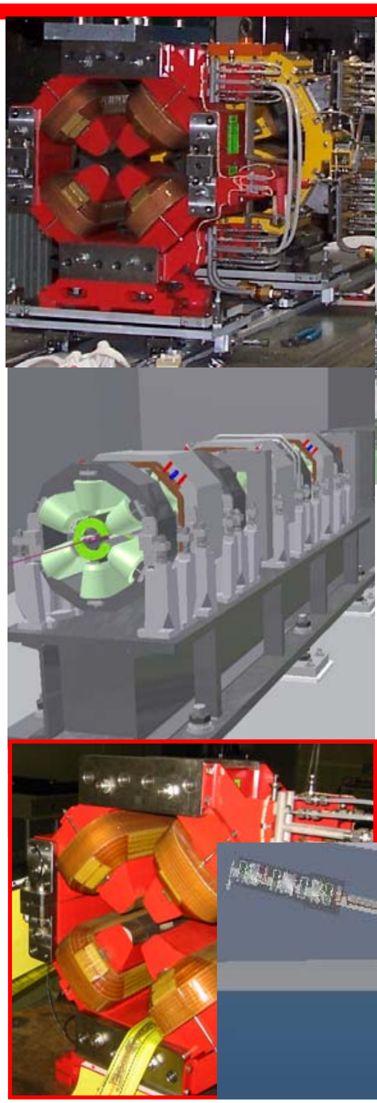
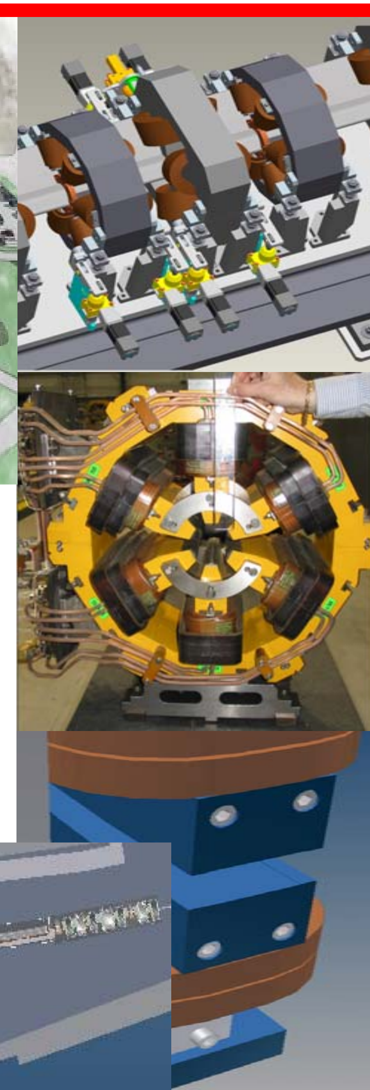
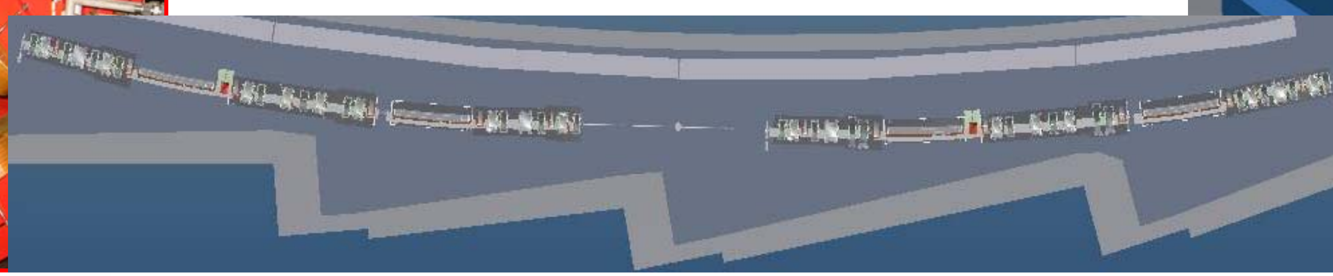
Review of the NSLS II Lattice Magnets
October 8th, 2007





Report to the NSLS-II Accelerator Systems Advisory Committee

John Skaritka for the NSLS-II magnet team



Acknowledgements

The Author wishes to thank the members of the of the NSLS II magnet team for their hard work, dedication, contributions, and helpful advice in the preparation of this document.

A. Gupta, M. Anerella, S. Plate, M. Rehak, P. Wanderer, P. Decker,

S. Sharma , A. Jain, J. Jackson, W. Meng, G. Danby, G. Mahler, G. Ganetis,

F. Willeke, S. Ozaki, R. Grubb, T. Dilgen, T. Tanabe, G. Rakowsky, S. Kramer,

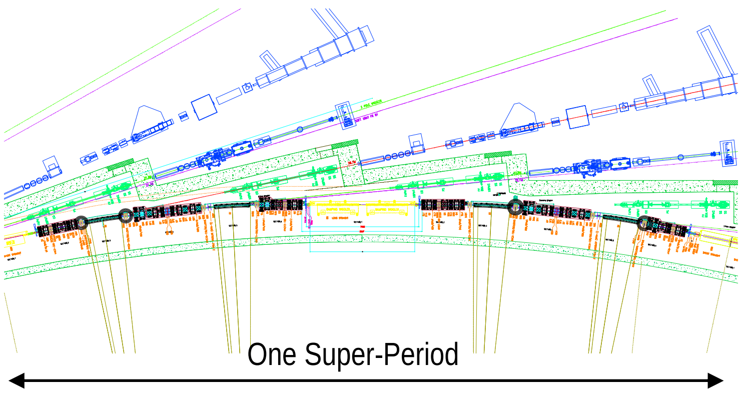
J. Bengtsson, B. Nash, W. Guo, G. Woods, D. Dale, H. Hseuh, C. Longo,

P, Kovach, B. Melanie, V. Ravindranath

NSLS II Lattice Magnets Specifications

This talk is based on the Value Engineered August 24th lattice.

The NSLS II is a 792 meter circumference 3 Gev Storage Ring using about 1000 magnetic elements.



- 60 Dipoles, 54 each 35mm gap , 6 each 90mm gap

  Good field region BX +/- 20mm, BY +/- 10mm

  Sum of all harmonics <1x10-4

- 300 Quadrupoles

  Good field region - 40mm x 20mm, Nom. Radius 22.4mm

  Field quality - 2x10-4 as defined by the sum of all harmonics from 4 to 20 pole with in the good field region.

- 300 Sextupoles

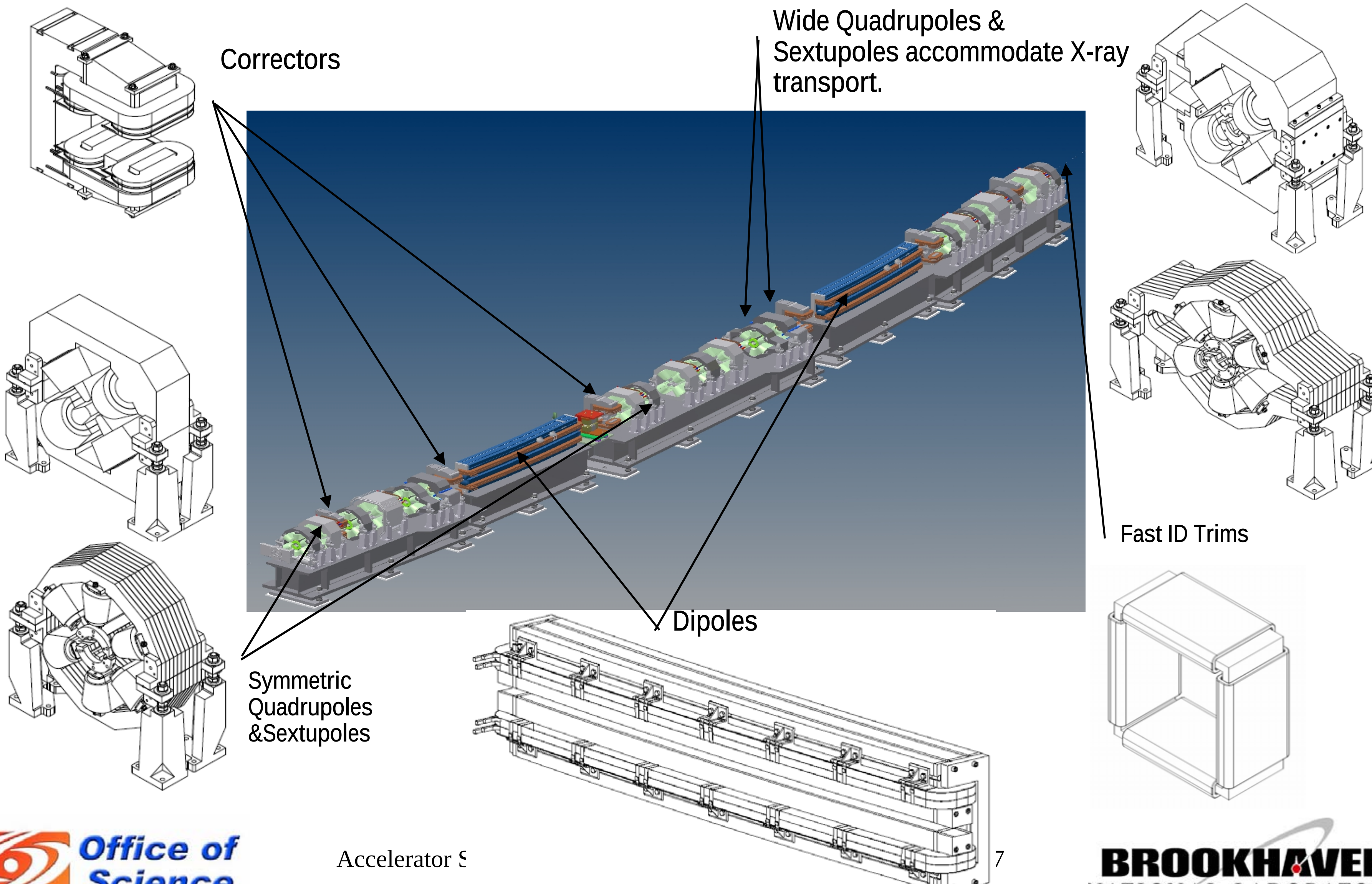
  Good Field Region- 40mm x 20mm, Nom. Radius 22.4mm

