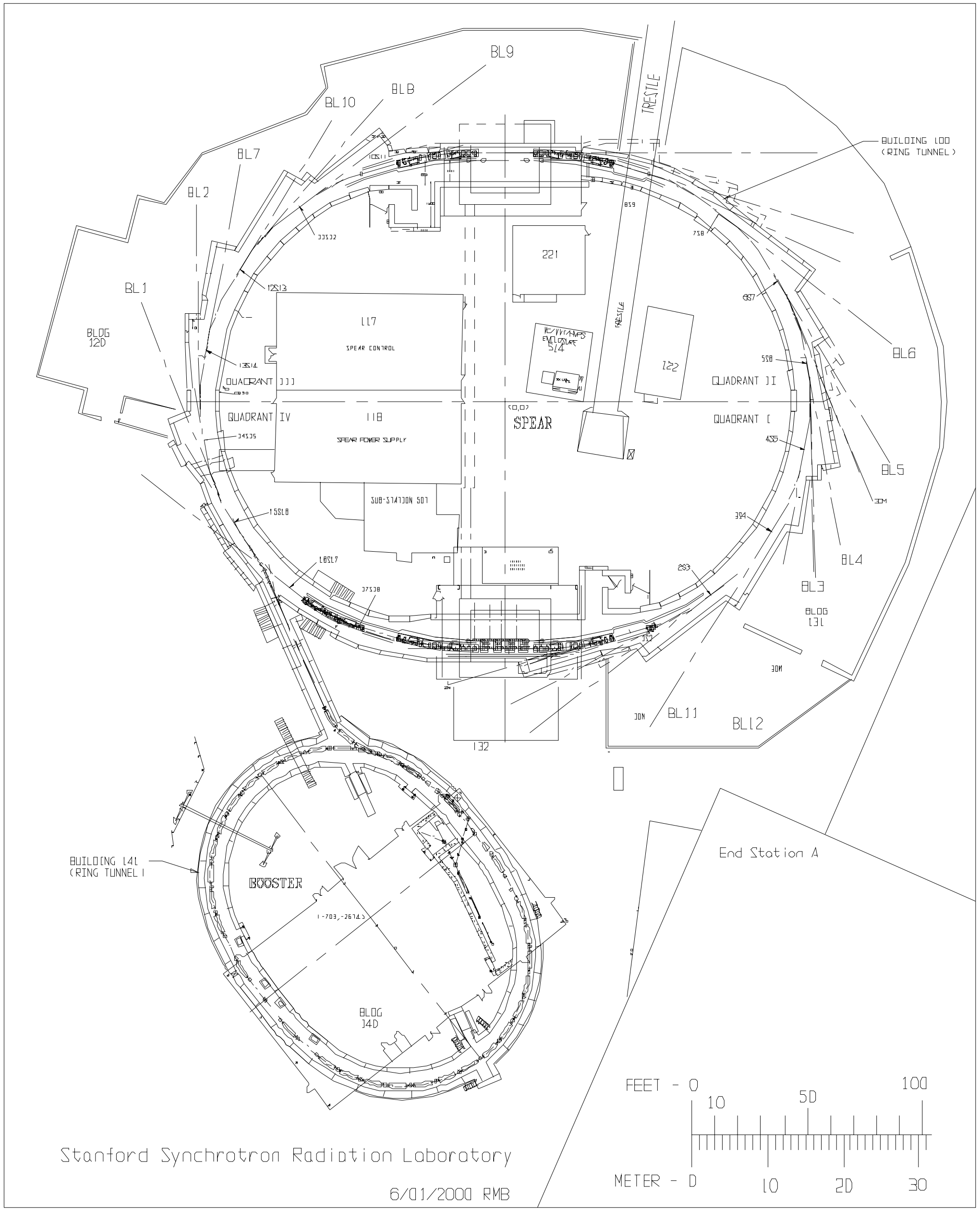
# SPEAR3 Magnets

Jack Tanabe, Nanyang Li, Ann Trautwein,
Domenico Dell'Orco, Dave Ernst,
Zach Wolf (SLAC Magnet Measurements),
Catherine L'Coq (SLAC Alignment),
Jeff Corbett, Bob Hettel (SPEAR3 Physics)
Institute of High Energy Physics
in Beijing, PRC (Magnet Manufacturing)

