Alignment Strategy for APS Upgrade Project

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Outline

- APS-U Overview
- Team
- Requirements and Tolerances
- Floor Stability and Control Networks
- Support and Alignment System
- Magnet Mapping and Fiducialization
- DMM Prototype Testing
- Summary

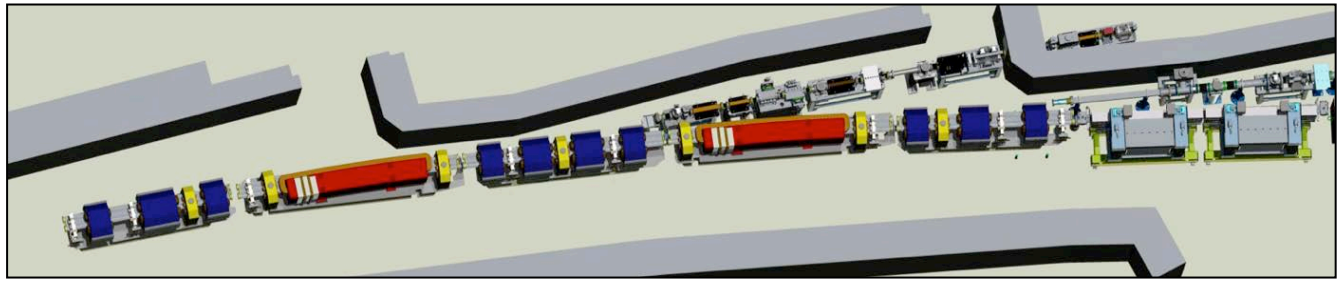
Advanced Photon Source today

- Built in 1990s
- Commissioned in 1995
- 66 Operational beamlines
- 5000+ users annually

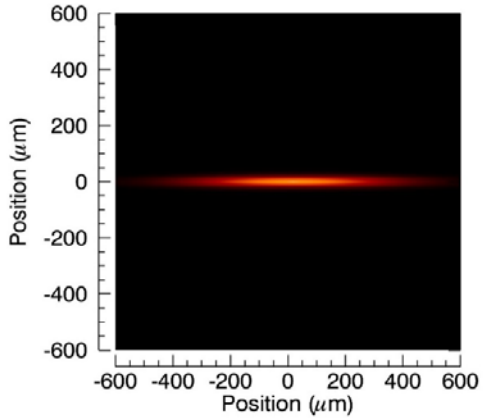
Third generation 7 GeV light source

APS Upgrade

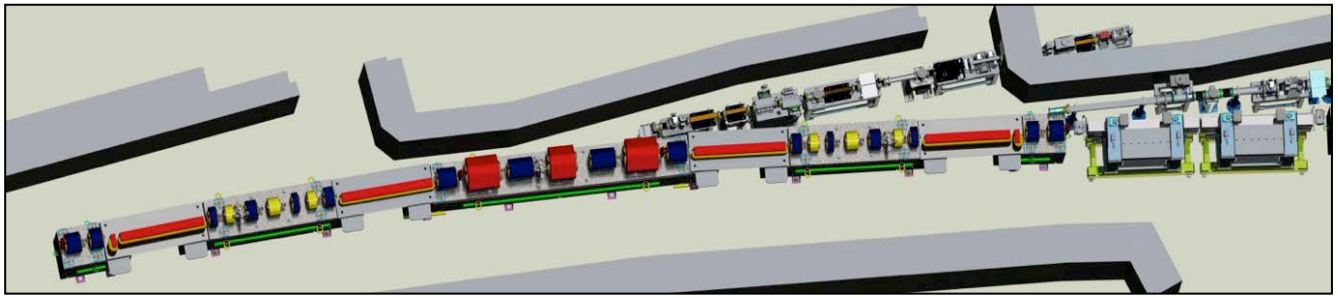
APS Today (3rd generation)



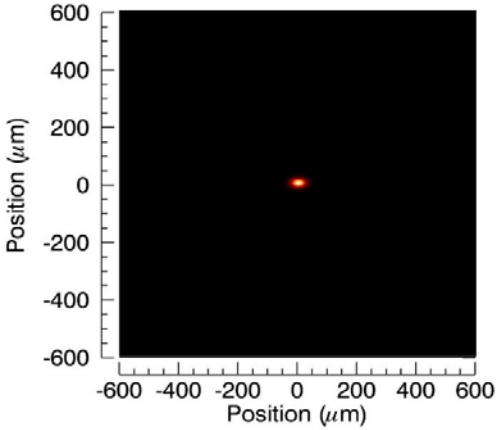
Double-Bend Lattice



APS Upgrade (4th generation)



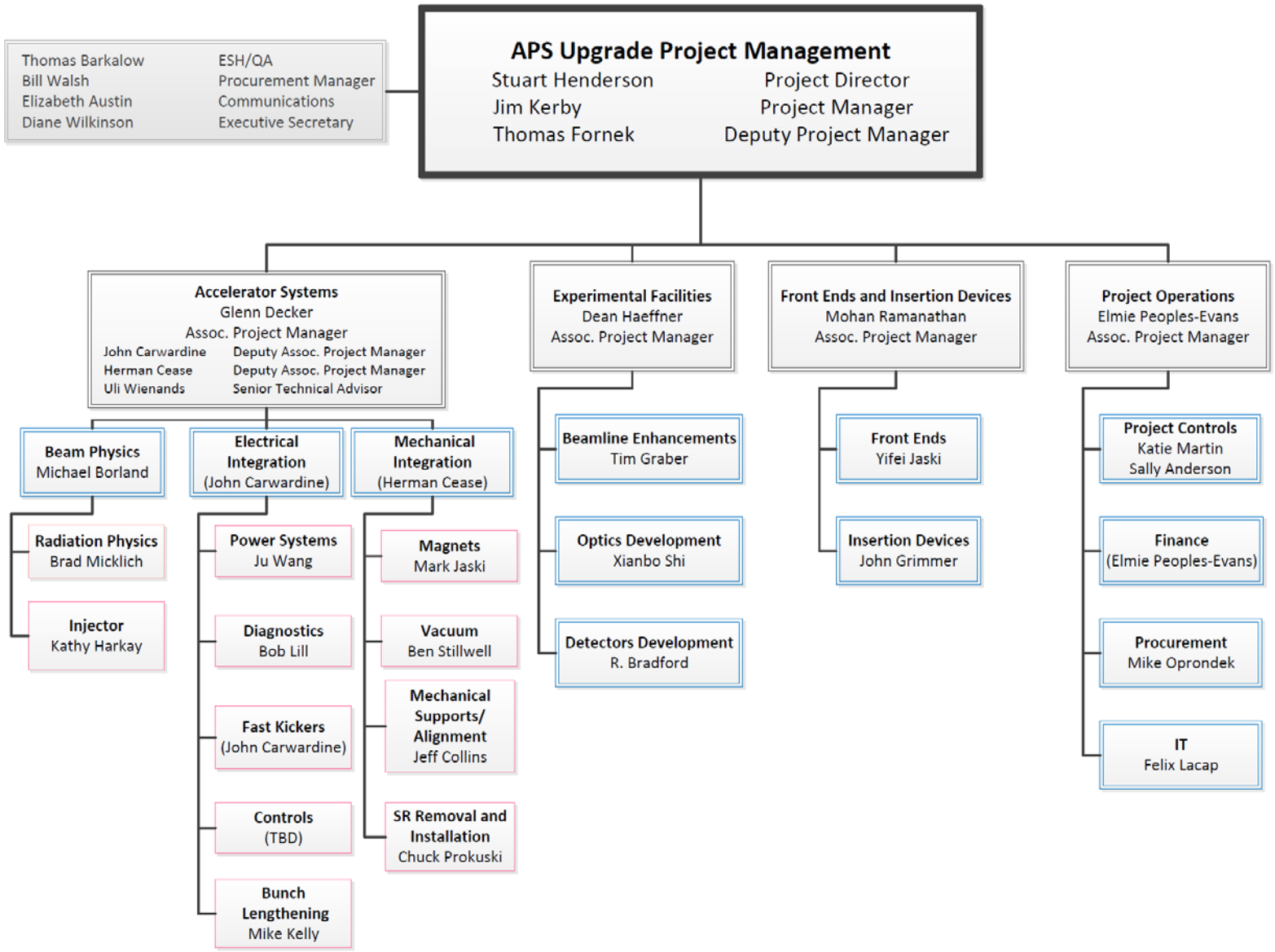
Multi-Bend Achromat Lattice



"APS-U exceeds the capabilities of today's storage rings by 2 to 3 orders of magnitude in brightness, coherent flux, nano-focused flux."