  Field quality -5x10-4 as defined by harmonic content in the good field region.

- 210 Corrector magnets, 120 Fast, 60 Slow, 30 Skew quads, field quality in the good field region -1x10-3

- 32 ID fast Correctors

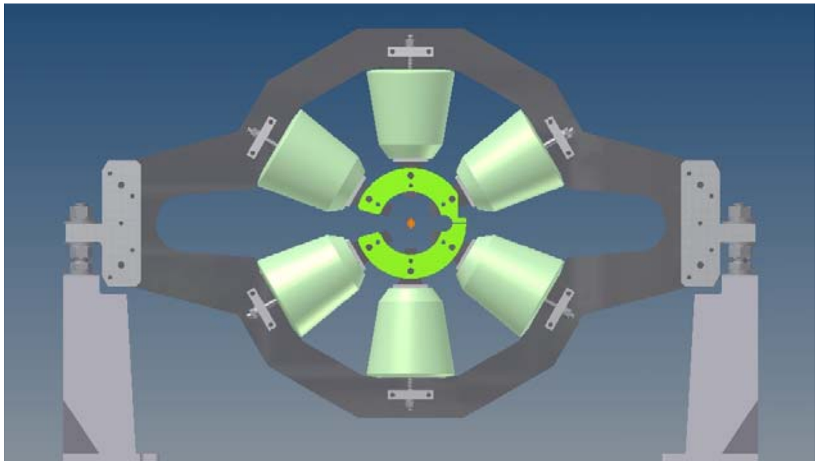
Magnet Types in a Typical Cell



Storage Ring Magnet Parameters

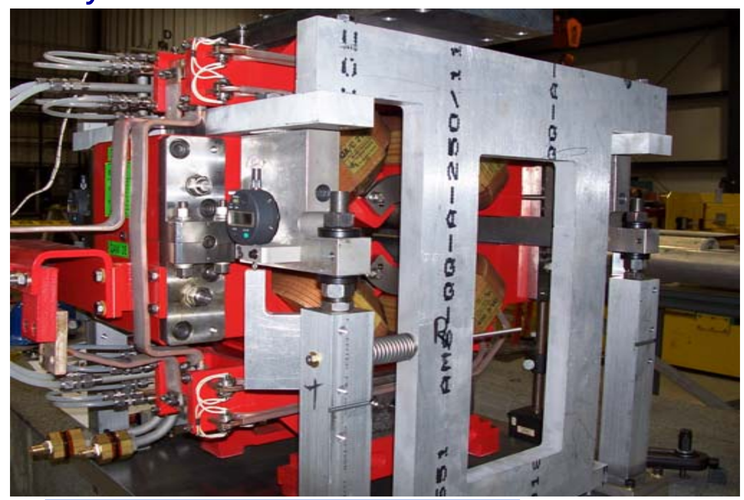
Magnet Typ.	Lattice Codes	QTY	MG. Length mm	Aperture, mm	Max .Field	Max NI/pole	3.0 Gev operating Current Amps.
Dipole	B1	54	2620	35	0.4 T	5760	360
Dipole	B2	6	2620	90	0.4 T	15120	360
Quadrupole	QD,QF,QH,QL	240	250	66	13 T/M	3685/5681	94.5/145.6
Quadrupole	QL2,QH2	60	400	66	25 T/M	11054	153.5
Sextupole	S1-3,SD,SL1-4,	270	200	66	300 T/M^2	2918	113
Sextupole	SF	30	250	66	400 T/M^2	3891	150
Corrector	HVC-156	120	300	156	0.032 T	2429/4188	15
Corrector	HVC-100	60	200	100	0.048 T	2292/3360	15
Corrector	IDFT,V/H	32	60/105	35/80	0.0052 T	180/360	2.4
Corrector	DPSQ	15	100	66	0.6 T/M	600	2.4
Corrector	IDSQ	15	100	40	0.43 T/M	300	2.4
Corrector	B1T	54	2620	35	0.012 T	210	2.5
Corrector	B2T	6	2620	90	0.012 T	546	2.5
Total # of magnetic elements		994					

Unique Mid-plane Support System

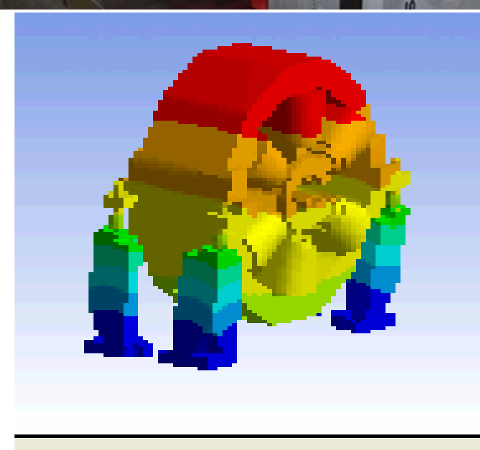


NSLS II Wide Sextupole

Bolting tests with the fixture shown below designed by Steven Plate and using a SLS Quadrupole appear to indicate that once aligned, the error caused by tightening the nuts can easily be controlled to less then 10 microns.



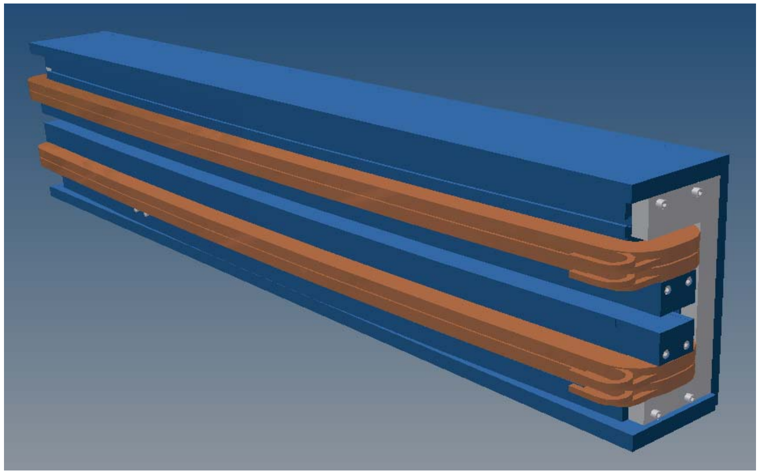
- The NSLS II multipoles are supported near the mid-plane.
- Multipoles require magnetic misalignment of less then +/- 30 microns about a common axis on each a girder.
- We believe magnetic alignment of < 20 microns is achievable.
- Tunnel temp. +/-0.1C will maintain support posts stable to a few microns. Magnet coil temperatures could rise > 10C .
- If supported at the base of the magnet. coil temperature variations will cause the center of a magnet to shift vertically at different excitations exceeding the required specification.
- Supporting the magnet near the mid plane allows the magnet to expand about it's center thus maintaining pre-alignment.