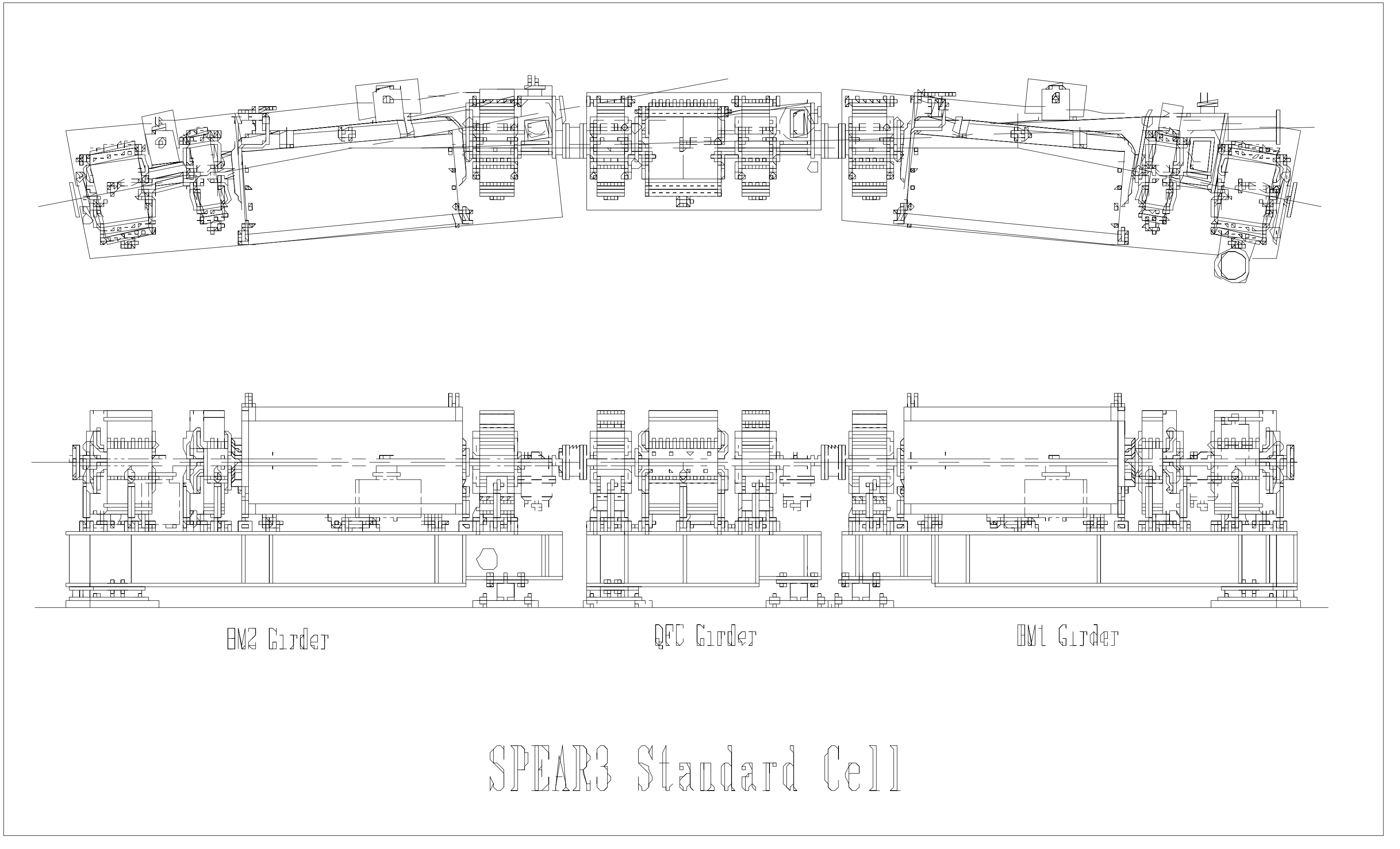
July 31, 2003

tanabe@slac.stanford.edu

# Lattice Overview



# Lattice Cell/Girder Assembly



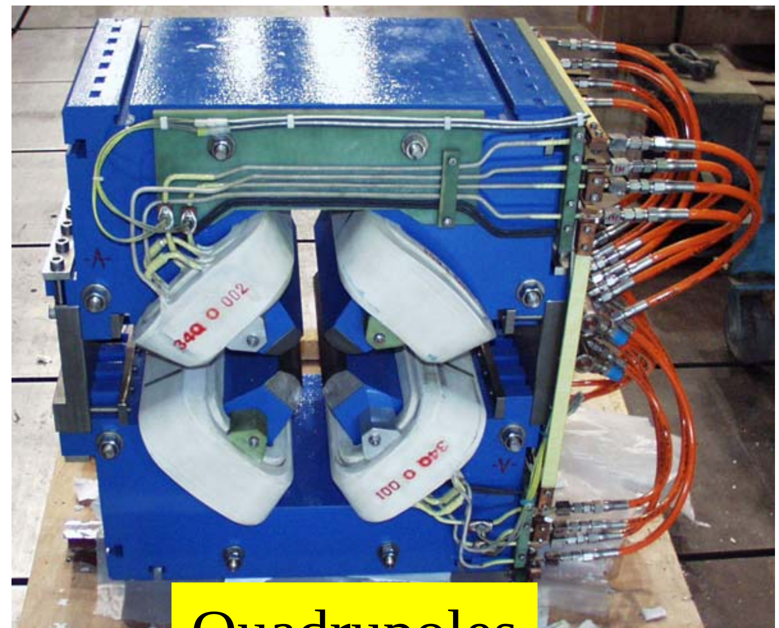
# SPEAR3 Lattice Magnet Elements

- Gradient Dipoles
  - 28 - 1.45 meter (nominal length) magnets
  - 8 – 1.0875 meter (nominal length) magnets
- Nine families of Quadrupoles - 94 Total Magnets
  - Nominal lengths – 0.15, 0.34, 0.50 and 0.60 meters
- Two Families of Sextupoles – 72 Total
  - Nominal Lengths – 0.21 and 0.25 meters
  - Includes Skew Quadrupole Corrector Trim Coils
- Correctors (Horizontal and Vertical Steering) – 72 Total

- The operating electrical and hydraulic parameters are for 3.0 GeV Operation. The magnet design parameters assume future upgrade to 3.3 GeV.
- Gradient Dipole
    - Constant field – 1.48 Tesla at magnet *center*
    - Gradient – 3.63 T/m
- Quadrupoles 22 T/m
- Sextupoles 440 and 550 $T/m^2$
- Correctors – 1.5 mrad horizontal and 0.75 mrad vertical steering

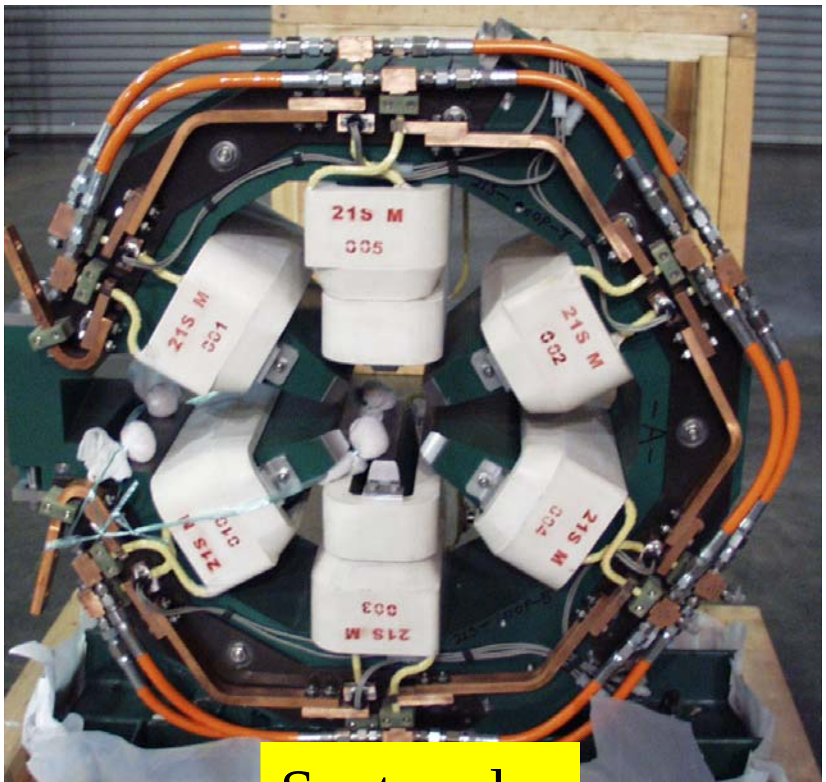
# Magnet Types

Gradient Dipoles




Quadrupoles

# Magnet Types




Sextupoles

Correctors

# Magnet Requirements

- Field Quality $\Delta BL_{eff}/BL_{eff} \leq$ 5e-4 in the good field region (10 $\sigma$ beam aperture)
- Magnet to Magnet Reproducibility
  - $\sigma$ for population approximately 1e-3.
- Alignment
  - $\Delta x$ and $\Delta y \leq$ 250 $\mu$m.
  - $\Delta z \leq$ 500 $\mu$m.
  - $\Delta$ pitch roll and yaw $\leq$ 500 $\mu$radian.