Stuart Henderson, Project Director

APS Upgrade organization



Contributor Acknowledgement

Mechanical Integration	Herman Cease

Support Structures & Alignment Systems Design	Magnet Design & Magnetic Measurement	Survey & Alignment
Jeff T. Collins Curt Preissner Jeremy Nudell Zunping Liu Scott Izzo Nate Poindexter Bill Turner Mike Bosek	Mark Jaski Chuck Doose Jie Liu Roger Dejus	Rolando Gwekoh Bill Jansma Keith Knight Kristine Mietsner

Survey and Alignment Tolerances

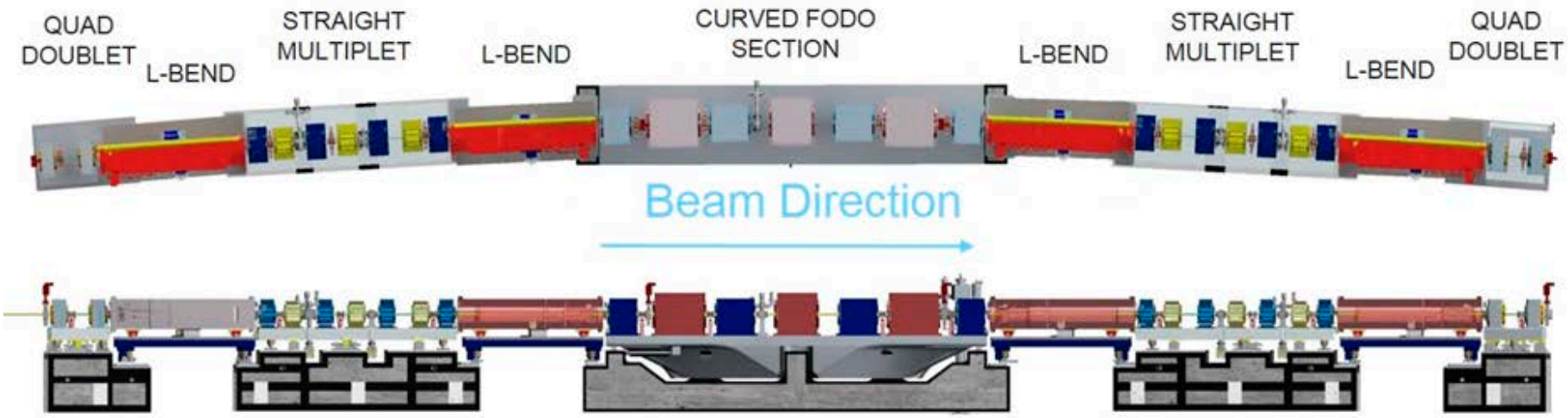
Parameter	value	unit
SR Circumference	30	mm
Girder to girder alignment	100	μm rms
Magnet to magnet	30	μm rms
Dipole tilt	0.4	mrad
Quadrupole tilt	0.4	mrad
Sextupole Tilt	0.4	mrad

APS survey control networks
Survey measurements
Alignment with respect to networks

Survey measurements
No control network constrains
Relative alignment / smoothing

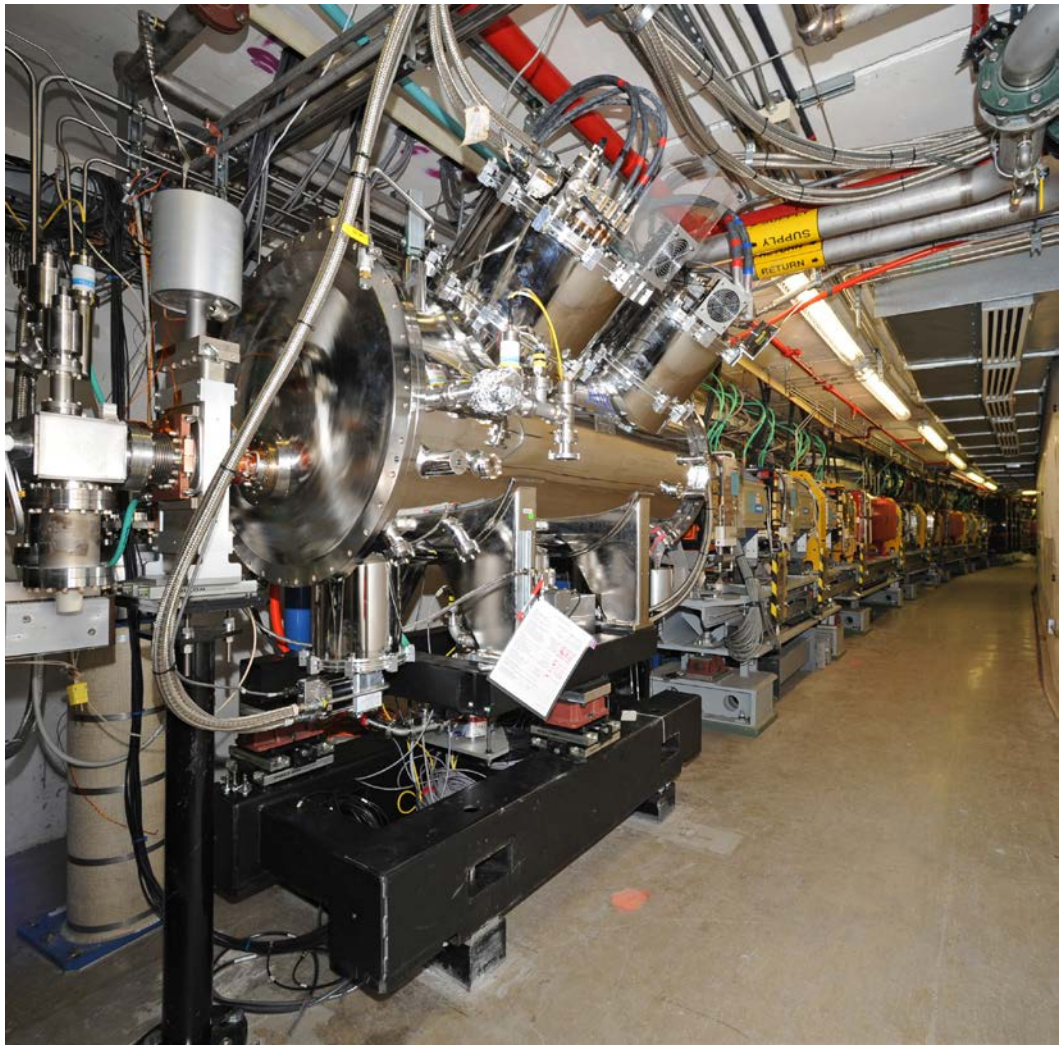
Mechanical design
Machining tolerances
Magnetic measurements