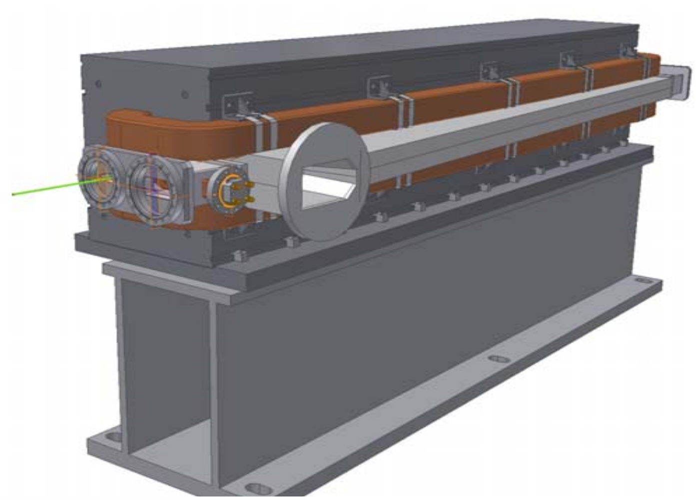
Modal Analysis has been performer to refine the design of the magnet support posts.

NSLS II Dipoles

35mm dipole Magnet

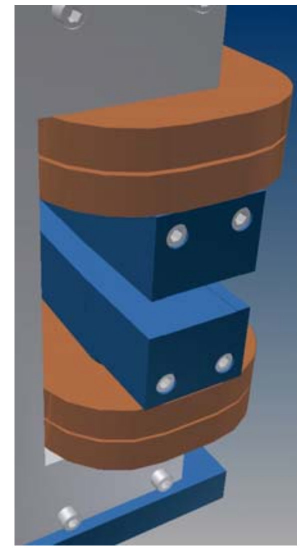


90mm Dipole magnet with IR vacuum chamber



Magnetic Design Preformed by Ramesh Gupta and independently checked by J. Jackson and G. Danby

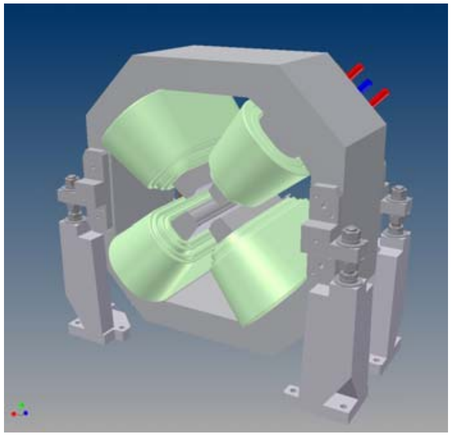
- The Dipole has a unique design due to it's low field, limited space, cost restraints and field matching requirements.
- Iron nose pieces protruding past the coil edge free over 10 meters of space around the ring, used for vacuum system components and diagnostics.
- This feature is used to improve the field quality of the C-magnet and to match the field distribution patterns of the 35mm and 90mm aperture dipoles.
- To reduce cost and maintain a precision gap with a minimum amount of iron a unique internal support is proposed for use with the 35mm aperture dipole.
- The two aperture dipoles are designed to allow one power supply to operate both magnets.
- A 3% trim allows for exact field matching as well as implementing Decker Distortion.
- Work is ongoing to develop a cost effective self supporting magnet on a simplified low cost stand.



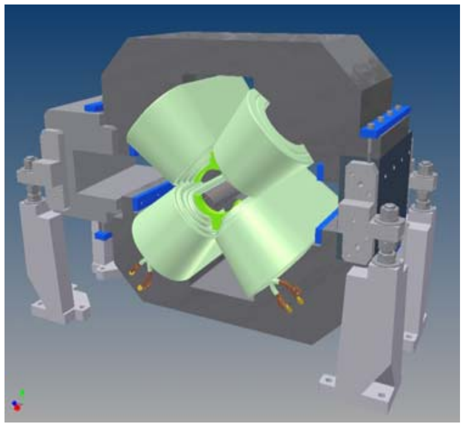
Dipole Nose

NSLS II Quadrupoles

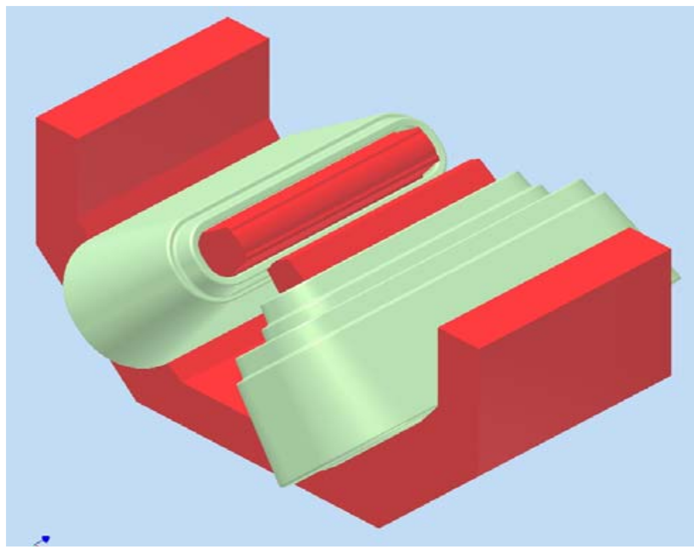
Standard Quadrupole

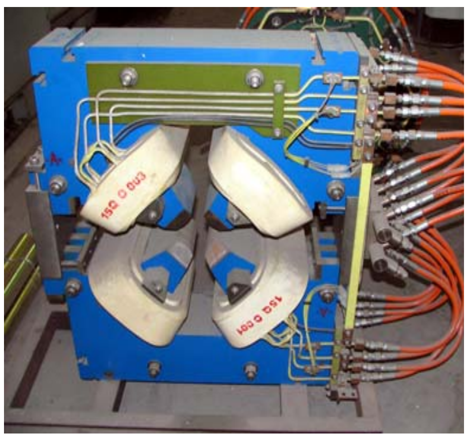


Wide Quadrupole



- To reduce random errors a Spear-3/PEP style magnet designs has been adapted.
- For the highest field lattice quads. a double coil is required. This technique was successfully implemented in Spear-3 Quads.
- The majority of the quadrupoles require only a single coil, reducing cost and improving system reliability.
- A single compound die can be used to produce laminations for either symmetric or wide Quadrupoles





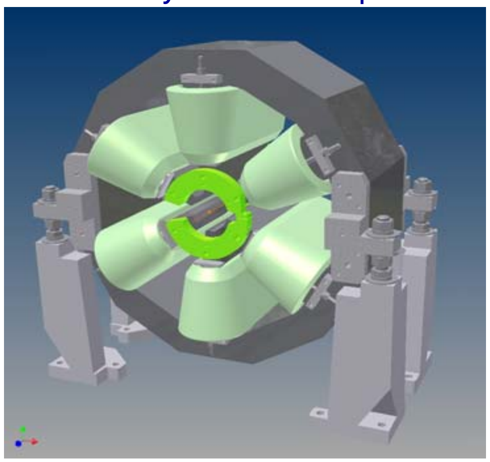
Spear-3 Quadrupole

Magnetic Design performed by W. Meng and M. Rehak and checked by the PSI Magnet group

All Quadrupoles are individually powered Current density remains relatively low at <4.3Amps/mm2. If higher quad fields are needed the current can be increased for specific magnets up to a J cu of 10 Amps/mm2 by adding power supplies to a specific circuit.

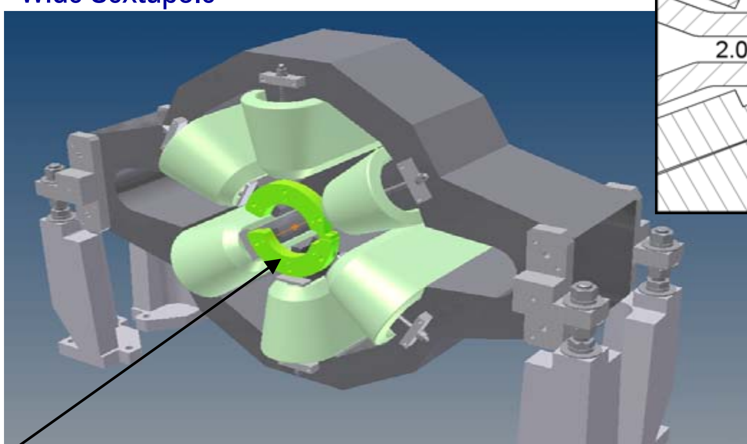
NSLS II Sextupoles

Standard Symmetric Sextupole

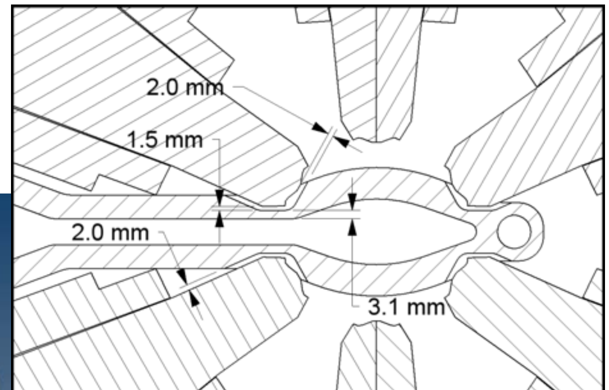


- To assure mechanical rigidity and field quality the NSLS II sextupole has a single mid-plane split with a removable center pole to allow coil assembly.
- This technique has been demonstrated in APS Sextupoles.
- The center pole location can be adjusted to correct the dipole errors inherent in the Wide Sextupole.
- The design of the sextupole is constrained by vacuum chamber.

