Mechanical System Overview
Module Assembly and Test

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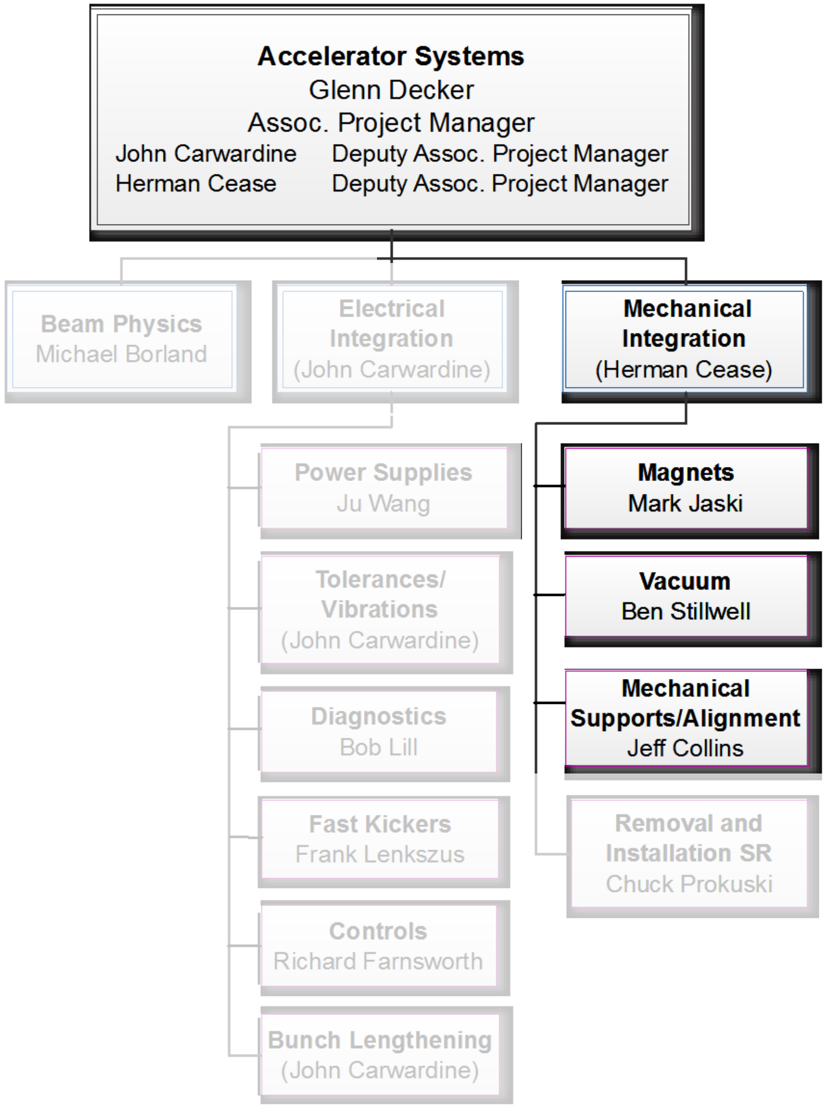
APS-U Accelerator Systems
Mechanical Integration

Forum
July 2015

Outline

- Mechanical team
- Mechanical system overview
  - Magnets
  - Vacuum
  - Supports
- Pre-installation
  - Storage area
  - Magnetic measurements lab
  - Accelerator integration, prep area and module assembly & test
- Risks and Risk Mitigation (R&D)
- Plans - The year ahead
- Summary