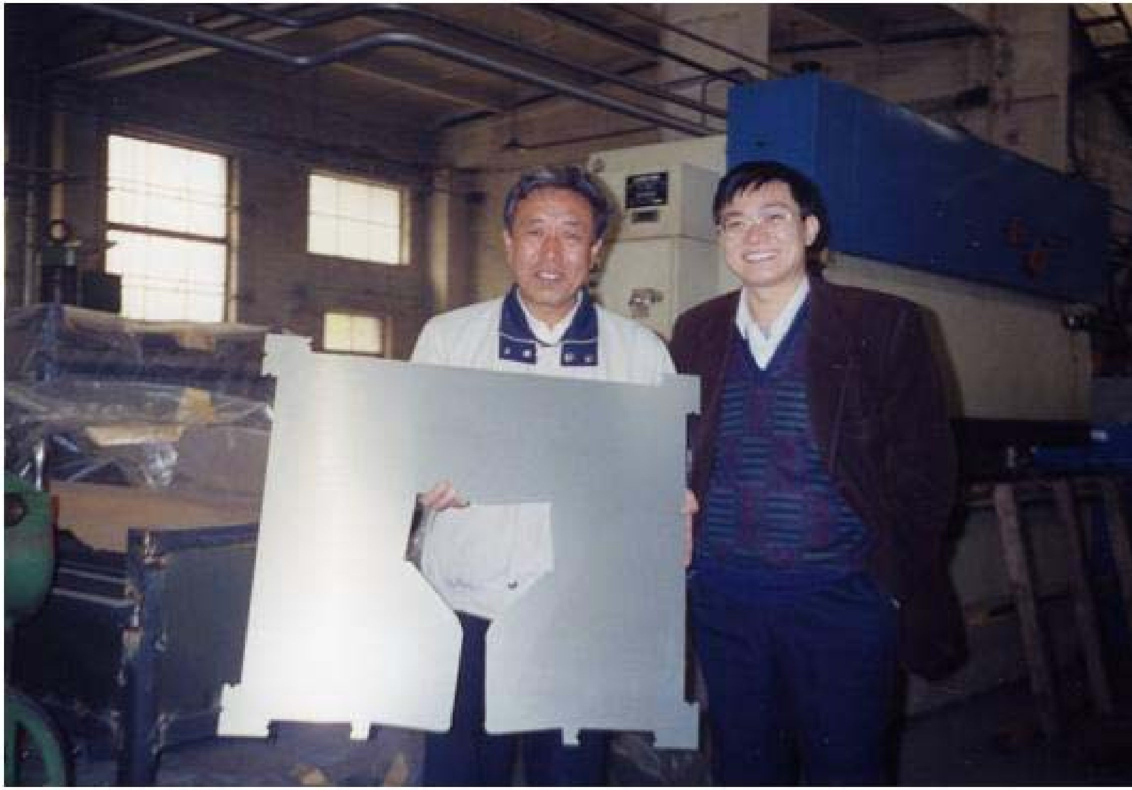
# Magnet Design Process

- *Conceptual* Design of the Magnets are based on scaling and conformal mapping of magnet designs originally developed for the ALS. (Gradient Magnets and Quadrupoles)
- *Engineering* Designs Developed by SPEAR3 Engineers to satisfy performance requirements and match SLAC water and power supply constraints.
- Mechanical Design *Layouts* Developed by SPEAR3 Engineers/Designers.
- Mechanical Design *Detail* and *Assembly Drawings* Developed from SPEAR3 Layouts by IHEP Engineers and Designers visiting SLAC.

# Magnet Manufacturing Process

- A collaboration was set up between IHEP in the PRC to manufacture the magnets for SPEAR3. This collaboration was a continuation of a collaboration among IHEP and SLAC for the manufacture of the PEPII LER magnets.
- Lamination stamping die sets were designed and fabricated by IHEP. Sample laminations were sent to SLAC for inspection and approval prior to stamping production quantities for each of the magnet types.

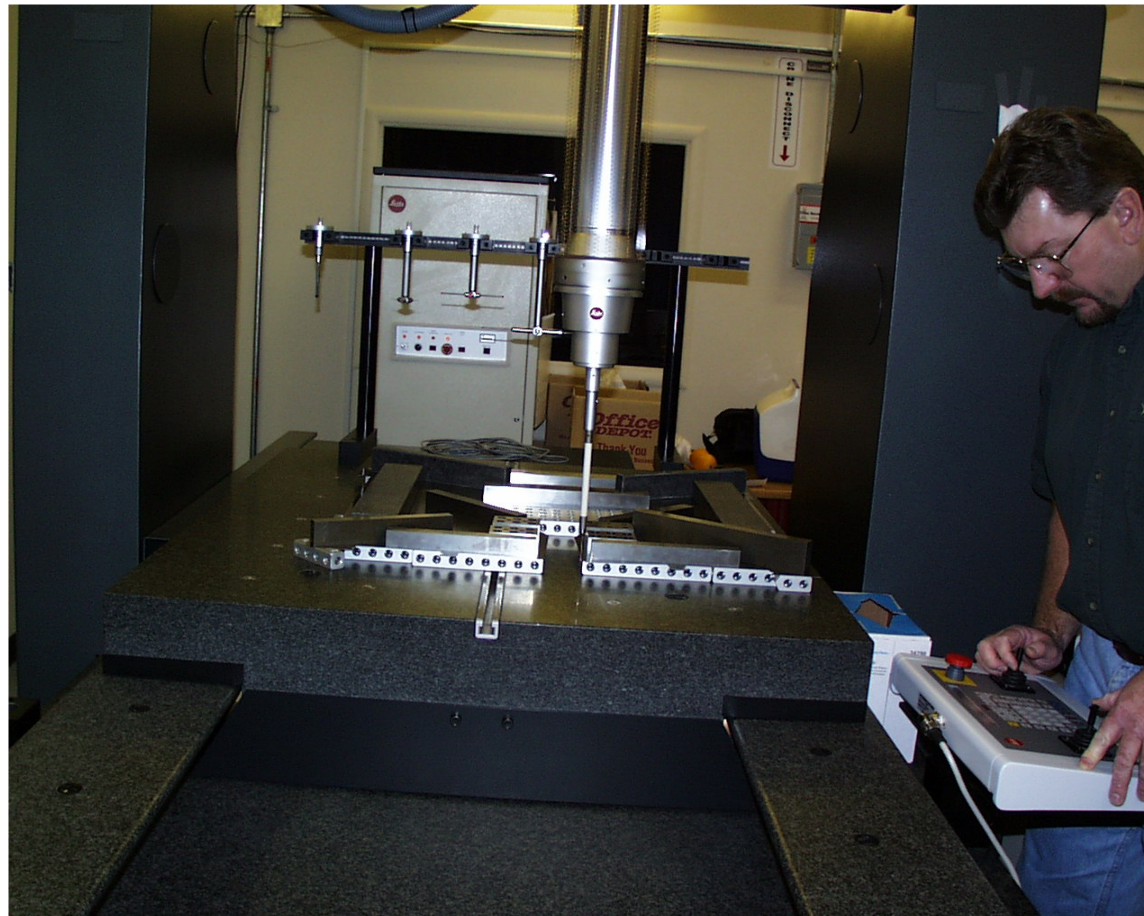
- Scanned photos of the magnet manufacturing process are available on the SPEAR Website
- /~nli



Dipole Lamination

# Lamination Inspection

- Three sample laminations were received from IHEP in February, 2000 to be measured using the Coordinate Measuring Machine.