Wide Sextupole

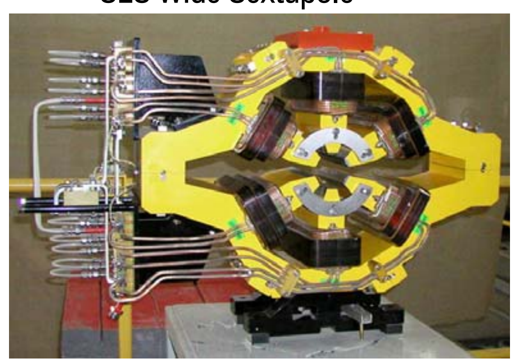


Inner pole stabilizer ring controls the position of the removable pole with respect to the two adjacent poles and stiffens the magnet assembly.



- Trim steering coils in the Sextupole are not used due to cost and affects on dynamic aperture.
- Magnetic Design was performed by R. Gupta and W. Meng and is being checked by the PSI magnet group.

SLS Wide Sextupole

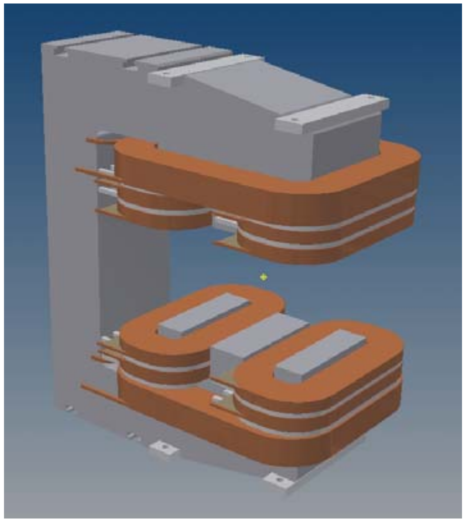


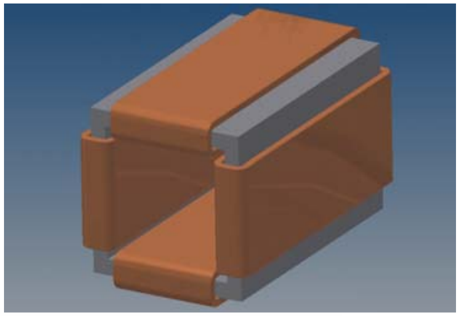
- The wide sextupole design is used to accommodate X-ray beam extraction, and has been used successfully by PSI at the Swiss Light Source

NSLS II Primary Correctors

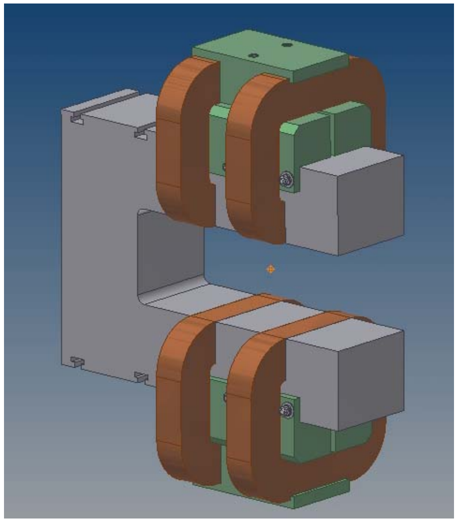
NSLS II is developing innovative discrete Corrector magnet designs that are required due to the limited space and vacuum chamber requirements.

On the left is a 6 coil design invented by Gordon Dandy and John Jackson, 3-D analysis performed and checked by Wuzheng Meng and Margareta Rehak. On the Right is a 4 coil design proposed by Ferdinand Willeke.





- The 6coil corrector is the base line design and operates with a minimum of 2 bi-polar power supplies one supply for vertical field one supply for horizontal field.
- Vertical field coil is air cooled the horizontal field coils have water cooled chill plates.
- 156 and 100 mm apertures
- The design can incorporate a skew quadrupole.
- This type of corrector can produce DC fields as well as operate with a superimposed AC field for Orbit feedback at up to 100 HZ or greater.

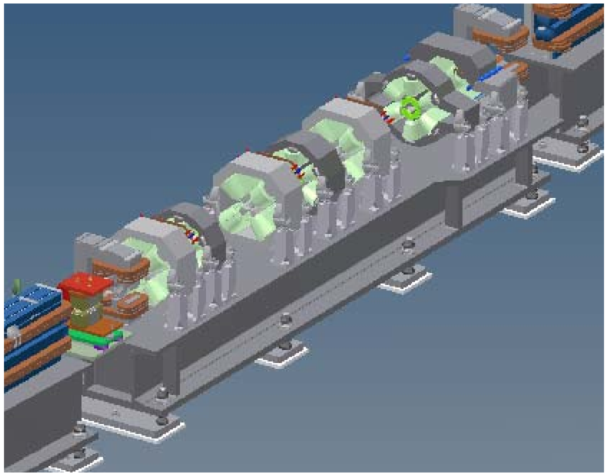


- All other discrete correctors are small conventional window frame devises.

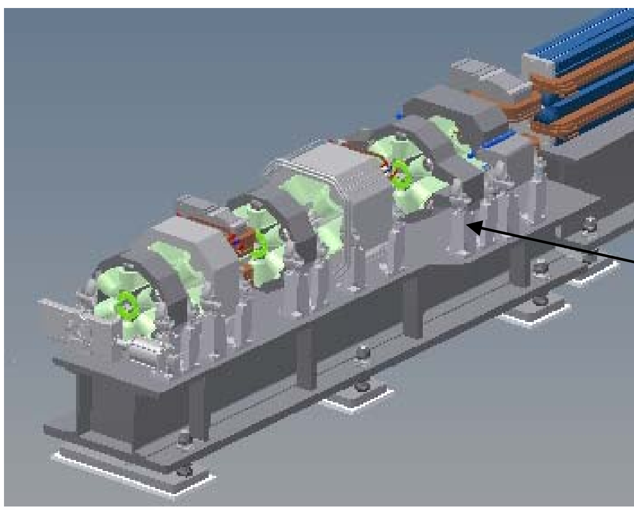
- The 4 coil corrector operates with a minimum of 2 bi-polar supplies, the two supplies are operated together to create either vertical or horizontal fields.
- The coils operate at low enough current density to be air cooled.
- This type of corrector would be suited for 156mm aperture application.
- This type of corrector can produce DC fields as well as operate with a superimposed AC field for Orbit feedback at up to 100 HZ or greater.