APS-U Storage Ring Sector



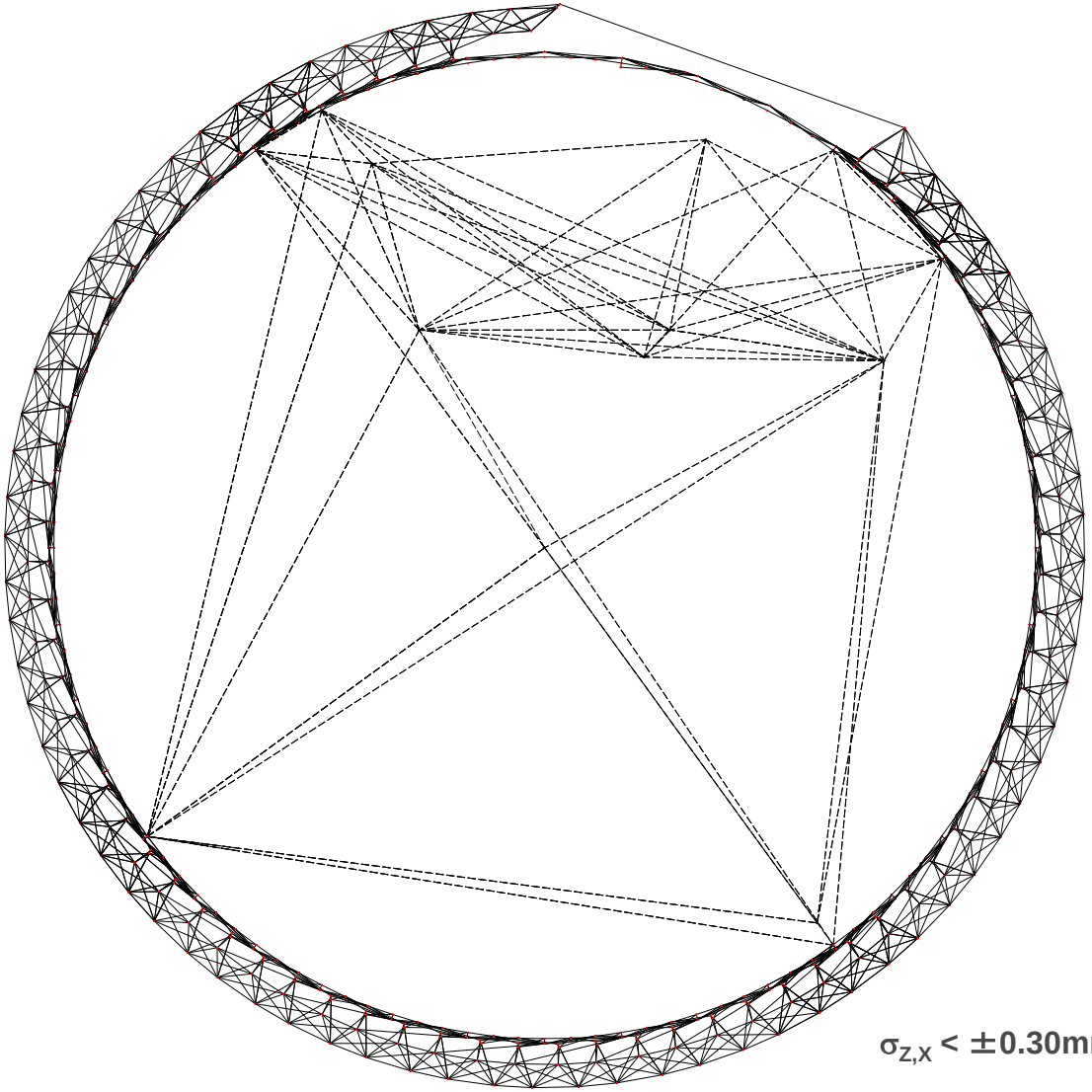
- **Forty sectors with nine module assemblies of four types**
  - Two quadrupole doublets: two quadrupoles and a fast corrector on each
  - Four longitudinal gradient bending magnets
  - Two straight multiplets: four quadrupoles, three sextupoles, one fast corrector on each
  - One FODO: four quadrupoles, three Q-bends and one 3PW source on each
- **Modules will be installed in the Storage Ring as assembled complete units.**

Retrofitting Existing Facility

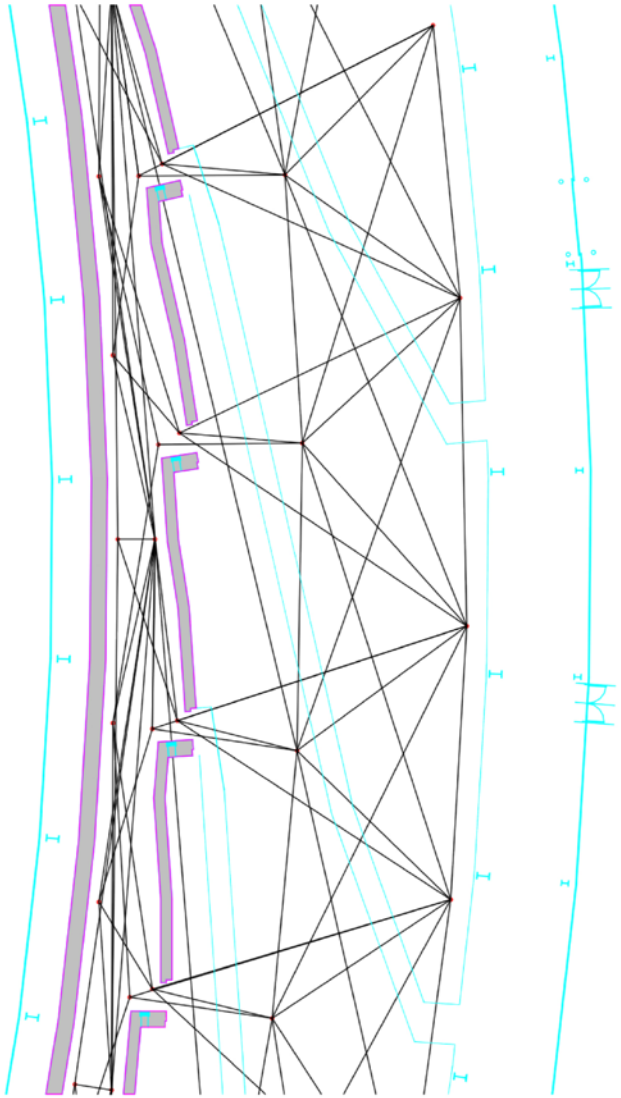


- Physical constrains of the storage ring walls
- Reuse of existing infrastructure (value>$1B)
- Intimate knowledge of building behavior (22 years of settlement data)
- Existing survey networks