Mechanical Systems Organization Chart



<u>FTEs</u>

10 Engineers, 6 Designers

<u>Additional Support</u>

Survey and Alignment

MOM's mechanical, water, vacuum

Rigging

<u>Other accelerator facilities</u>

Magnets: BNL, FNAL

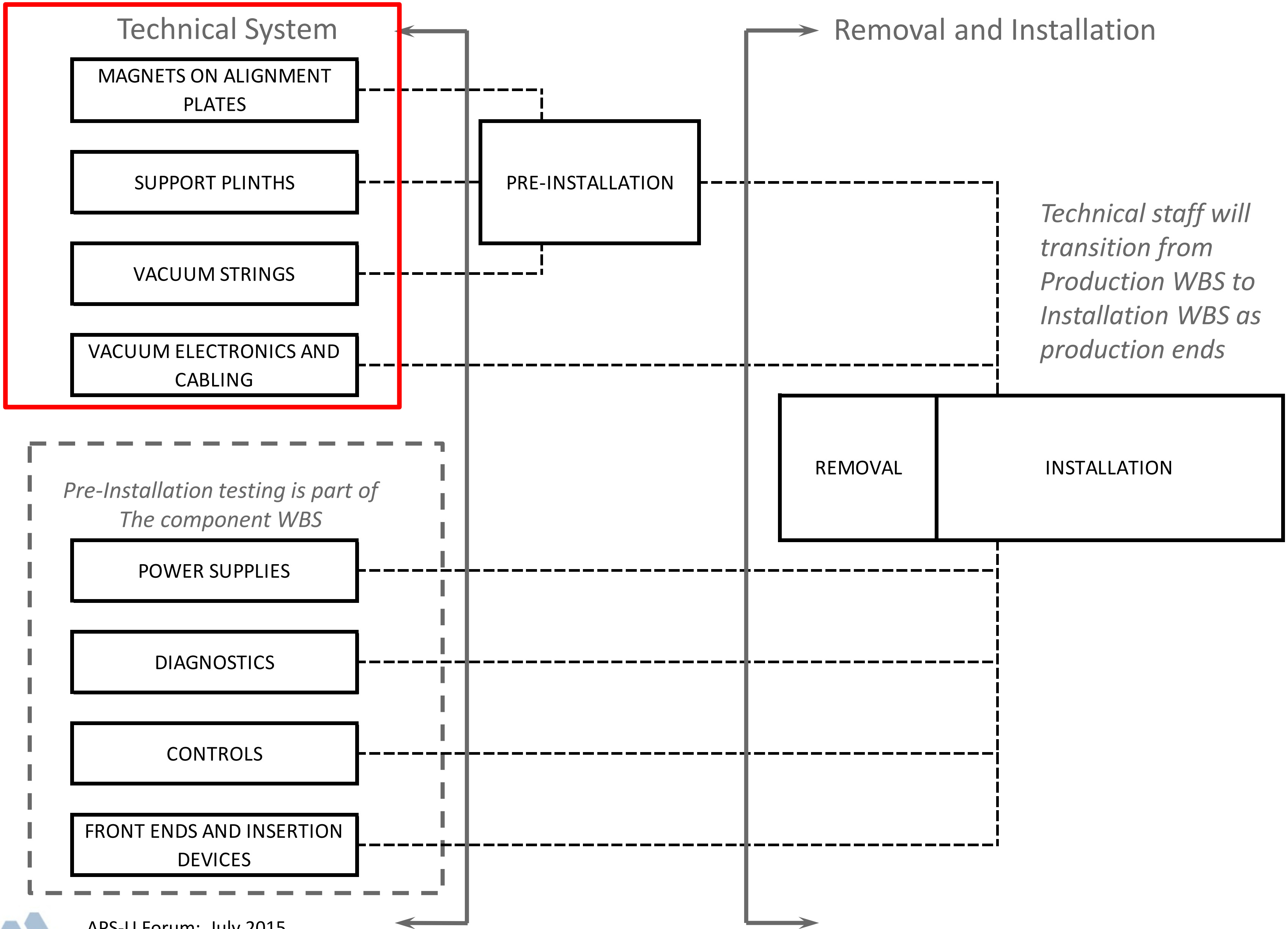
Vacuum simulations: CERN

Supports: MAX IV

SIRIUS

Illinois Institute of Technology

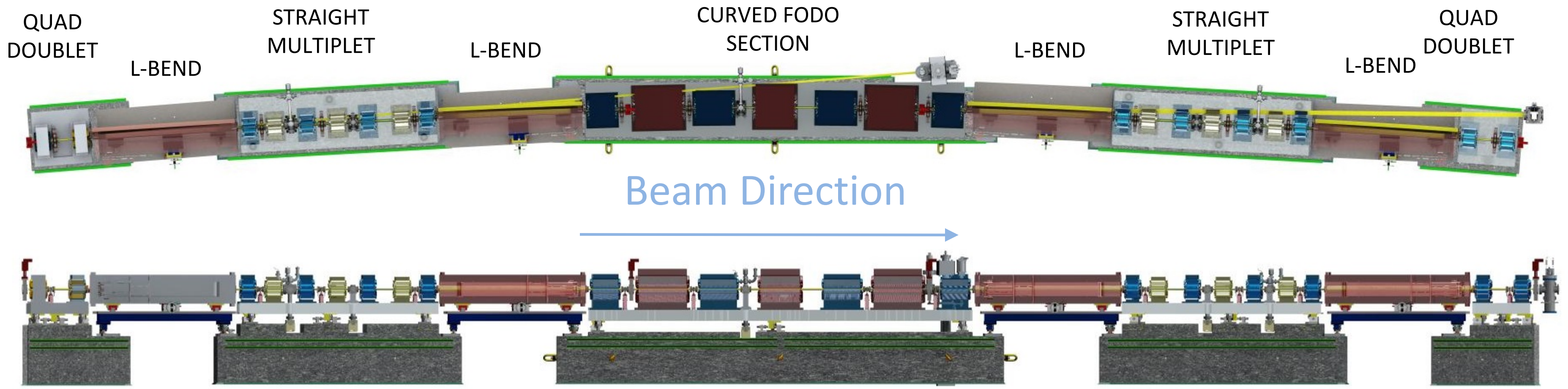
Mechanical System Overview



Mechanical System Overview

Mechanical system

- Storage ring consists of 40 Sectors. Each arc section identical. Length ~27.6 m
- Sector arcs consist of nine modules, four types:
  - Quadrupole doublet: Two quadrupoles and a fast corrector
  - L-bend magnets with a base support, moves laterally for access to vacuum chamber
  - Straight multiplet: Four quadrupoles, three sextupoles, and one fast corrector
  - FODO: Four quadrupoles, three Q-bends, and one 3PW BM source
- 5 Straight sections in Zone F: Length ~5.8 m
  - Scope for injection/extraction and rf modules in their own section
- Assembly and installation readiness:
  - Each module pre-assembled, components aligned, full system tests prior to installation



Design Drivers