Multipole Magnet to Girder Integration

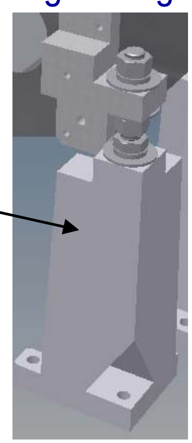
Typical Long Center Girder Assembly

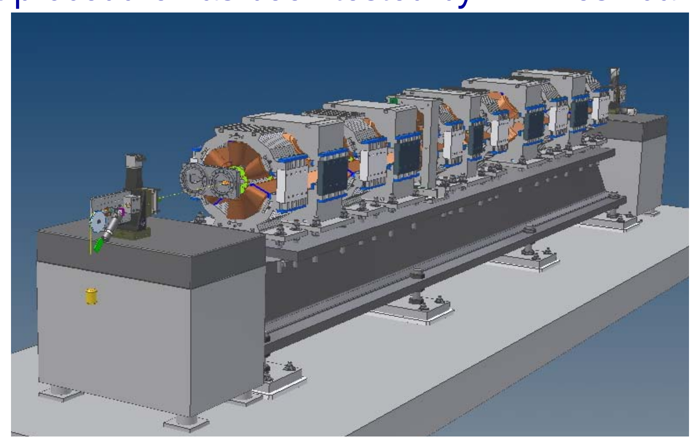


Short matching section Girder



- Templates are used to position the magnet and vacuum chamber supports that are bolted to the Girder.
- The magnets are parted and lifting fixtures place the bottom magnet halves onto the threaded studs, nuts and spherical washers of the magnet supports.
- The vacuum chamber is installed, pre-aligned and fixed into place.
- Lifting fixtures are used to safely locate the top half of the magnets. The magnets are keyed at the mid-plane and then bolted together.
- Once the magnetic field centers are aligned to < 30 microns about a common axis the nuts on the studs are tightened.
- A magnet alignment procedure has been tested by Animesh Jain





Sample of Findings from Previous Reviews

From the Magnet Systems Review August 6-7 2007

- Strong endorsement on the 2 piece quadrupole design choice and the 2 piece sextupole with removable poles.
- Endorsement of supporting the multipoles magnets near the mid plane.
- Recommendation to consider the use higher current densities in the conductor, approx. 10 ampheres/mm2
- Endorsement of the proposed R&D and preproduction plans
- Reviewers prefer the vendors to "Build to Print" vs. "Build to Spec."
- Strong endorsement of the vibrating wire alignment concept .
- Consider Straight dipoles instead of curved dipoles.

From the Comprehensive Design Review September 11-13 2007

- Despite very tight time constraints each type of magnet should be prototyped.
- High Current densities up to 10 ampheres/mm2 are not recommended.
- Consider vibration caused by the water cooling circuits on individual Quadrupole and Sextupole magnets.

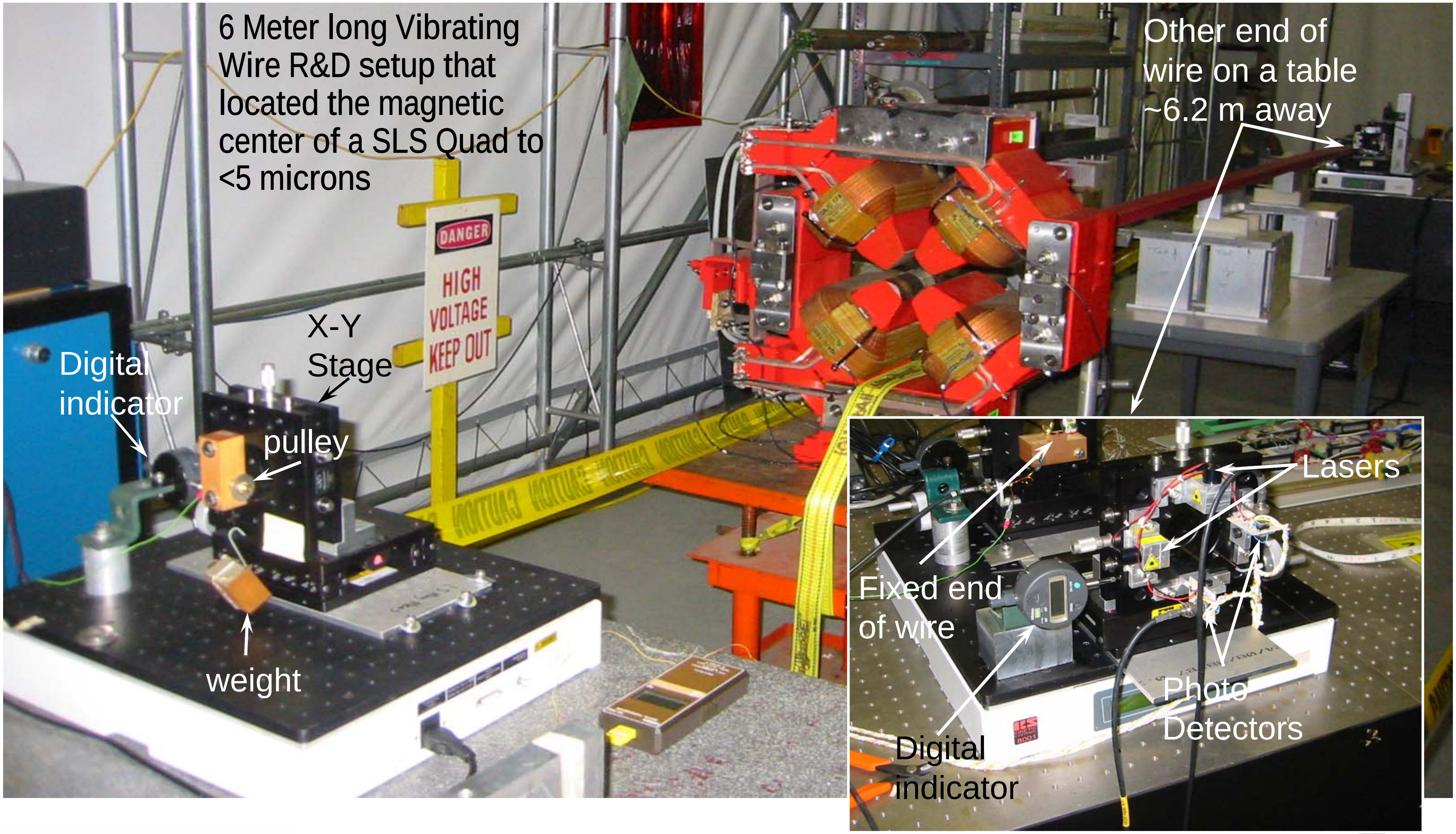
Consideration of Review Findings:

- A design for a straight dipole with a curved iron yoke is being developed.
- Value engineering of the magnet and power supply systems is ongoing.
- Carefully considering the production plan in light of committee comments.
- The reviewers believe time pressures may force NSLS II to use defective magnet as has happened at other facilities.
  - Discussions with industry indicate that the "build to Spec. method with a baseline reference design" has advantages over build to print .
  - Everson-Tesla actually preferred this method when it was used by SLAC for the LCLS Quadrupoles . It allowed the vendor to value engineer the reference design and to take advantage of in-house resources and expertise to produce a robust yet cost effective final product.

Progress since the Reviews

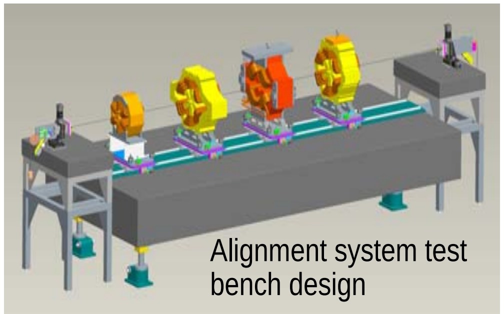
- Testing indicates that the bolting plan will achieve <10 micron position control.
- Systematic harmonics of all magnets are being evaluated by Accelerator Physics.
- Industry has begun fabrication of the R&D prototype magnets.
- We are accelerating the Multipole R&D by expanding our collaboration with IHEP.
- We are attempting to expand our collaboration with PSI.
- Incorporated value engineered cost savings items into the new lattice
- Storage ring magnet R&D, preproduction and production schedules updated .