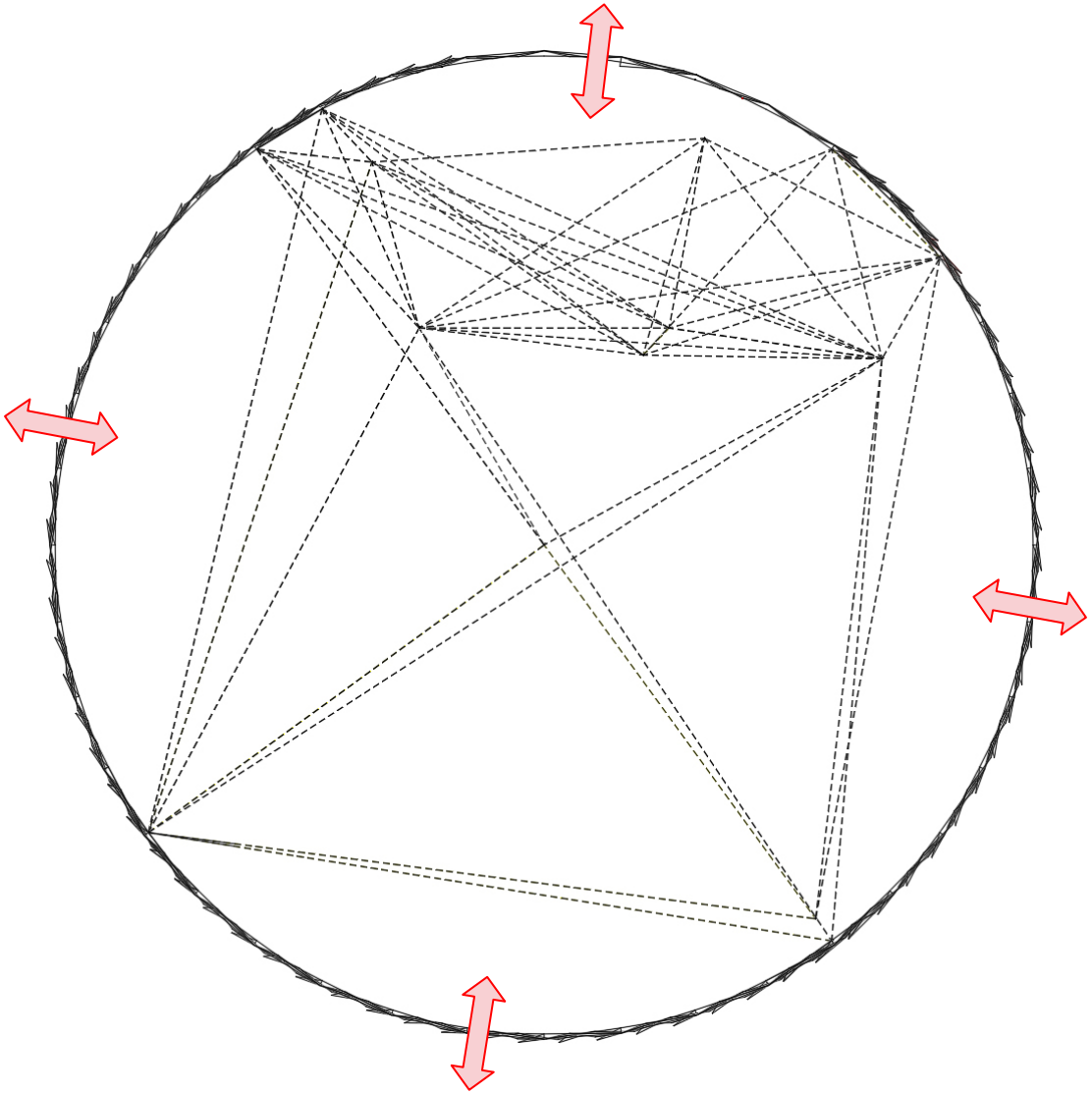
Original SR Horizontal Control Network

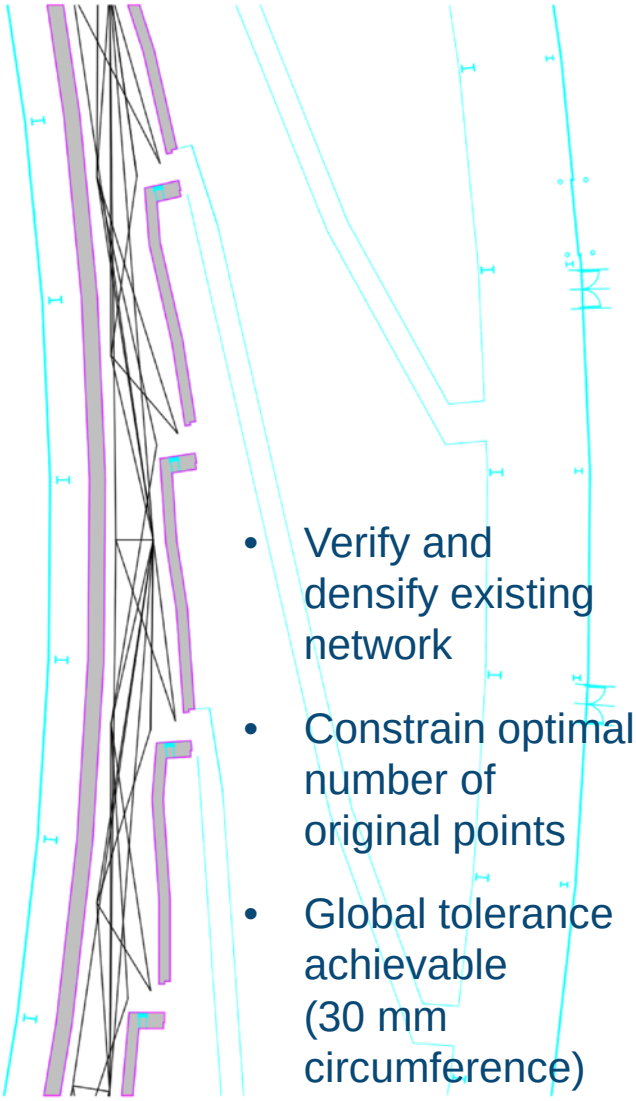


$\sigma_{z,x} < \pm 0.30mm$



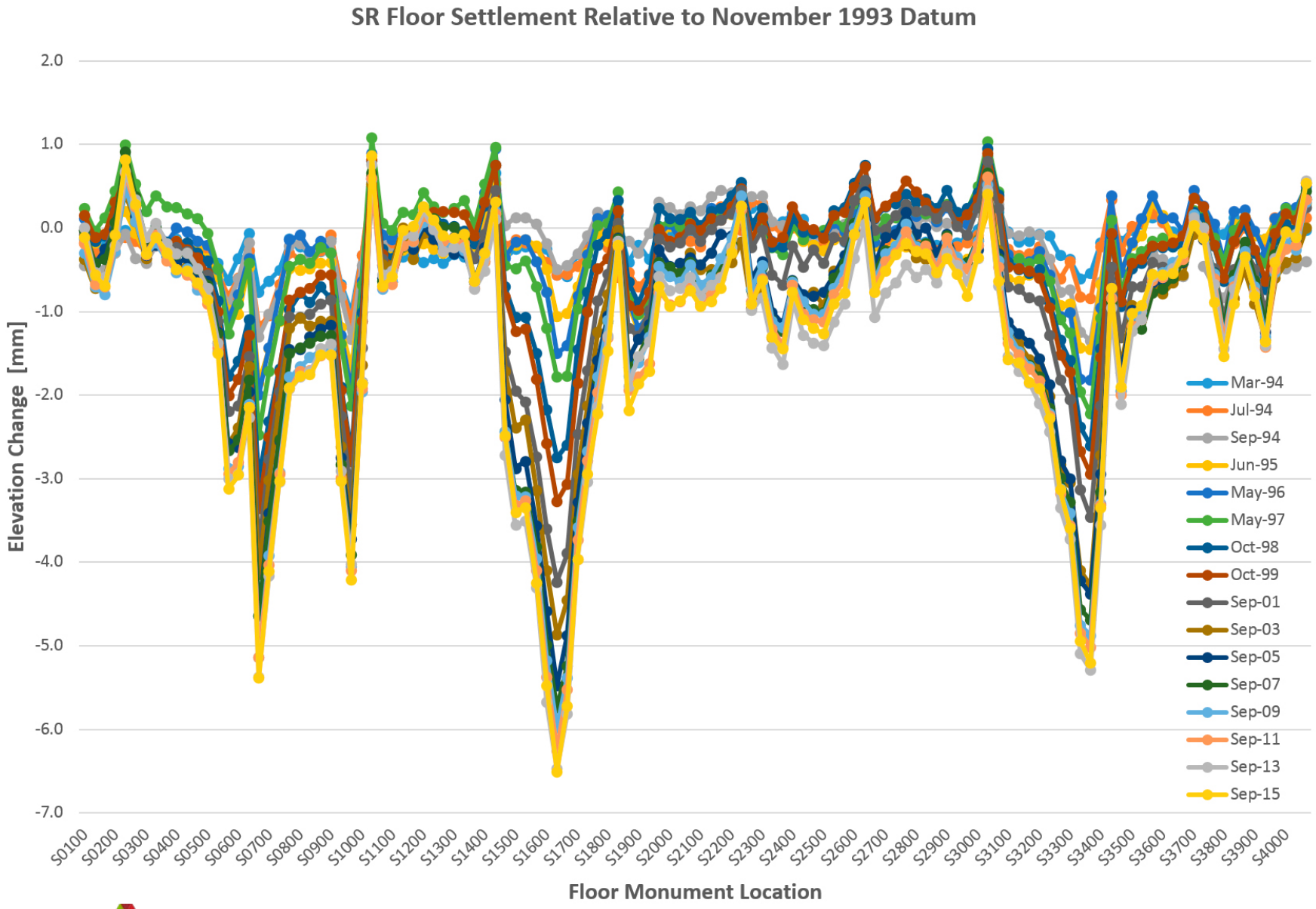