Design drivers affecting multiple systems:

- Installation duration
    - FODO section installed as a one piece module
- Alignment capability in the tunnel during installation
    - Final alignment of assembled units to 100 microns rms
    - FODO section installed as a one piece module
    - Final alignment and survey after vacuum chamber bakeout to align absorbers
- Photon apertures from source points to front ends
    - Interface with magnet pole tip and coil gaps
    - Photon extraction apertures in vacuum chambers

Design Drivers

Physics tolerance requirements:

- Vibrational errors:

CDR Table 3.17 Summary of vibrational tolerances

	X (rms)	Y (rms)	X (rms)	Y (rms)
	1-100 Hz		0.1-1000 Hz	
u_{girder}	32 nm	40 nm	320 nm	400 nm
u_{quad}	13 nm	9 nm	130 nm	90 nm

- Static errors:

CDR Table 3.18 Various errors used for start-to-end commissioning simulations

Girder misalignment	100 μm
Elements within girder	30 μm
Initial BPM offset errors	500 μm
Dipole fractional strength error	$1 \cdot 10^{-3}$
Quadrupole fractional strength error	$1 \cdot 10^{-3}$
Dipole tilt	$4 \cdot 10^{-4}$ rad
Quadrupole tilt	$4 \cdot 10^{-4}$ rad
Sextupole tilt	$4 \cdot 10^{-4}$ rad