Magnet Alignment R&D in FY 07



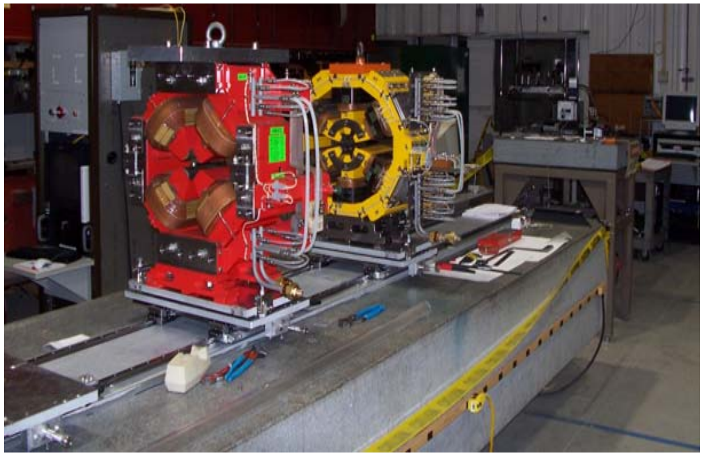
Progress on Magnet R&D Activities

- Magnet Alignment System Development

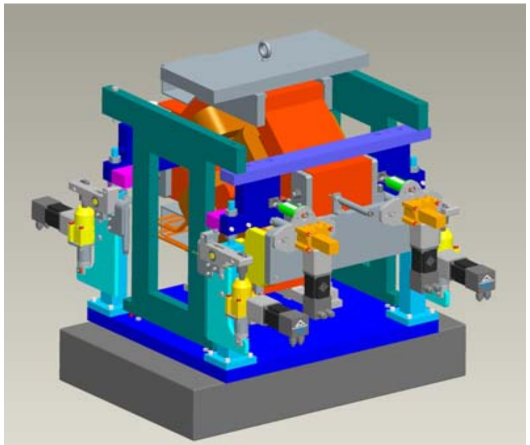

Alignment system test bench design

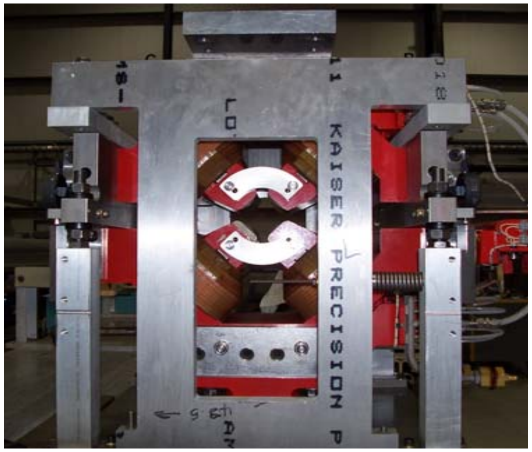
- Vibrating Wire End Station, wire manipulator being assembled and aligned.

- Magnetic Measurements of individual and assemblies of Loaned magnets from SLS and IHEP



- Bolting and magnet manipulator test fixture


R&D 1st magnet manipulator System Design



FY07-08 Magnet R&D Activities

- Magnet measurements of loaned magnets from the SLS/PSI
- Magnet models are being developed by the Vector Fields Co. for each of the loaned magnets.
- Multi-magnet interaction models will be developed and results compared with measurements.
- Magnet to magnet interactions are being measured and evaluated. In this manor the design tools can be calibrated against actual measurements
- Advanced conceptual designs are be prototyped for each novel magnet type as follows.
  - 156mm, 6 coil corrector, 150 mm long
  - 100mm, 6 coil corrector, 100 mm long
  - 156mm, 4 coil corrector, 150 mm long
  - 35mm, nose end Dipole magnet , about 750mm long
  - Wide removable pole Sextupole, 200mm long
  - Wide Quadrupole 250mm long.
- Prototype reference magnets will used on the prototype girder to evaluate vibration and stability prior to CD-3.

Ongoing reference design and magnet R&D program

- NSLS II is integrating Total Quality Management principles into lattice magnet design.
- Unified Conventions were established between magnet designers and accelerator physics.
- Individual magnet designs are developed using 2D & 3D modeling.
- Field Harmonic content of each magnet type is reviewed by accelerator physics to assess effects on dynamic aperture (DA).
- Magnet Interactions are being studied.
  - Evaluation of magnet interactions through measurements of multiple SLS magnets.
  - SLS magnet models developed and calibrated against actual measurements.
  - Magnetic models of adjacent reference magnets will be evaluated for effects on DA.
- Deficiencies shall be evaluated and corrected in modeling prior to preproduction

NSLS II Magnet Development and Production Plan

- Preliminary reference and R&D magnets prototyped and evaluated.
- Preliminary Design Review (PDR)
- Pre-production magnet RFPs
- Intermediate Design Review (IDR)
- Pre-production magnet fabrication at multiple vendors and testing at BNL
- Critical Design Review (CDR)
- Production contract RFPs
- Award Production Contracts to a minimum of two pre-qualified vendors
- Integrate safety, quality control and oversight at the production vendors.
- Magnet production and incoming inspection
- Magnet to girder assemble, alignment and integration in BNL,Bldg.902