# Prototype Development

- Prototypes of each magnet type were built.
  - Preliminary magnetic measurements were performed on the prototype magnets at IHEP. The end chamfers of the prototype magnets were empirically shaped in order to assure three dimensional field quality. Measurements of the final chamfered magnets were made. These measurements were repeated at SLAC and evaluated. Evaluation consisted of comparing the IHEP measurements with the SLAC measurements and determining whether or not field quality specifications were met. On acceptance of the field quality measurements, production of the full quantity of magnets was approved.

# Production Component Manufacturing

- Cores
  - In order to ensure repeatability and symmetry of magnet iron properties among all magnets and their segments, the laminations were sorted in stacks for each individual magnet core segment.  For the two piece quadrupole and the 3 piece sextupoles, the number of separate stacks was the product of the number of manufactured magnets times the number of segments for each magnet.
- Coils
  - Each coil was wound and vacuum impregnated.  The finished coils were high voltage tested and impulse tested to ensure the absence of turn to turn or intermittent shorts. Water flow and resistance measurements were performed and recorded for each coil.

# Production Assembly and Testing at IHEP

- After magnet assembly, electrical and hydraulic tests and measurements were performed for each magnet. Measurement results were recorded in *travellers* accompanying each completed magnet.
- Each production magnet was magnetically measured at IHEP and the results recorded on disks sent to SLAC.  A website is being developed to archive the results of these measurements.
  - Dipoles
    - Transverse uniformity of the field was measured with a compensated translated coil.
  - Quadrupoles and Sextupoles
    - Rotating coils measured the excitation, multipole content and the offset of the magnetic center with respect to the mechanical center for each magnet.

# SLAC Magnetic Measurements

- 100% of all gradient dipoles were measured at SLAC.
  - Gradient magnet measurements were integrated with the alignment and fiducialization of these magnets.
- Approximately 15 to 20% of all quadrupoles and sextupoles were measured at SLAC.
- Less than 10% of the corrector magnets were measured at SLAC.
  - Measurements of the quadrupole, sextupoles and correctors were meant to verify the IHEP data. Also, SLAC measurements included using wire (absolute) measurements to calibrate the rotating coils for the measurement of the magnet excitation.

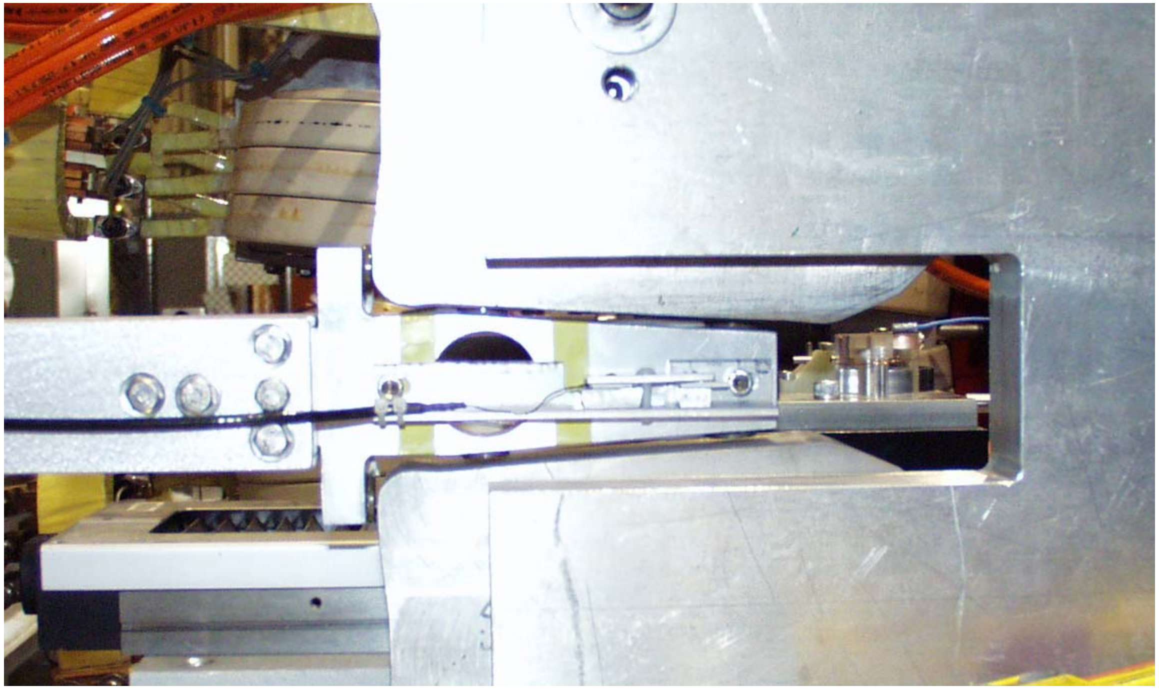
# SLAC Gradient Magnet Measurements

- The photograph shows the capacitive probe system developed by Zach Wolf, leader of the SLAC Magnetic Measurement Group.