SR Horizontal Control Network Today



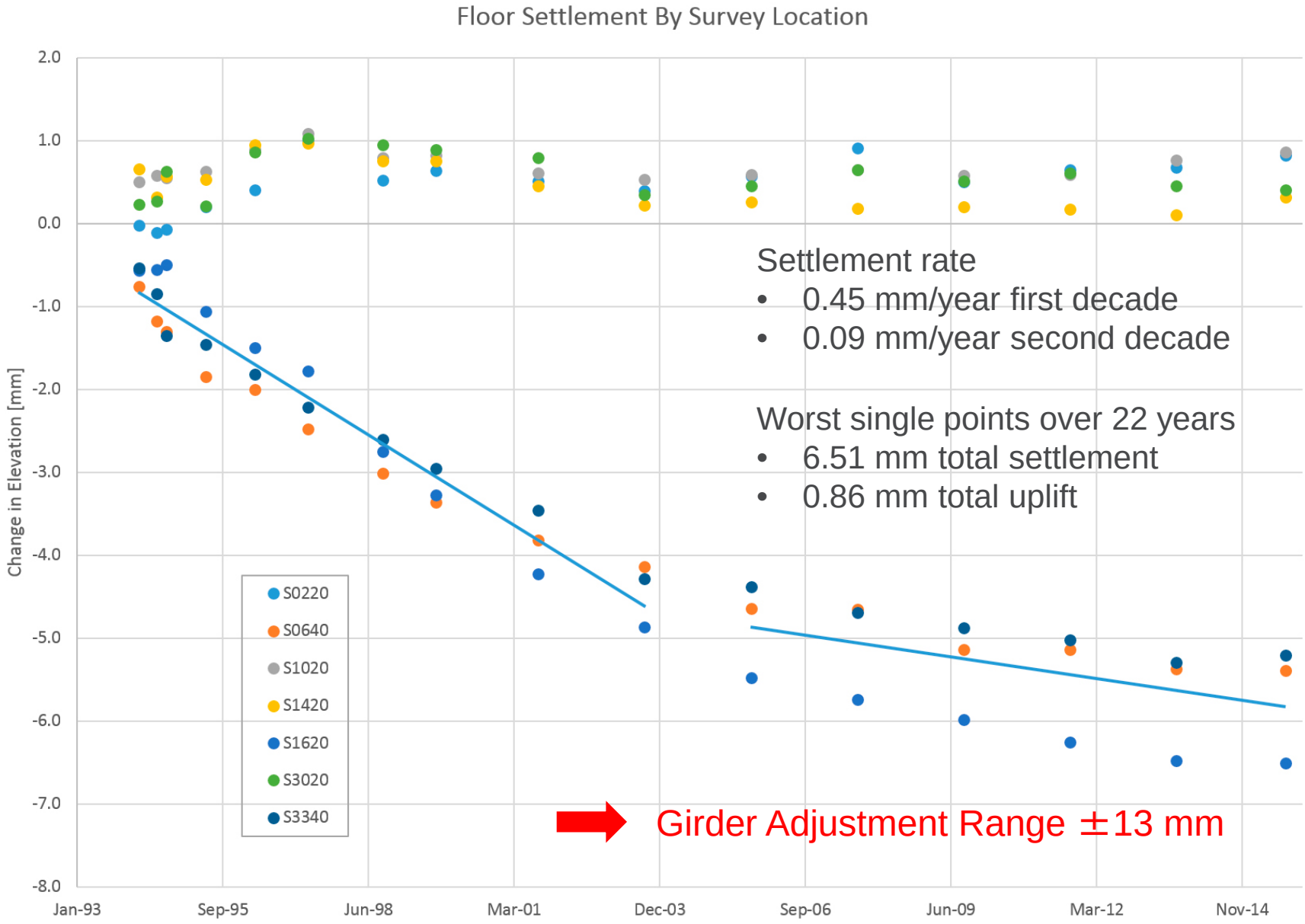


- Verify and densify existing network
- Constrain optimal number of original points
- Global tolerance achievable (30 mm circumference)