Magnet Division Building 902 Facility

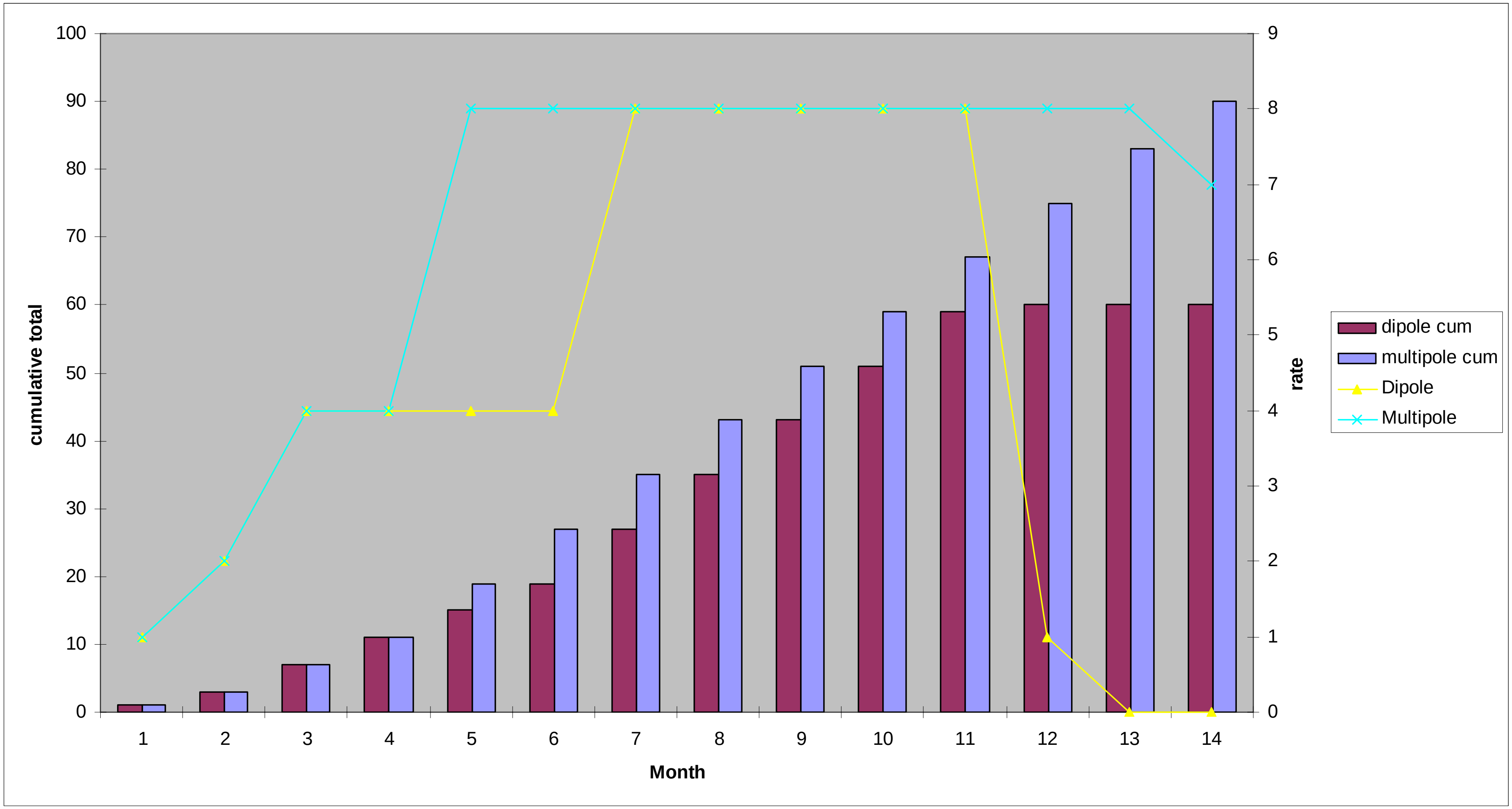
Approx. 55,000 sq. ft. total space

- ~ 48,000 sq. ft., main building
- ~ 7,000 sq. ft., annex

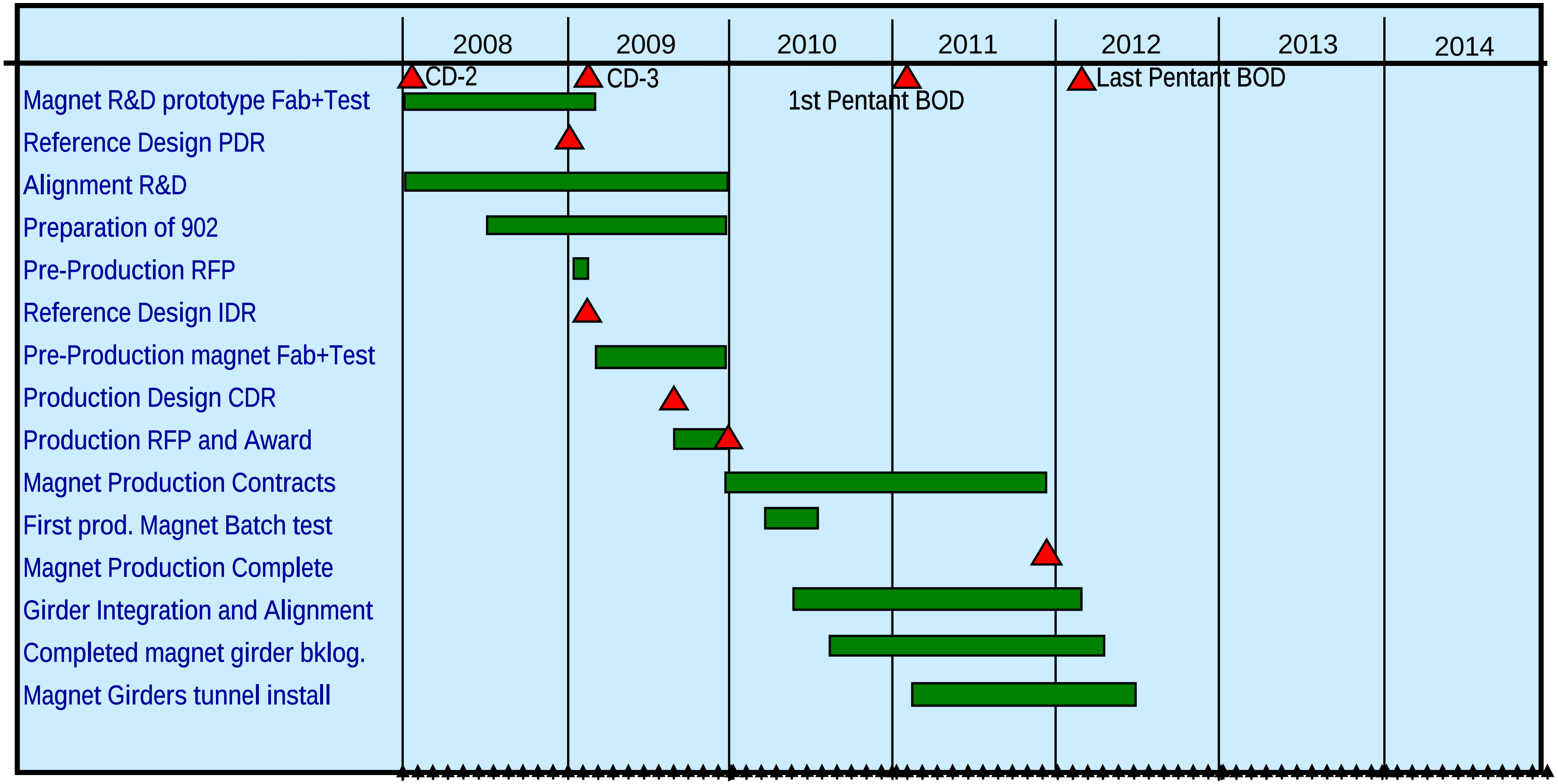
Approx. 13,000 sq. ft. planned for NSLS-II

- 7,000 sq. ft., magnet final assembly and testing (Annex)
- 4,000 sq. ft., magnet storage
- 2,000 sq. ft., deliveries and temporary storage (905)

Projected Rate



NSLS II Magnet Schedule



Items planned to be completed for CD-2

- Reference magnet designs shall be refined of each magnet type.
- Magnet leads and utility design, maintenance, and reliability will be evaluated.
- Magnet bolting tests completed.
- Magnet mover prototype assemble complete and under test.
- Laser tracker alignment and CMM arm procurement complete and system under test.
- Magnet parameters list updated to reflect latest lattice and impact of value engineering.
- Revised Vendor Cost Estimates.
- Magnetic measurements for several Inter-magnet spacing.
- The vibrating wire magnet alignment system to be demonstrated on test bench.
- Value engineered magnet/power supply systems evaluated and optimized, fully consistent system proposed.
- All reviewer comments will be considered and appropriate actions taken.
- Magnet development, and production plans will be refined to present a coherent acceptable acquisition strategy for successful on time delivery of high quality magnets at minimum cost and risk.

Summary

- Presented is an overview of the preliminary reference designs of the NSLS II magnets.
- A summary of the August and September review magnet findings was presented.
- Progress made on lattice magnet R&D in FY07 and plans for FY08 were presented.
- Magnet acquisition strategy and planning for girder assembly and alignment was described.
- A clear path forward toward CD-2 was defined.

Back-up Slides

Preliminary Reference Design Program

- Due to stringent alignment and field quality requirements NSLS II magnets have a unique development path to achieve a viable base line design.

- Preliminary base line reference designs will be prototyped for all lattice magnets types.

- At the end of the R&D period a lattice magnet Preliminary Design Review shall be performed to confirm magnet system parameters have been achieved prior to proceeding to build the Preproduction Prototypes

Pre-Production Magnets

- Upon completion of the PDR, We will issue a minimum of two or more RFPs to industry to manufacture the Pre-Production magnets.
- In the RFP, refined reference designs shall be supplied along with performance and manufacturing specifications. The manufactures will be required to meet the Specifications but will have a choice to either use the reference design, propose their own design, or introduce improvements to the reference design to lower cost, improve performance or enhance reliability.
- An Intermediate Design Review (IDR) Shall be performed to evaluate the proposals and determine which manufactures will build the Preproduction Magnets.
- Contracts shall be placed with potential production vendors in such a manor as to mitigate cost escalation, improve quality, and reduce late delivery risks.
- Iron, copper, and laminations may be supplied to the vendors as government supplied materials

Pre-Production Magnets

- Selected contractors shall manufacture Preproduction
- Prototypes magnets shall be thoroughly tested until performance specifications are met.
- A Critical Design Review (CDR) shall be performed to confirm that as least two Vendors have been qualified to produce magnets that shall meet all the operational requirements of the NSLSII at minimum cost and risk.
- After the CDR Production contracts shall be placed with a minimum of two pre-qualified vendors in such a manor that the risk of non compliance is negligible.
- The production contracts shall have a duration of less then two years with first article and batch delivery occurring with in 6 months of contract start.

Magnet Production and Incoming Inspection

- Source inspection, the use of travelers, imbedded QA , materials certification, and production oversight shall be implemented to mitigate risk during production.
- Magnetic measurements shall initially be performed on 100% of all production magnets in a batch delivery.
- If 100% magnetic measurements source inspection is performed by the manufacturer and perfect agreement is achieved with BNL measurements in the first batch delivery, statistical sampling per batch maybe performed there after.
- If the vendor does not perform 100% magnetic measurements or agreement is questionable, BNL's Magnet division shall perform 100% measurements and inspection of all magnets from that vendor prior to acceptance
- In short, 100% of the magnets shall be measured at the vendors site or at BNL
- After measurements, inspection and acceptance magnets shall be stored at building 902 over a period of about 1 year, with a back log of several months to assure that schedule pressure or lack of magnet stock will not cause the negation of proper Girder integration or precision alignment.

Girder /Magnet /Vacuum Chamber Integration.

- First magnet delivery will occur with in 3 months after placement of Magnet production contracts.
- First Magnet Batch delivery will occur with in 6 months after placement of Magnet production contracts.
- Incoming inspection and testing of all first batch magnets should be completed in approximately 3 to 4 months.
- Production Girder integration can begin shortly after first batch acceptance with a singly production line at a rate of about 1 girder/per month.
- The rate of Girder integration will gradually ramp up over a period of approximately 6 to 9 months with up to 3 multipole and one Dipole assembly lines.
- At full production rates 90 multipole and 60 dipole Girders integration will be completed in approximately 6 months.