Magnets: Conceptual Design

Courtesy of Magnet team
M. Jaski

Magnet designs

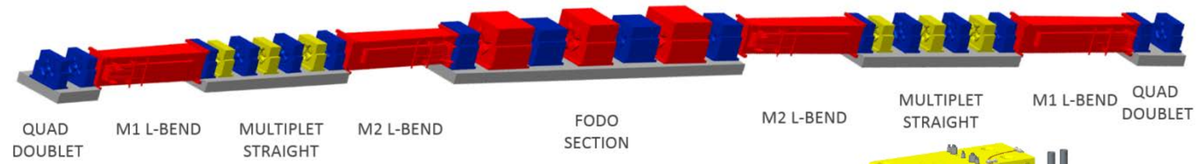
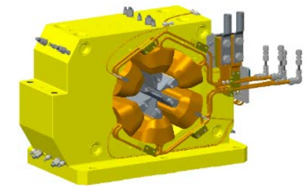


Table 3.44. Summary of MBA magnet types.

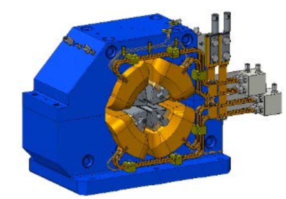
Magnet type		Q1	Q2-Q6	Q7	Q8	S1, S3	S2	M1	M2	M3	M4
Qty/Sector		2	10	2	2	4	2	2	2	2	1
Qty total		80	400	80	80	160	80	80	80	80	40
Insertion length	(m)	.238	.238	.438	.592	.256	.256	2.10	2.12	.780	.650
Pole tip material		VP	ST	VP	VP	ST	VP	ST	ST	VP	VP
Trim winding?		No	No	H+V	H+V	H+V	Y[a]	No	No	H	H

[a] S2 trim windings unpowered.

ST = low carbon steel
VP = vanadium permendur

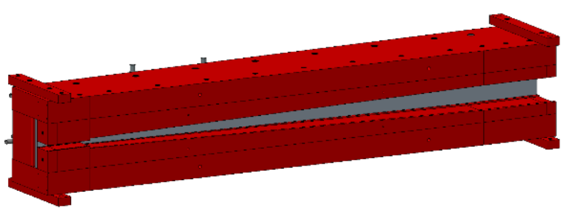


Sextupole Magnets
S1-S3

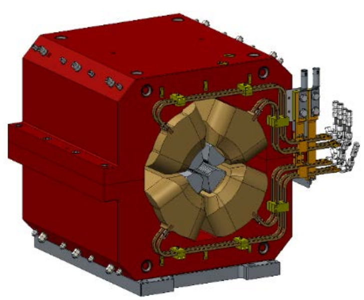


Quadrupole Magnets
Q1-Q6

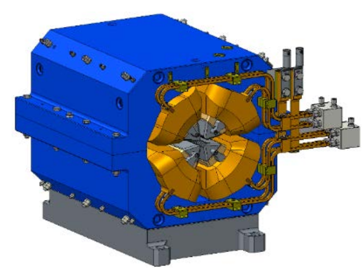
Total number of magnets: 1320 (including 160 fast correctors)
Requirements listed in the CDR and FReD



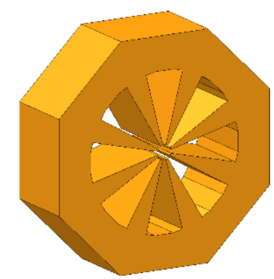
L-Bend Magnets
M1, M2
R&D collaboration with FNAL



Q-Bend Magnets
M3, M4



Quadrupole Magnets
Q7, Q8



8-Pole Corrector
R&D collaboration with BNL

Magnets: Module assembly

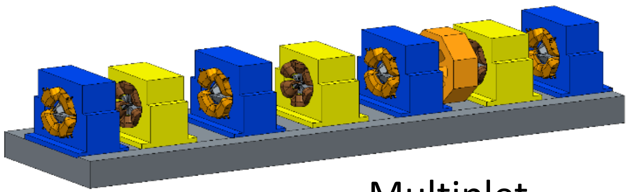
Courtesy of Magnet team
M. Jaski

Magnetic measurements

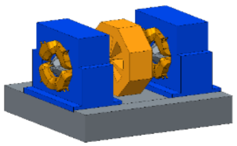
- APS will perform magnetic measure in detail: verify field strength, field harmonics
  - data for installation and operations stored in component database
- Collaborating with BNL and FNAL for measurement systems development