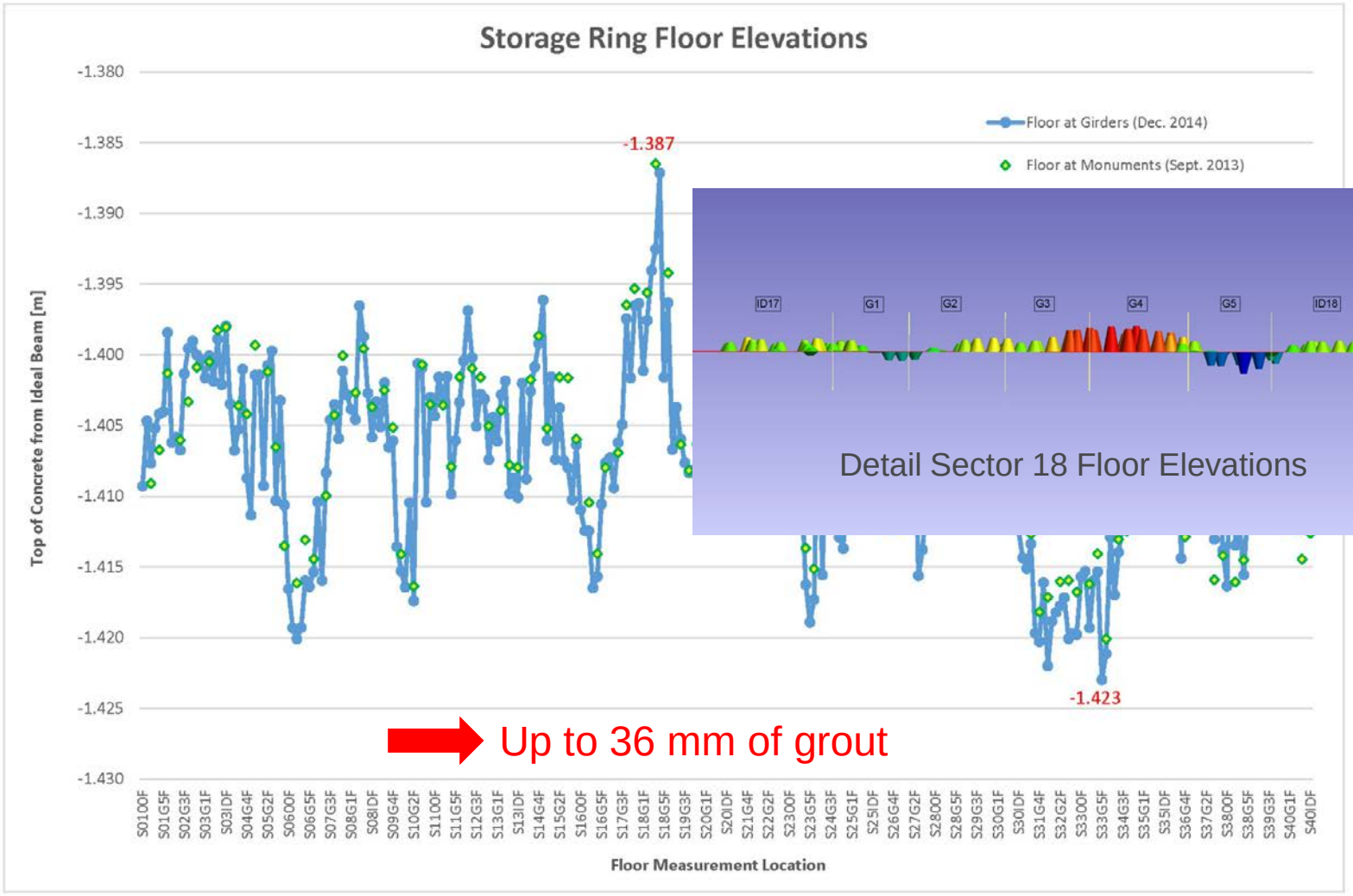
APS Settlement History



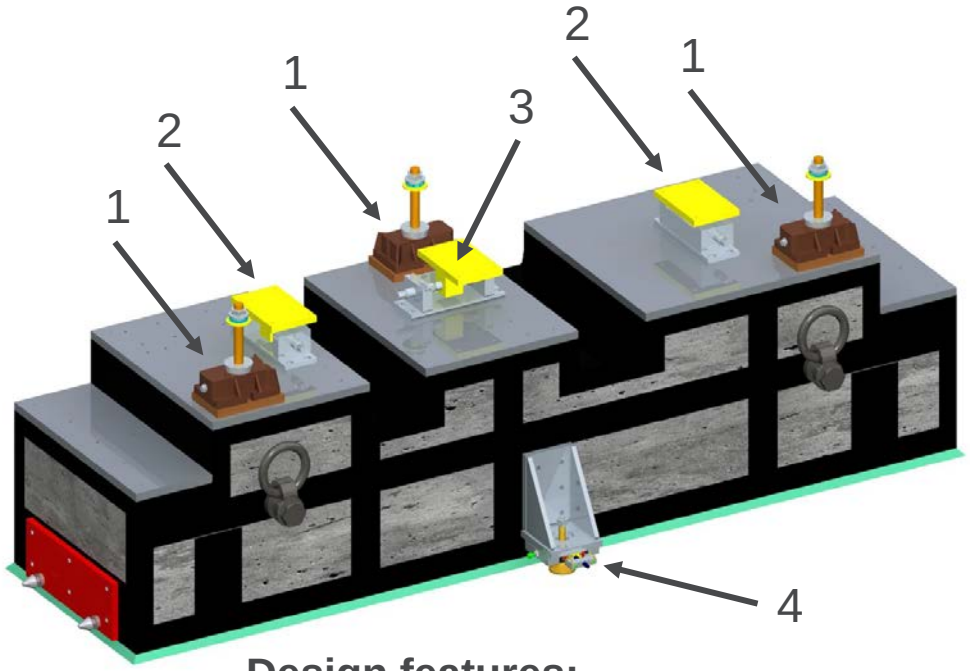
Rate of Settlement



Survey of Storage Ring Floor Elevations



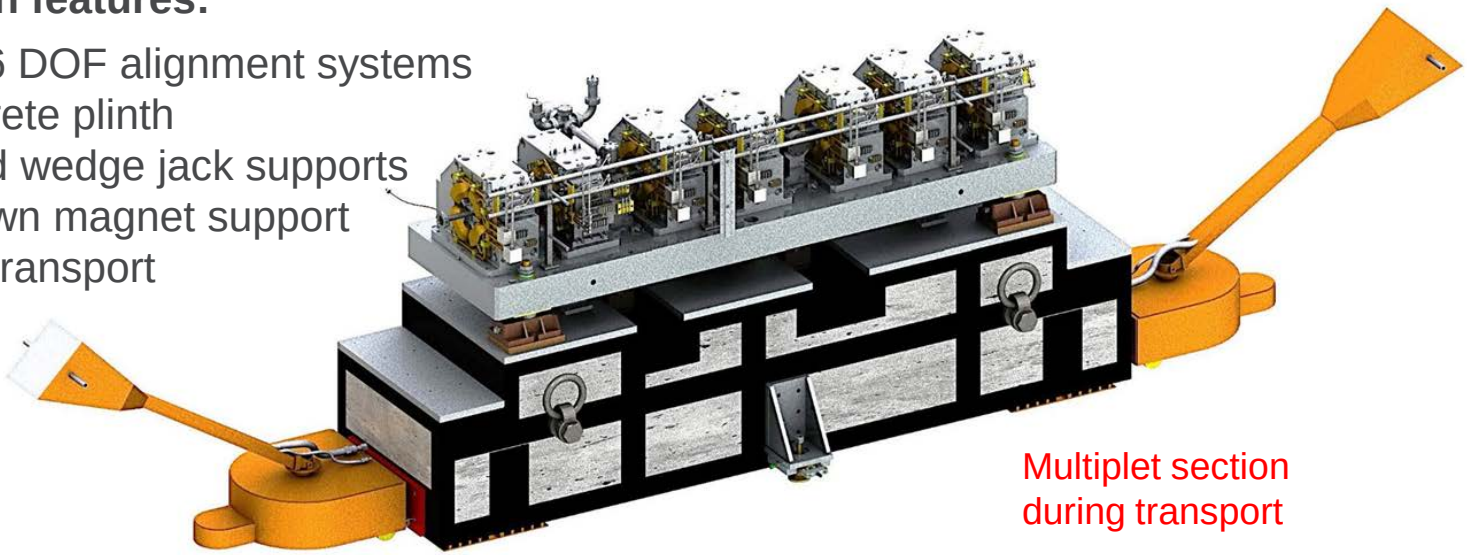
Typical Support Structures & Alignment Systems Design



1. Three-point vertical wedge jack supports with spherical bearings and slip plates to decouple translation and rotation from the vertical motion
2. Lateral pushers to provide lateral and yaw constraint and alignment while decoupling vertical motion
3. Longitudinal pusher to provide longitudinal constraint and alignment while decoupling vertical motion
4. Support outriggers (3 total) to provide 6 DOF for plinth alignment prior to grouting

Design features:

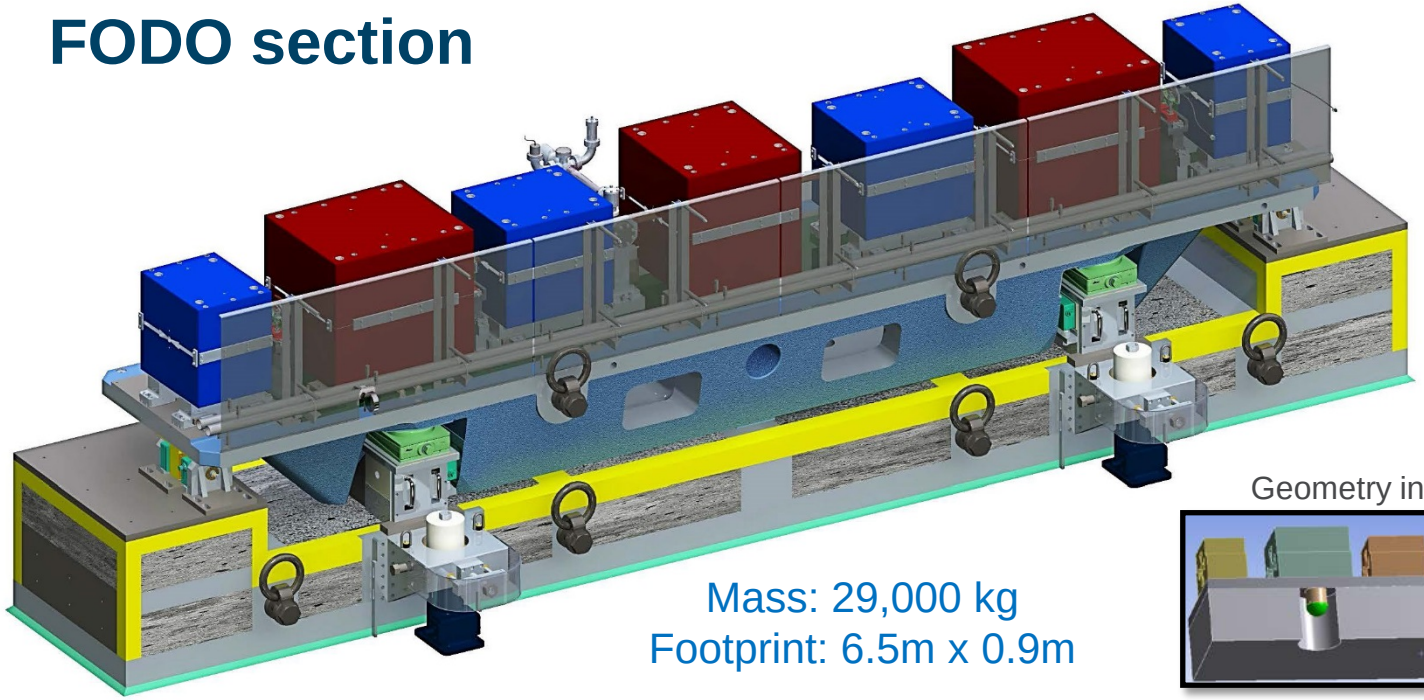
- Semi-kinematic 6 DOF alignment systems
- Reinforced concrete plinth
- Ability to pre-load wedge jack supports
- Ability to lock down magnet support structure during transport