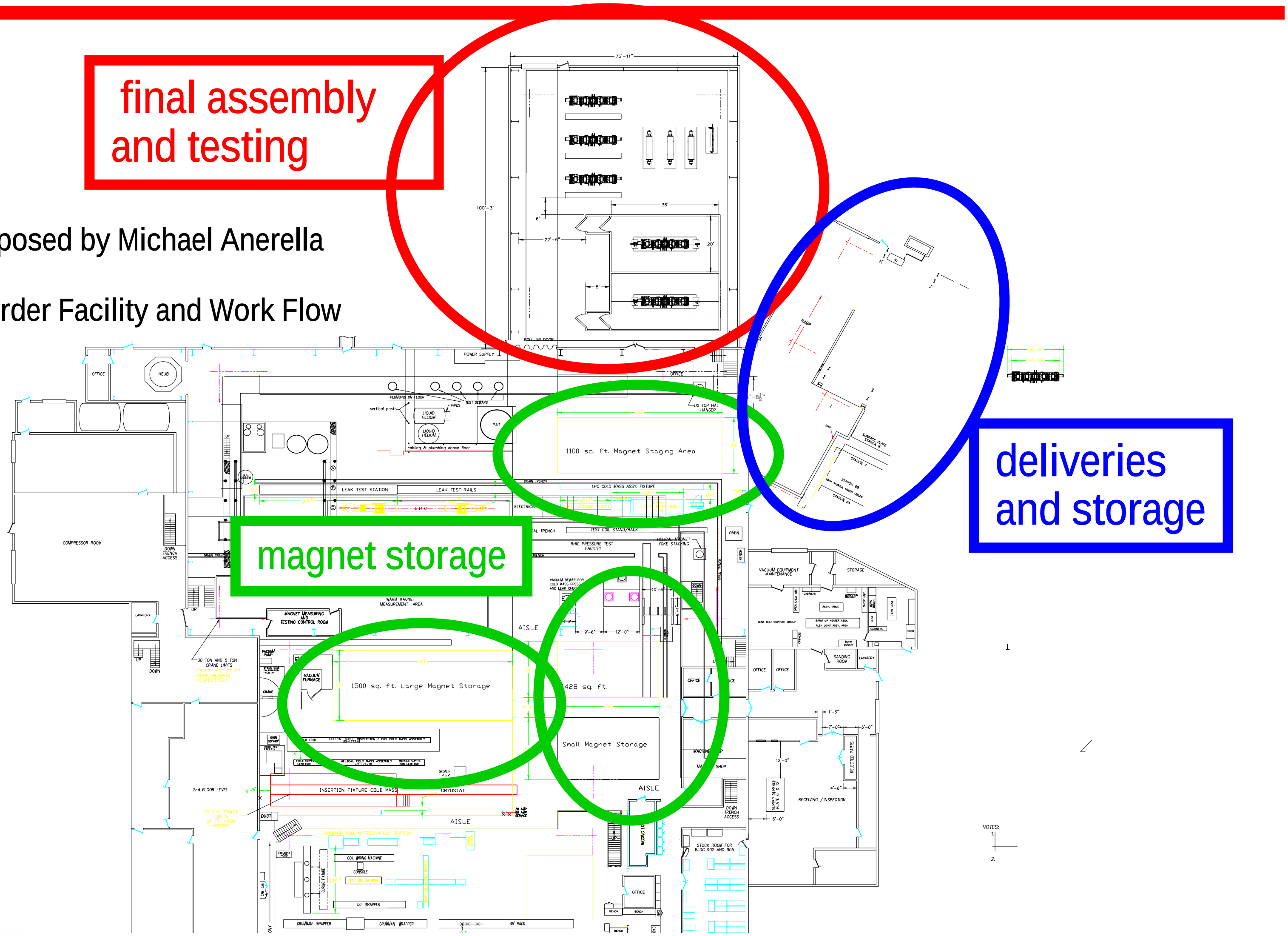
Girder /Magnet /Vacuum chamber integration Continued.

- Over this period Integrated Safety management will be implemented to eliminate worker injuries.
- Magnet design will incorporate safety items from inspection through installation.
- Safety will be imposed beginning with the magnet vendors to perform work safely and supply safe components and assemblies to BNL.
- Breaking sharp corners, providing well marked and adequate lifting points, and providing pre-tined connection points reduce risk for potential injury.

902 Facility Planning Overview for NSLS II

Facility plan as proposed by Michael Anerella

NSLS II Magnet Girder Facility and Work Flow

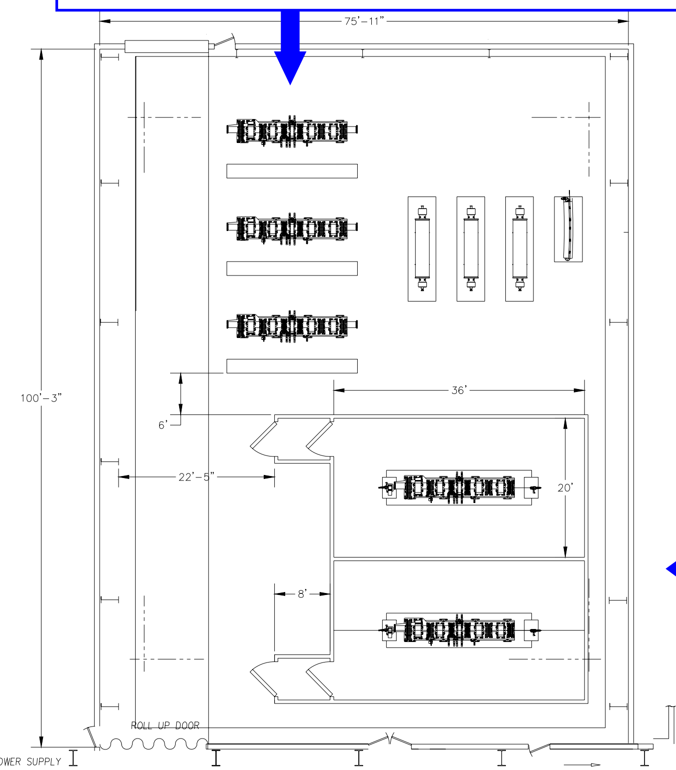


magnet final assembly and testing (Annex)

Temperature controlled environment to +/- 0.1C

Magnet to Girder Integration:
- Initial alignment
- disassemble upper halves
- install vacuum chamber
- re-install upper halves

Individual magnet inspection:
- mechanical
- electrical
- magnetic



Final Multipole Alignment:
- Vibrating wire
- Laser (after bolting)

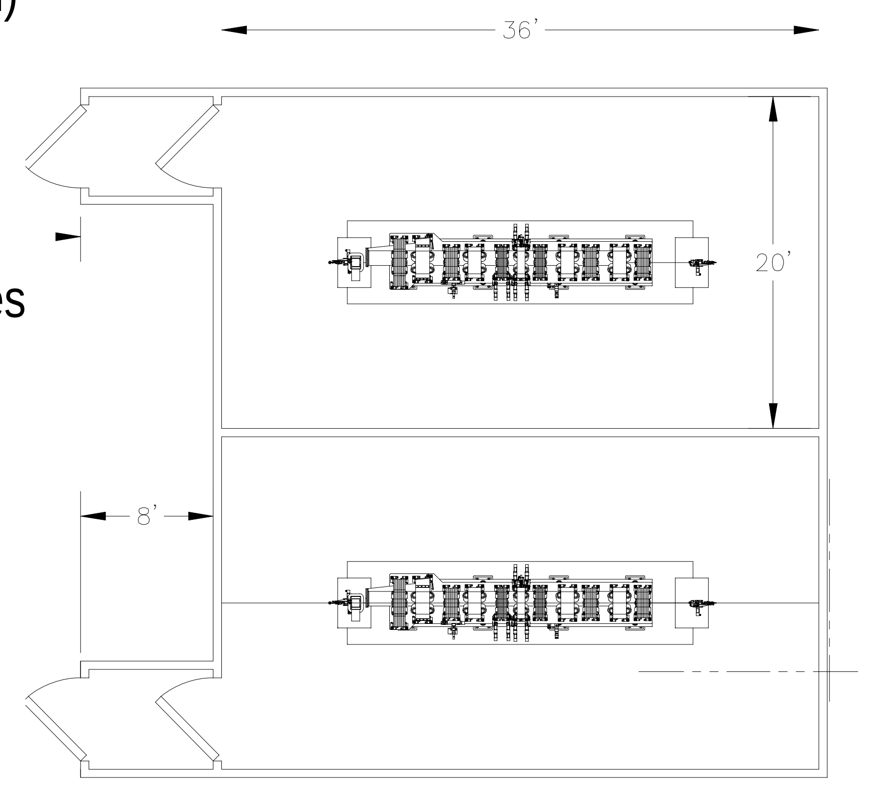
Work Flow (multipoles)

- Incoming Receipt & inspection
- Storage as required
- Individual magnet tests
- Installation & initial alignment (mechanical) onto girder
- Upper magnet disassembly & removal
- Installation of vacuum chamber
- Re-installation of upper magnets
- Installation of water lines and power cables
- Install in controlled environment
- Final alignment
  - Vibrating wire, each magnet
  - Bolt tightening
  - Confirmation by laser
- Store for ring installation

Environmentally Controlled Rooms

For

Final Alignment



Development and Production Schedule for the Storage Ring Lattice Magnets