# Capacitive Probes and *Garage*

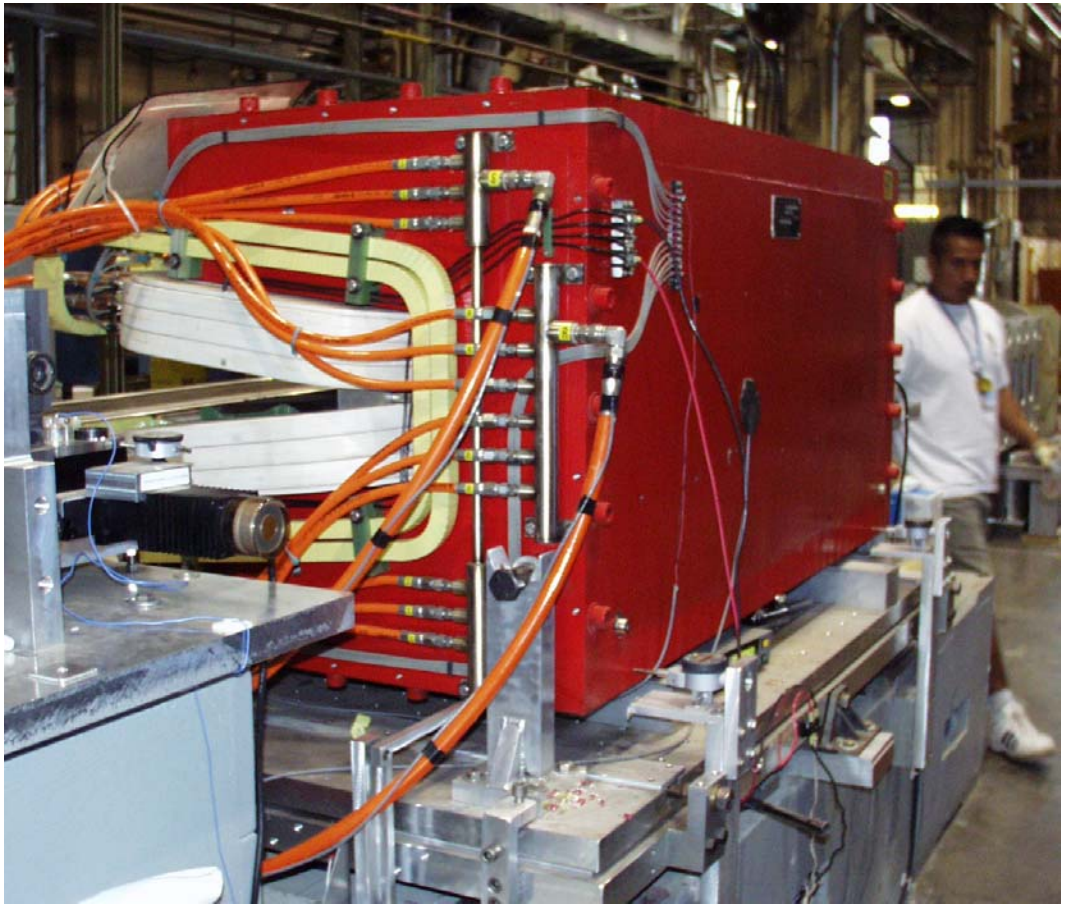
- The photo shows the capacitive probes and the reference *garage* for the mechanical measurement of the alignment of the magnet gap.

The signals from the probes are compared with the signals in the garage to measure the transverse and vertical displacement and the roll of the magnet gap at any one longitudinal location.



# Magnet Alignment to the Reference Axis Established by the *Garages*

- The probe is moved longitudinally to measure the z distribution of the displacements and roll. From these measurements, the average displacements as well as the rotations (pitch, roll and yaw) of the magnet can be established. The magnets are moved until the magnet axis is aligned along the reference axis.



# Gradient Magnet Fiducialization

- Once the magnet is aligned along the axis established by the measurement system, the locations of the six fiducial balls are measured with a laser tracker. The coordinates of these balls with respect to the magnet coordinate axes are computed. These data are archived in a website set up and maintained by the SLAC Alignment Group.

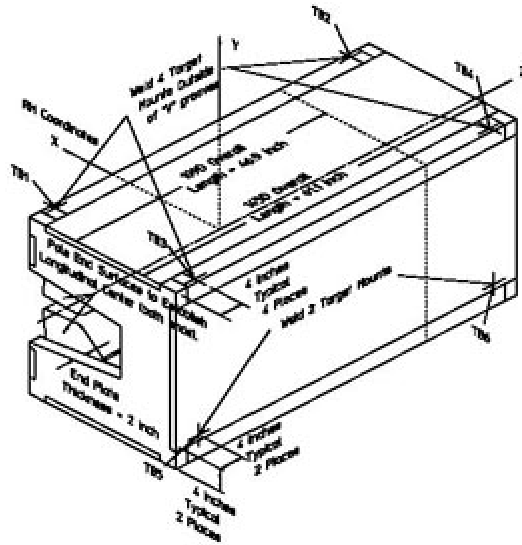
| Gradient Dipole Magnet Checks | 145D04 |
|---|---|

Date: 5/15/01

Magnet: 145D04

Operators: J. McDougal, H. Imfeld

Notes:




**Magnetic Fiducial Coordinates: (inches)**

| Fiducial | Z | X | Y |
|---|---|---|---|
| TB1 | -26.5554 | 3.4277 | 16.9994 |
| TB2 | 26.5063 | 3.4346 | 17.0043 |
| TB3 | -26.5646 | -22.4094 | 16.9971 |
| TB4 | 26.5328 | -22.4154 | 16.9963 |
| TB5 | -26.4866 | -24.2482 | -11.7594 |
| TB6 | 26.4978 | -24.2669 | -11.6356 |

Offset: 0.0034 inches

***Description:***

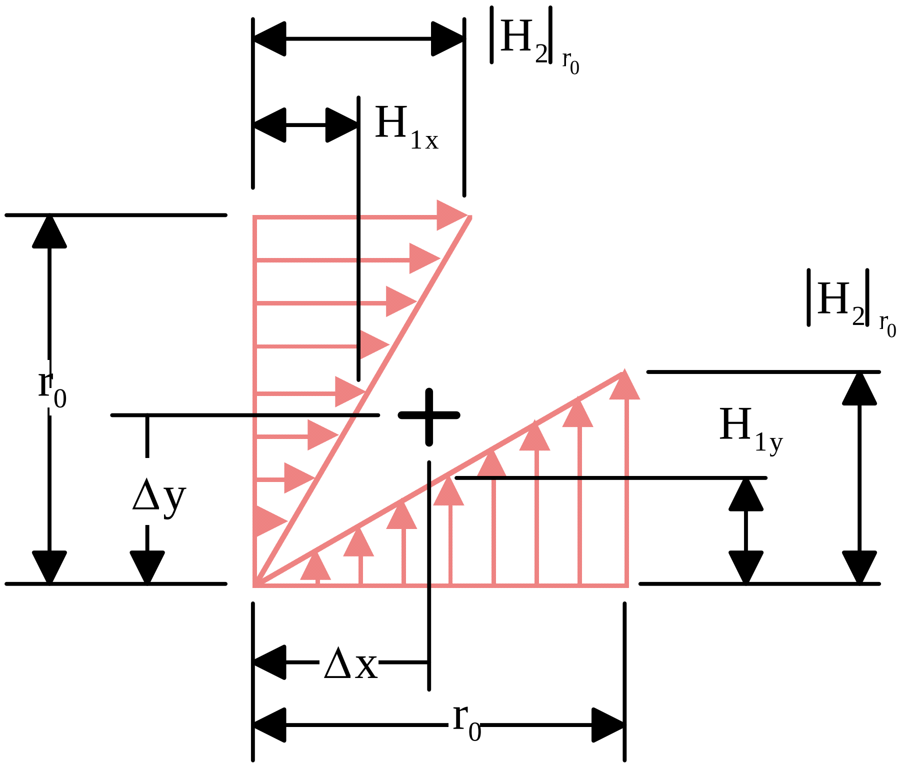
*Fiducial values based on the x-offset of the mechanical center line to the magnetic.*

# Alignment Tolerances

- Alignment tolerances are set by modeling the lattice on a computer to determine the distribution of the beam envelope around the perimeter of the ring.
- The gradient magnet operating field and gradient are approximately 1.2 T and 3.3 T/m. Therefore, a 1 mm error in the transverse or vertical alignment of this magnet will cause an error of 0.0033 Tesla, which is about 0.28% of the central field. This error will cause a 0.28% error in the bend angle in this magnet. Therefore, the fiducialization process which provides the datum for the alignment of the magnet must be done very carefully.