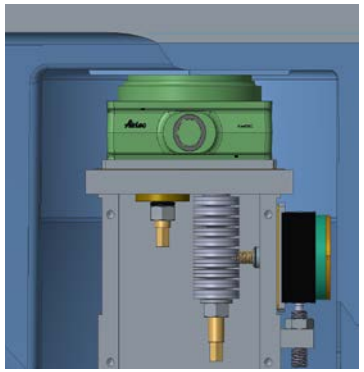
Multiplet section during transport

Support Structures & Alignment Systems Design

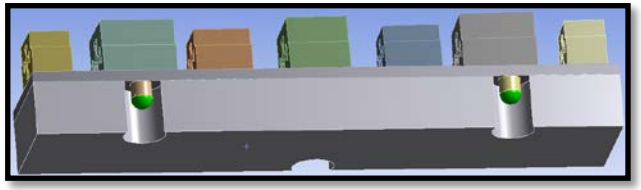
FODO section



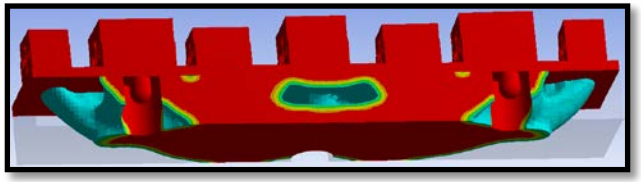
Mass: 29,000 kg
Footprint: 6.5m x 0.9m



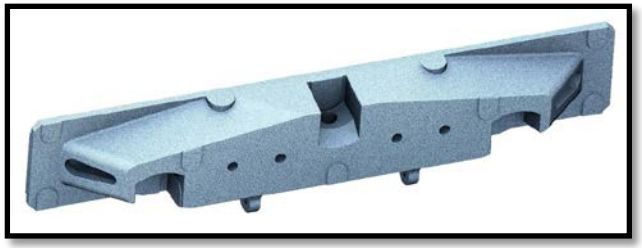
Geometry input to GTAM software



Geometry output from GTAM software



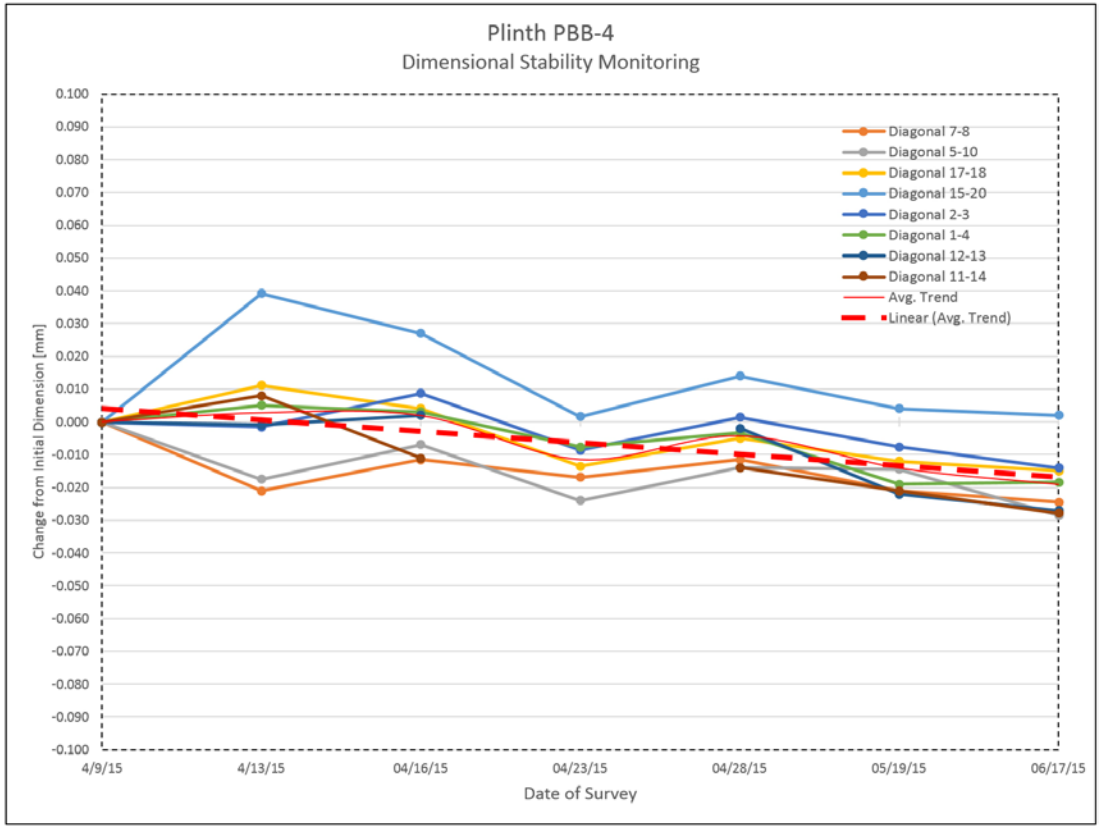
Manufacturable geometry for foundry



Optimization courtesy Zunping Liu

- Wedge jacks used for all lateral pushers
- Aisle side adjustments for all alignment features
- Topology optimization software (GTAM) used to design cast magnet support structure (girder)
- Girder optimized to maximize fundamental frequency and minimize static deflection along the beam path

Concrete Plinth Dimensional Stability Monitoring

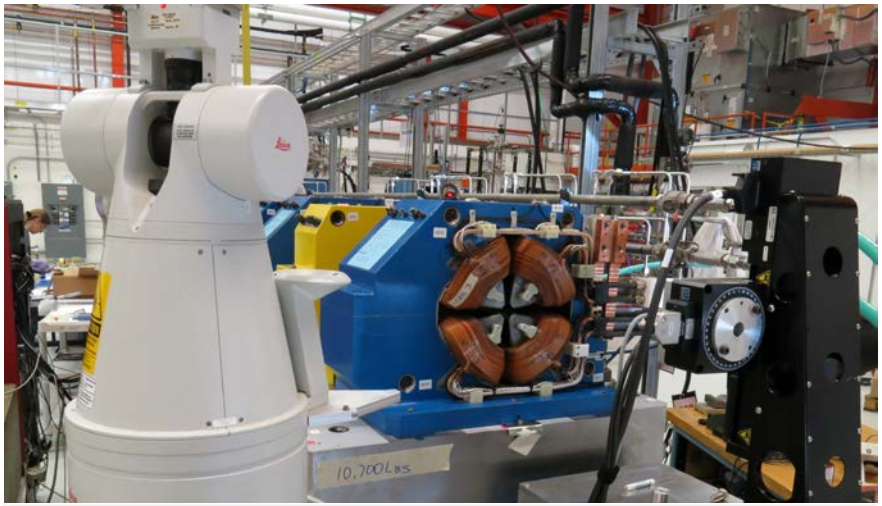


FRONT AND LEFT VIEWS

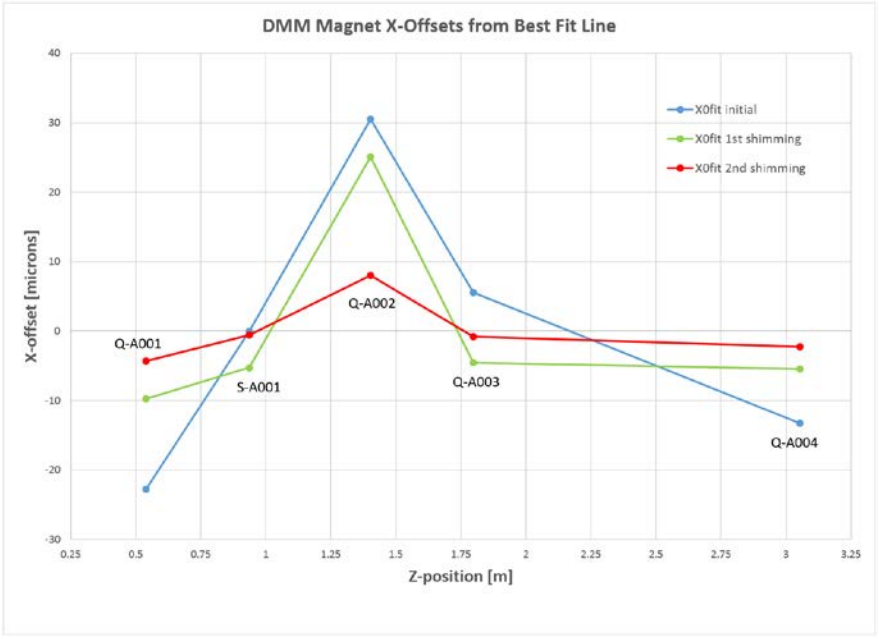
BACK AND RIGHT VIEWS

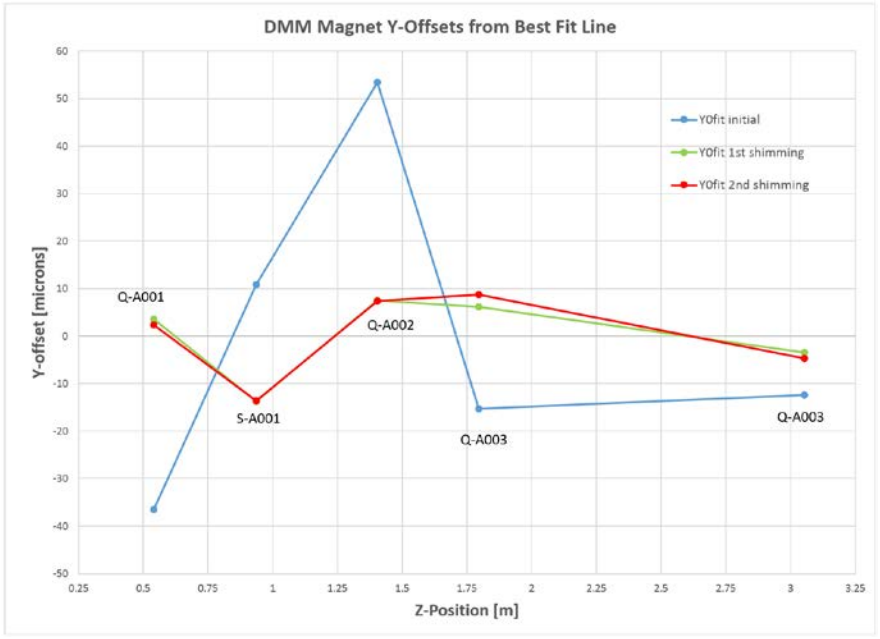
- Plinths effectively raise the floor
- The continuous welded steel frame and proprietary concrete mixture help minimize distortion
- Concrete was poured on 3/27/2015
- Less than 20 µm of shrinkage has been measured

