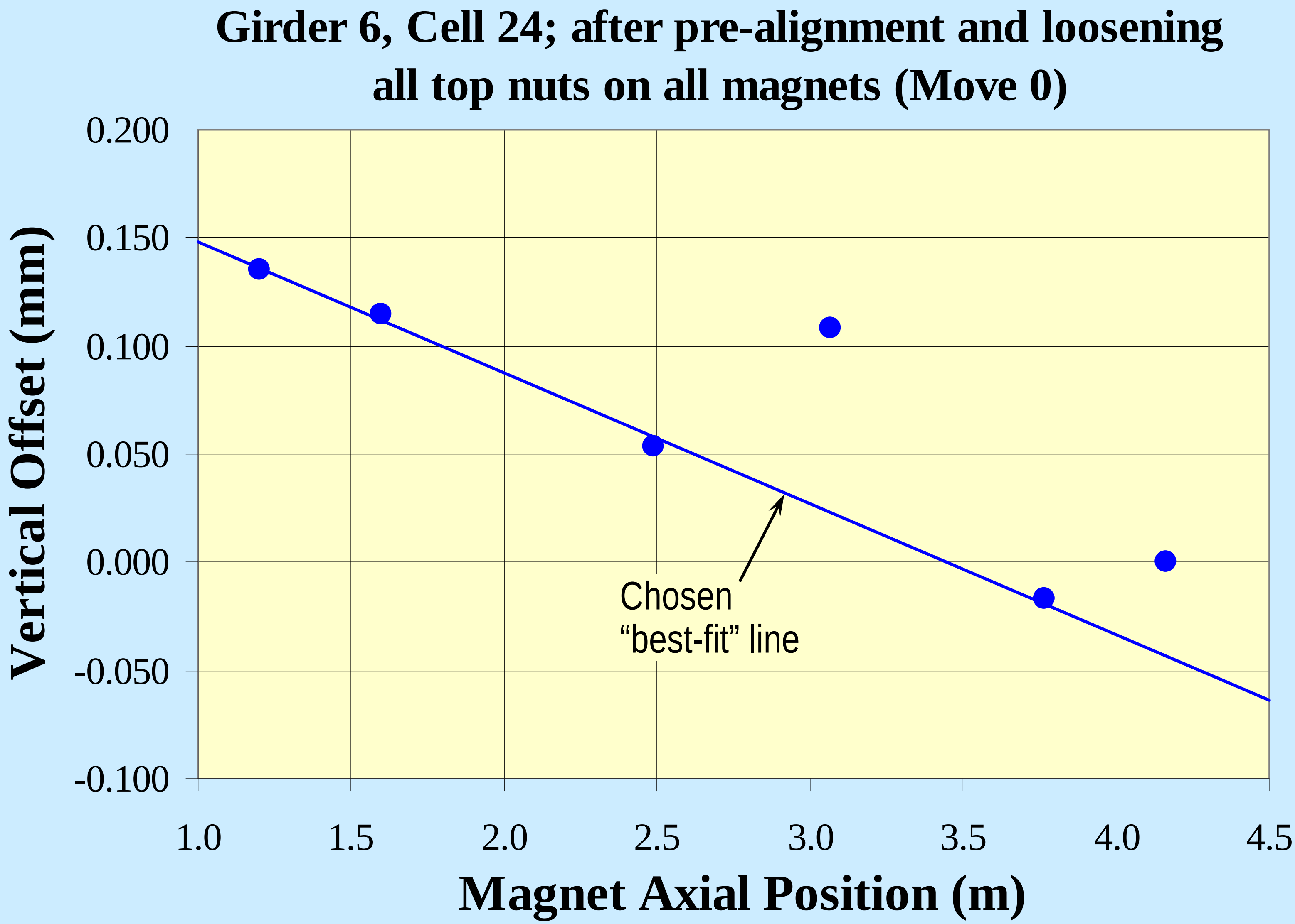




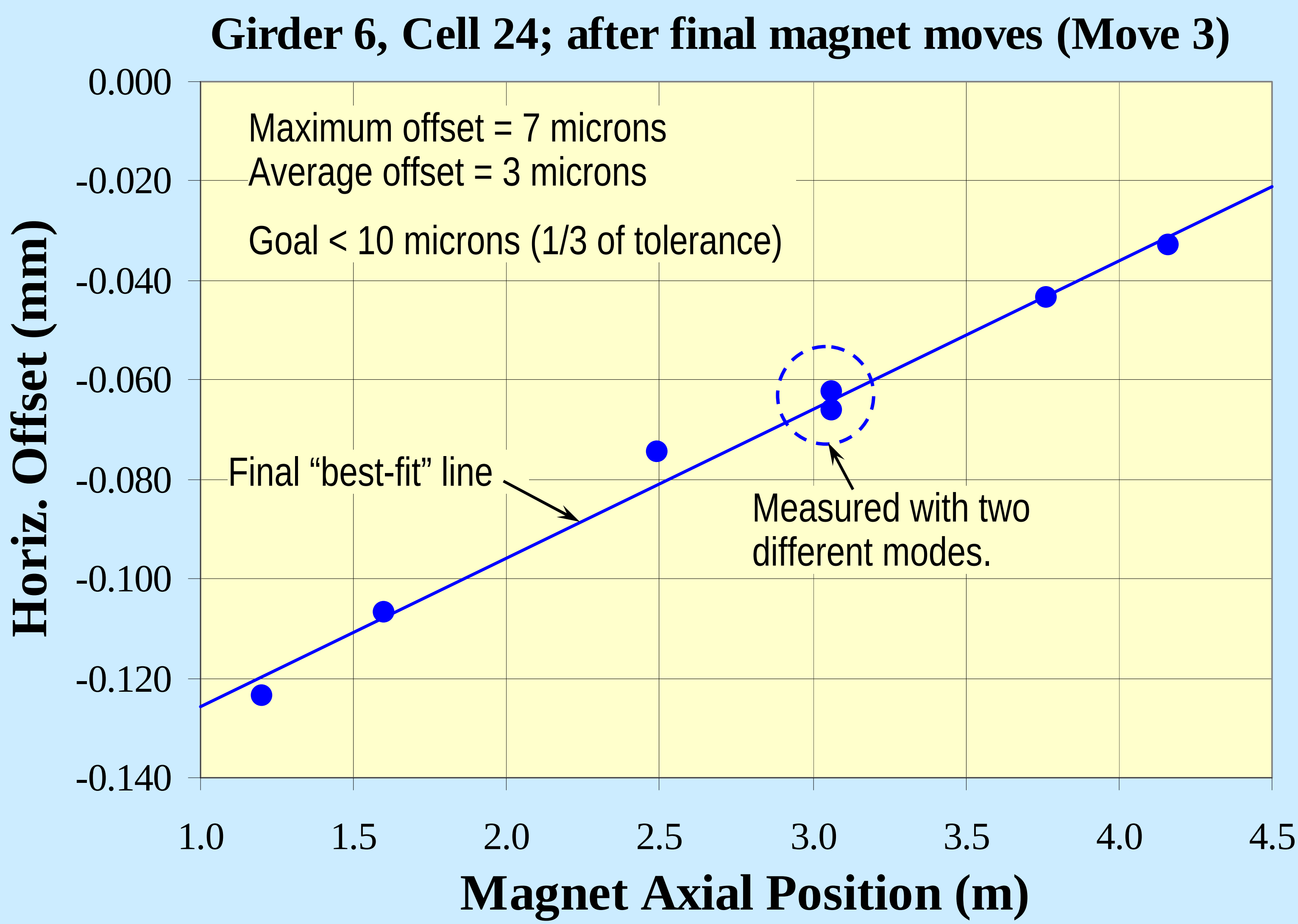
Alignment Example: Prealigned Girder



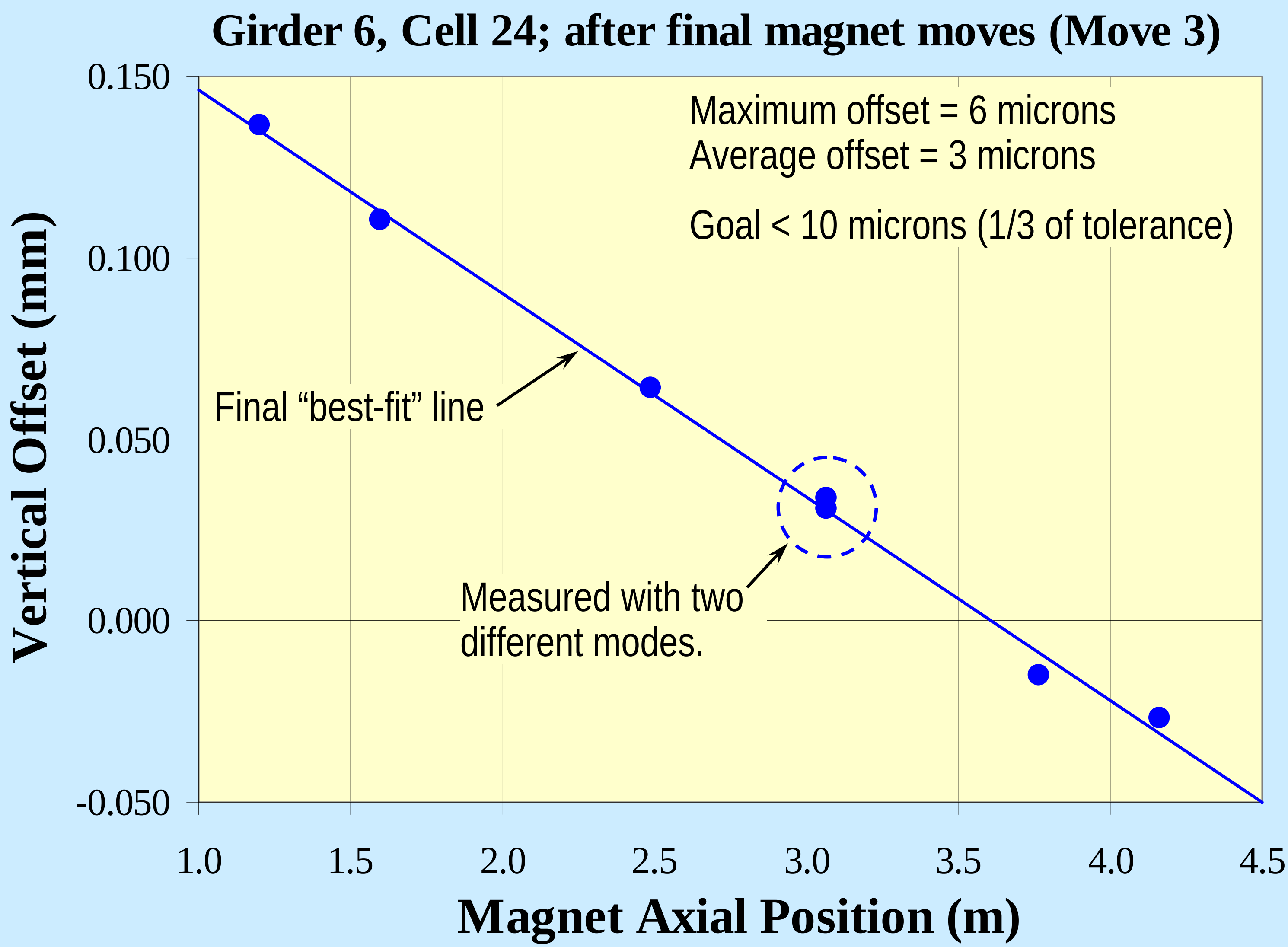
Alignment Example: Prealigned Girder



Alignment Example: Final Alignment



Alignment Example: Final Alignment



Difficulties Encountered

- So far, the alignment process has not been as smooth as expected.
- There are some measurement related issues:
  - Sometimes noisy data. Precise reason not known, but mostly at low fields.
  - Sensitivity of sextupole center to small errors in the data points.
  - Many more data points need to be taken to allow discarding of bad data, if needed, and still be left with enough data to get reliable center.
    (At present, 6 positions are measured for quads, 11 positions for sextupoles.)
  - Measurement time too long (~1.5 hrs per quad, ~2 hrs per sextupole).
- There are some issues with the magnet move process:
  - DVRTs are not always a reliable indicator of the magnet position due to their locations far away from the magnet midplane (sensitive to roll/yaw/pitch).
  - High torque of 270 N.m can potentially bend the base plate, causing DVRTs to change without a real change in the magnet position.
  - Typical accuracy of magnet move is ~10 microns, which is sufficient, but we often encounter surprises exceeding 20 microns, requiring multiple moves.

Summary & Status

- The alignment requirements for NSLS-II are challenging, and a state-of-the-art vibrating wire system is now in operation to meet this challenge.
- Two simultaneous measurements, and plenty of redundant data ensure the measured centers are accurate to < ±5 microns.
- Magnets are aligned on the test bench to better than 10 microns, allowing for girder profiling uncertainty, etc., in order to comfortably meet the final tolerance of 30 microns.
- The process of moving, and in particular, securing the magnets, is quite an art, and is still being perfected. Other measurement issues are also being worked on.
- We have completed alignment in four girders so far (out of 90).