# Quadrupole Alignment

- The field distribution in a quadrupole magnet is illustrated in the figure.
- Assume the magnet is aligned along the "X". (That is the beam travels along an orbit through the "X" point.) Then, the field that it sees is a dipole field plus the quadrupole field. Therefore, the beam will experience *both* steering and focusing.

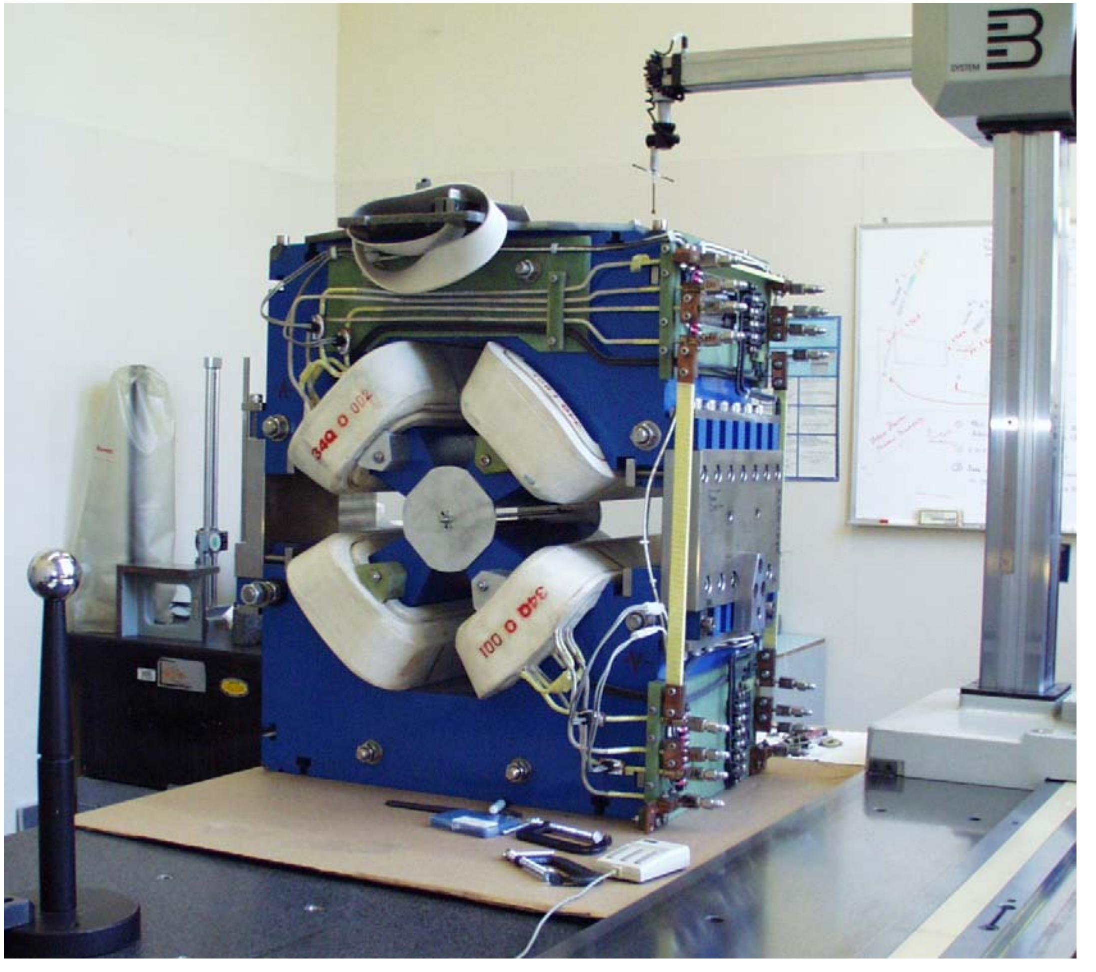


# Beam Based Alignment

- Each quadrupole is supplied with modulation coils. These coils are designed to provide a Δfield. Thus, if a particular quadrupole is slightly misaligned, the field can be modulated (probably at some frequency). The output of beam position electrodes are then monitored for signals at the same frequency. If these signals are detected, the beam is not going through the center of the magnet and the magnet is misaligned.
- Rather than realigning the magnet, corrector magnets upstream from the misaligned magnet are used to steer the beam through the magnetic center of the misaligned quadrupole.

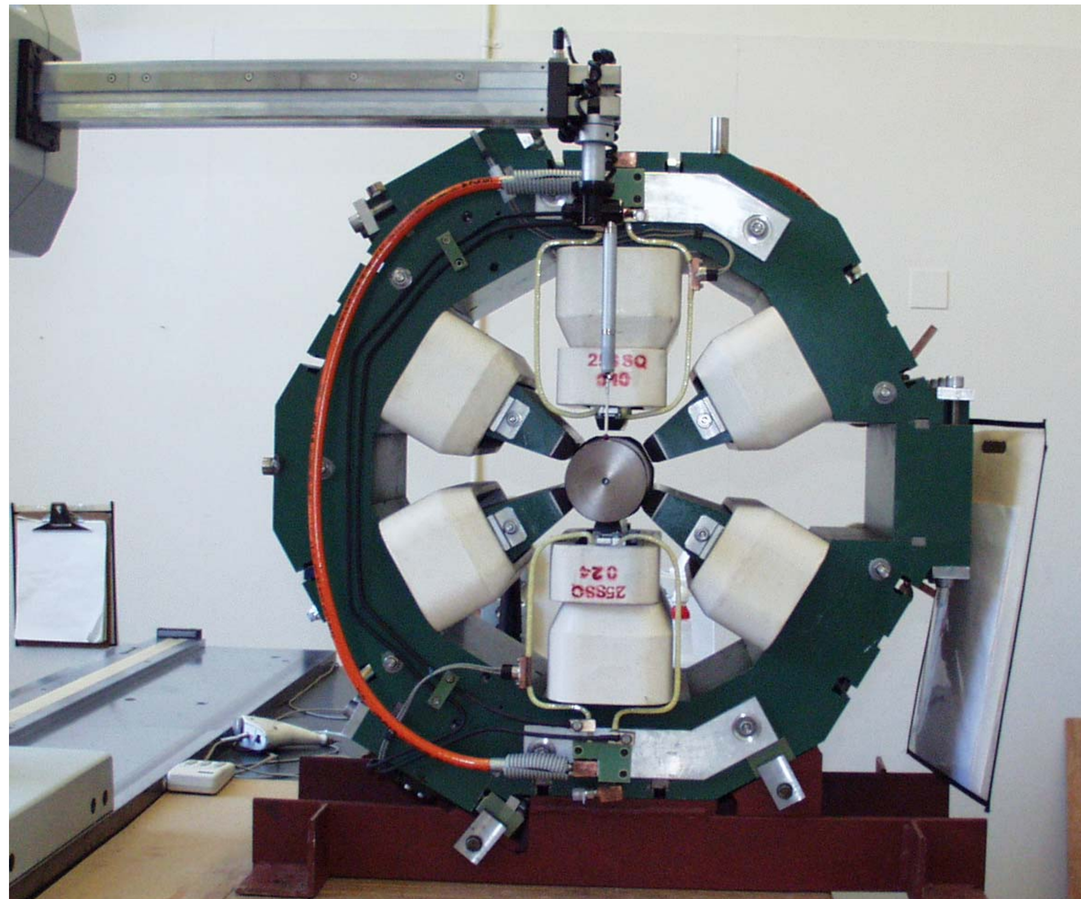
# Quadrupole Fiducialization

- The 15 and 34 cm long quadrupoles were measured on the SLAC CMM.  The 50 and 60 cm long quadrupoles are too large and heavy for the CMM.  Therefore, fiducialization of these magnets used the laser tracker system.