DMM Assembly and Measurement



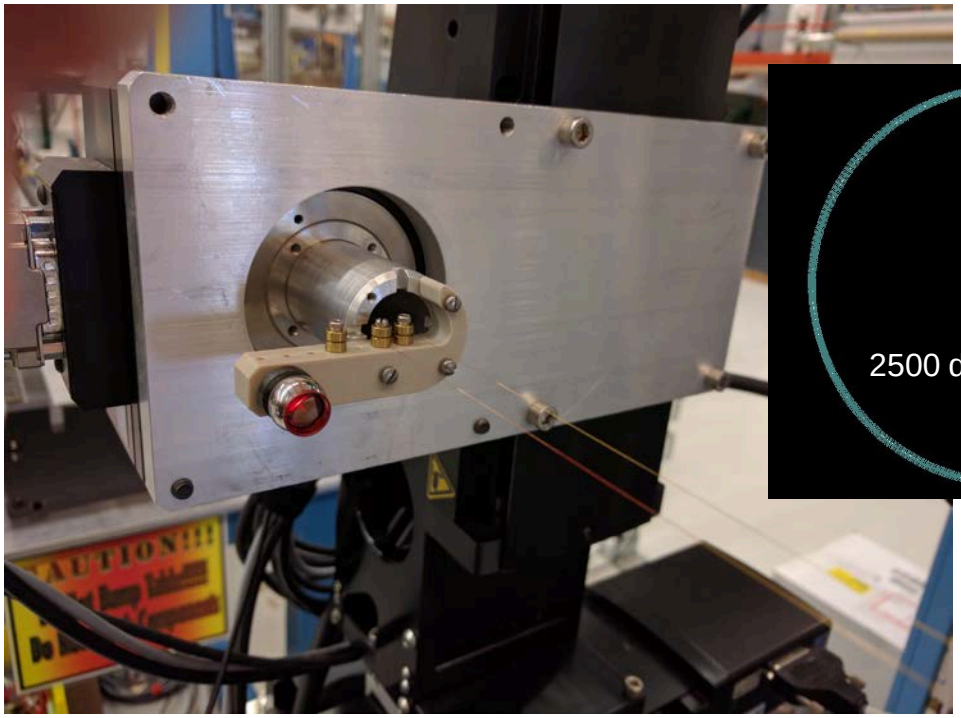
- Initial alignment of the magnets on the girder rely on machining tolerances of the mating parts
- Rotating wire magnet mapping
- Shimming based on magnet mapping data
- 1-2 iterations (45 min. per iteration)



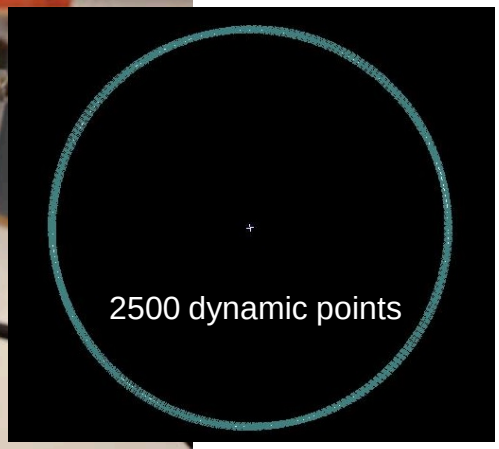


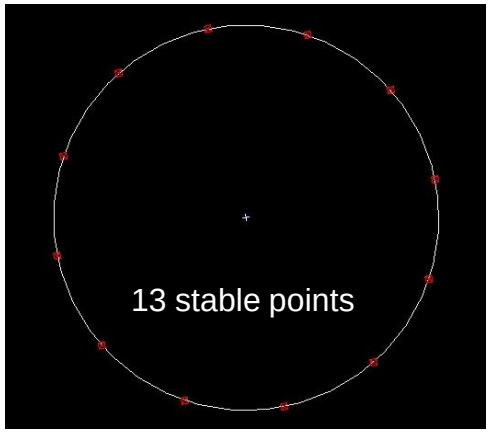
Mag. measurements courtesy Chuck Doose

DMM Fiducialization Tests



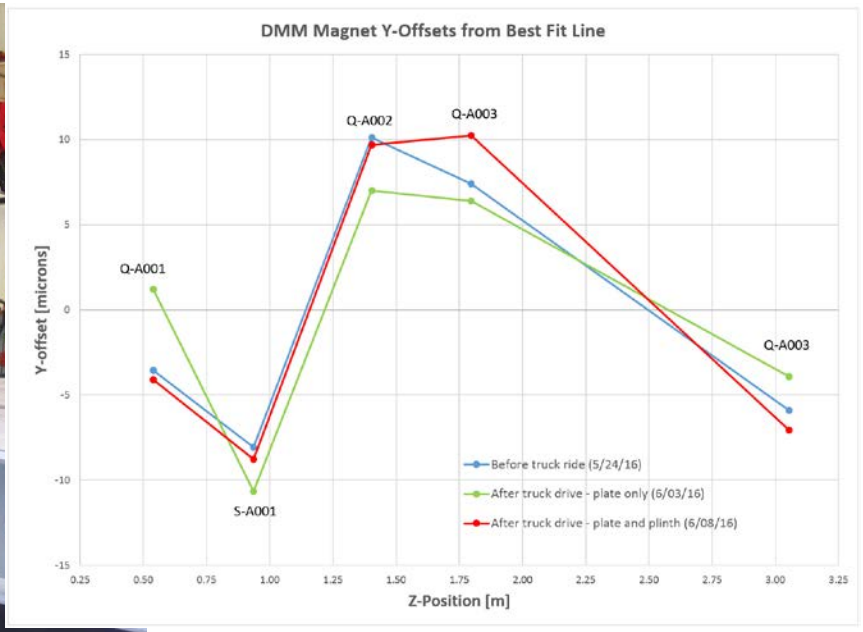
Leica AT930 rotating wire circle measurements



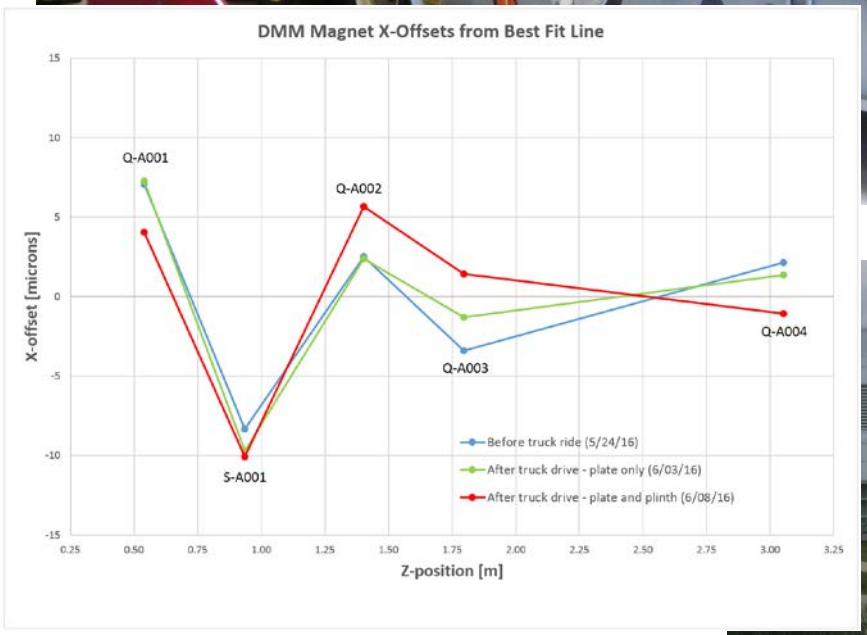


CIRCLE	CENTER			RADIUS	NO. OF POINTS MEASURED
	X (mm)	Y (mm)	Z (mm)	(mm)	
DS DYNAMIC 1	-0.003	0.002	3482.250	36.594	2500
DS DYNAMIC 2	0.001	0.002	3482.251	36.591	2500
DS DYNAMIC 3	-0.002	0.002	3482.251	36.595	2500
DS STABLE MODE (REF)	0.000	0.000	3482.251	36.597	13

DMM Transportation Tests



Repeatability 5 microns per magnet



Final X-alignment 5.5 microns rms

Mag. measurements courtesy Chuck Doose

Summary

- **Survey and Alignment involved in the preliminary design phase of the project.**
  QC of component hardware, helping define design parameters, testing of prototype support and adjustment systems, fiducialization and magnet mapping ⟹ a better design that will be easier to implement.
- **Substantial progress made on preliminary designs of the support structures and alignment systems.**
  Several prototypes have been built and tested, many in procurement.
- **Identified approaches and methodology for meeting alignment tolerances.**
  Identified directions for survey and alignment R&D to validate them.
- **The solution for the most challenging 30 microns components within girder tolerance looks very promising.**
  Approach validated by DMM tests, more work has to be done on optimization of this process and testing the effects of thermal changes, transportation, and long term storage on the stability of alignment.
- **Identified need to start developing a database for S&A data and a model for alignment data flow for the project.**

Thank you for your attention!

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