# Sextupole Alignment

- The sextupole field distribution is parabolic.
- Misalignment
  - Introduces both a dipole and quadrupole field.
  - Therefore, misalignment results in both steering and focusing errors.

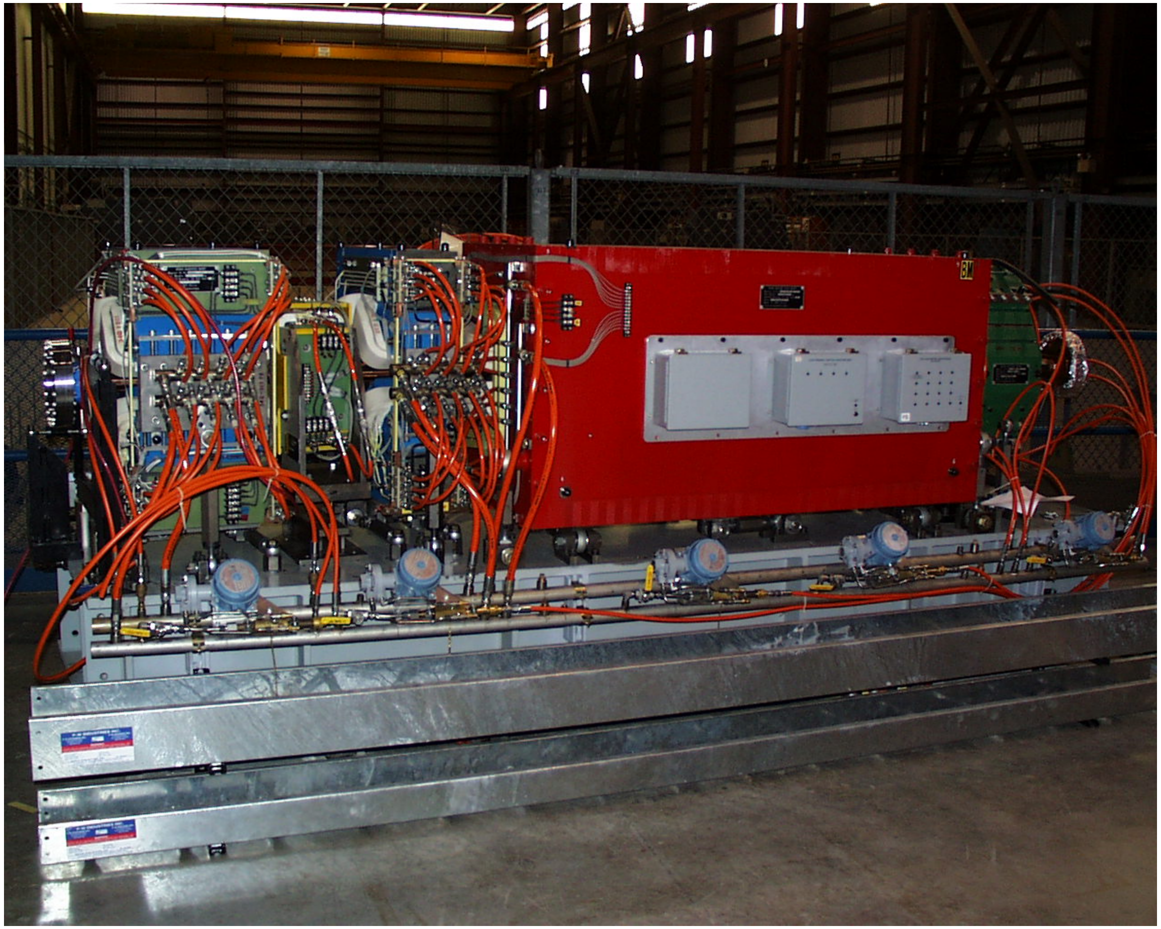


# Raft Fabrication

- Each one of the rafts on which the magnets are assembled were manufactured by outside contractors.
- A precision template was manufactured in order to inspect the precision of the holes drilled on top for magnet and chamber supports.

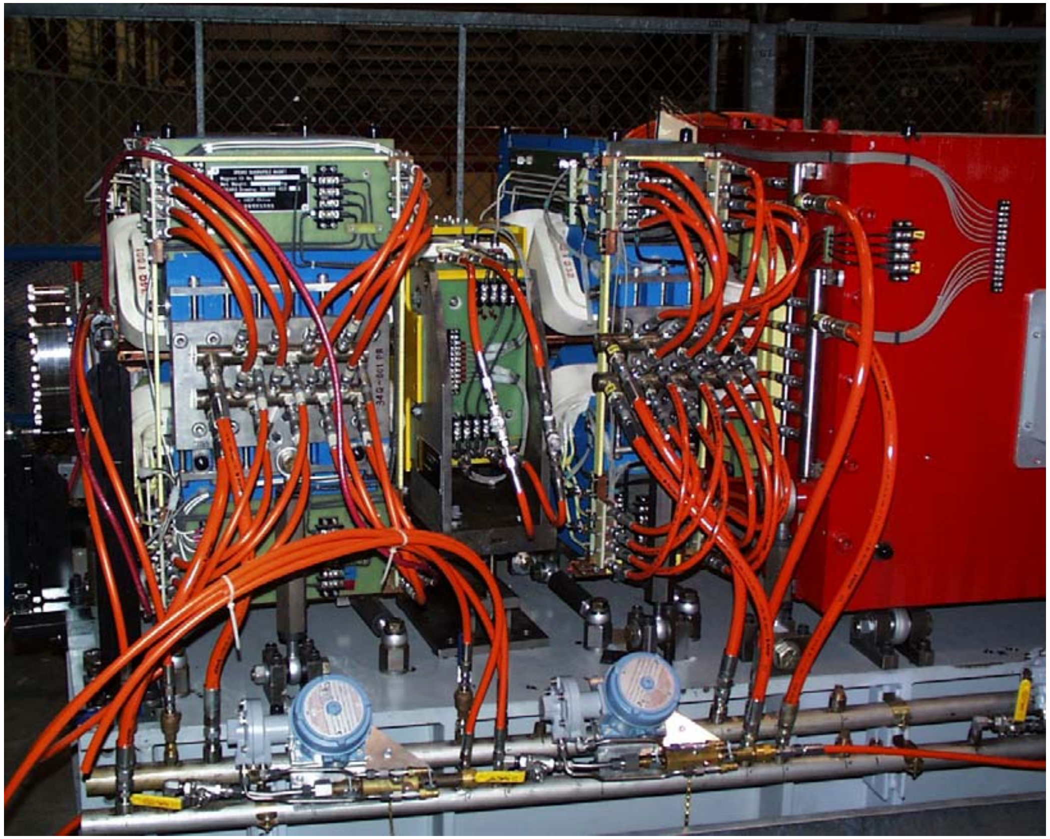
# Raft Assembly

- The magnets and vacuum chambers are mounted onto the completed raft and aligned using a laser tracker system.
- Shown here is the first raft in the standard  cell.



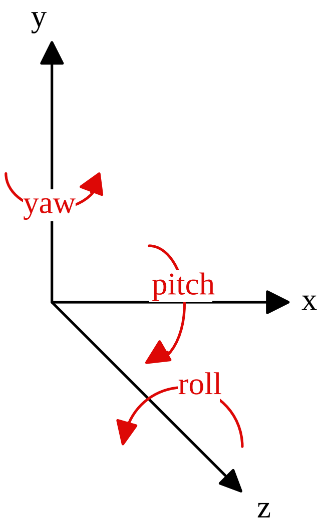
# Magnet Alignment

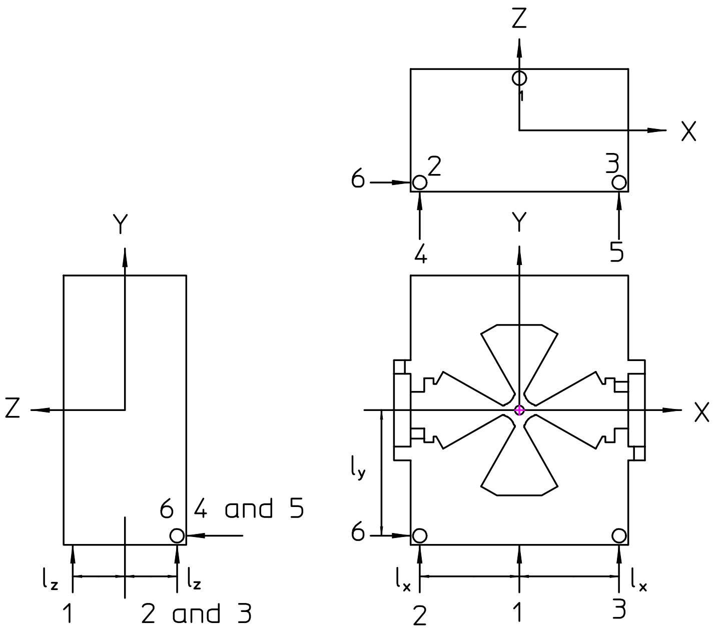
- Each magnet is supported using a kinematic six strut system -
  - 3 vertical
  - 2 transverse
  - 1 longitudinal
- The number of struts corresponds to the six degrees of freedom –
  - x, y, z,
  - pitch, roll and yaw.



# Six Struts

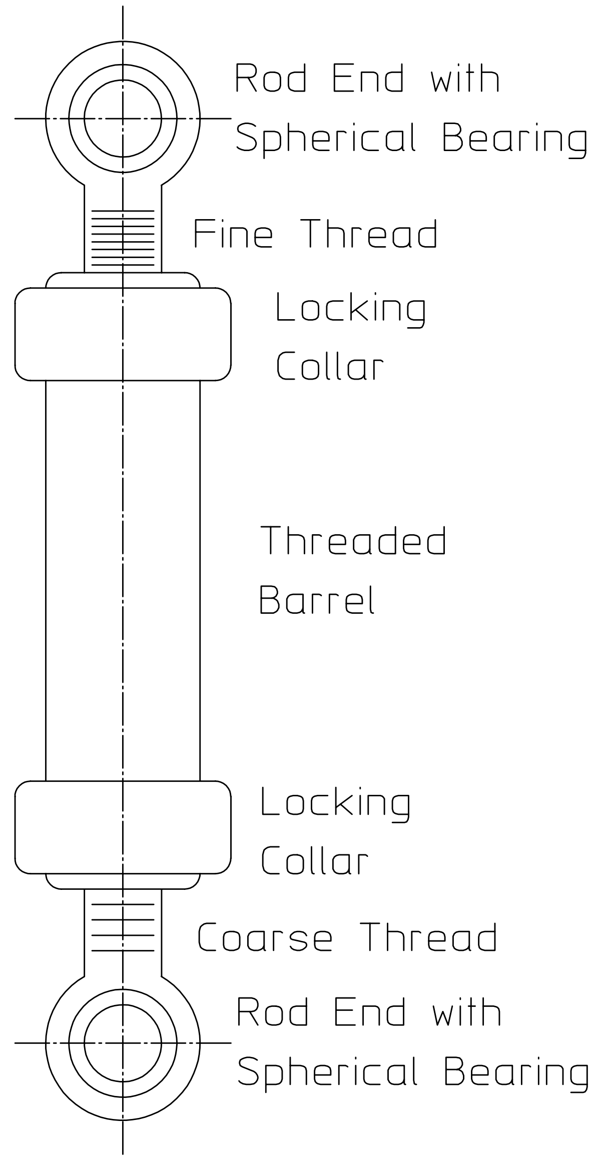
- The figures illustrate the six degrees of freedom and the location of the six struts (slightly different SPEAR3 system.)
- Vertical struts at 1, 2 and 3 provide vertical motion.  A combination of 4 and 5 controls roll.  A combination of 1 and the average of 2 and 3 controls pitch.
- Struts 4 and 5 provide longitudinal motion.  The difference of 4 and 5 controls yaw.
- Strut 6 provides transverse motion.



# The Strut

- Each strut consists of a barrel, two rod ends and two locking collars. The rod ends are both right hand thread, but one is fine and the other is coarse. Therefore, each rotation of the barrel provides an adjustment equal to the *difference* in the pitches of the two threads.



# Magnet Measurements and Archiving

- The magnetic measurements consist of field quality measurements, excitation and offset of the magnetic center with respect to the mechanical center.
- IHEP measurements include measurement results from 100% of all magnets.
- SLAC measurements include measurement results from 15 – 20% of all quadrupoles and 100% of all gradient magnets.
- The IHEP measurements are available on a SPEAR website.
- Fiducialization Data are available from a SLAC website.
- Summaries of IHEP measurements and SLAC measurements *will be* available on a SPEAR website. This process is continuing.
  - Presently, the summaries can be obtained by accessing the public folder on the Q drive under STAFF/Tanabe/DropBox.