Module assembly and magnet to magnet alignment

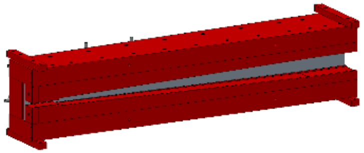
- Magnets mechanically aligned to the support,
  - Machining and assembly tolerance study and R&D fabrications shows that 30 micron rms magnet-to-magnet alignment is feasible.
- Magnetic center alignment verified using stretched wire during Assembly and Test.
  - Tested in R&D



Multiplet

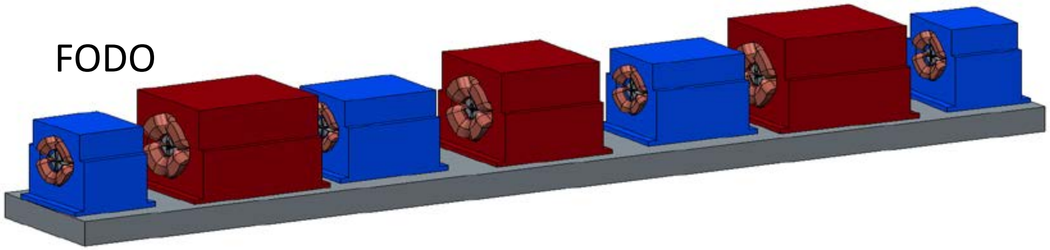


Doublet



L-Bend

FODO

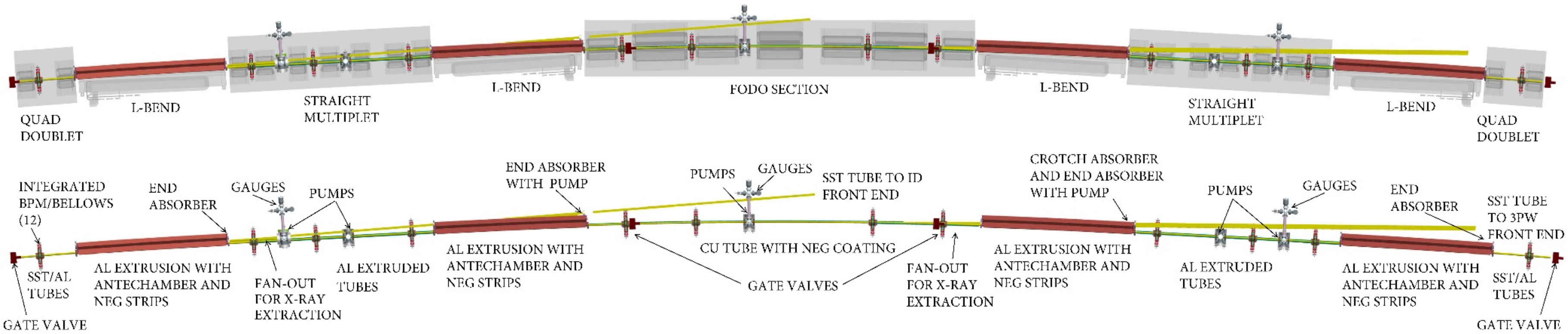


Deliverables:

80 Quad doublet modules
80 Multiplet modules
40 FODO modules
160 L-bend magnets

Vacuum: Deliverables to pre-installation

Courtesy of Vacuum team
B. Stillwell



Hybrid design:

- Quad-doublet, and straight multiplet: Aluminum chambers,
  - Alloy steel at fast correctors
- M1 and M2 L-bend dipoles: Aluminum chamber with antechamber
- FODO: Six chambers, four are NEG coated at regions with high PSD

Vacuum deliverables:

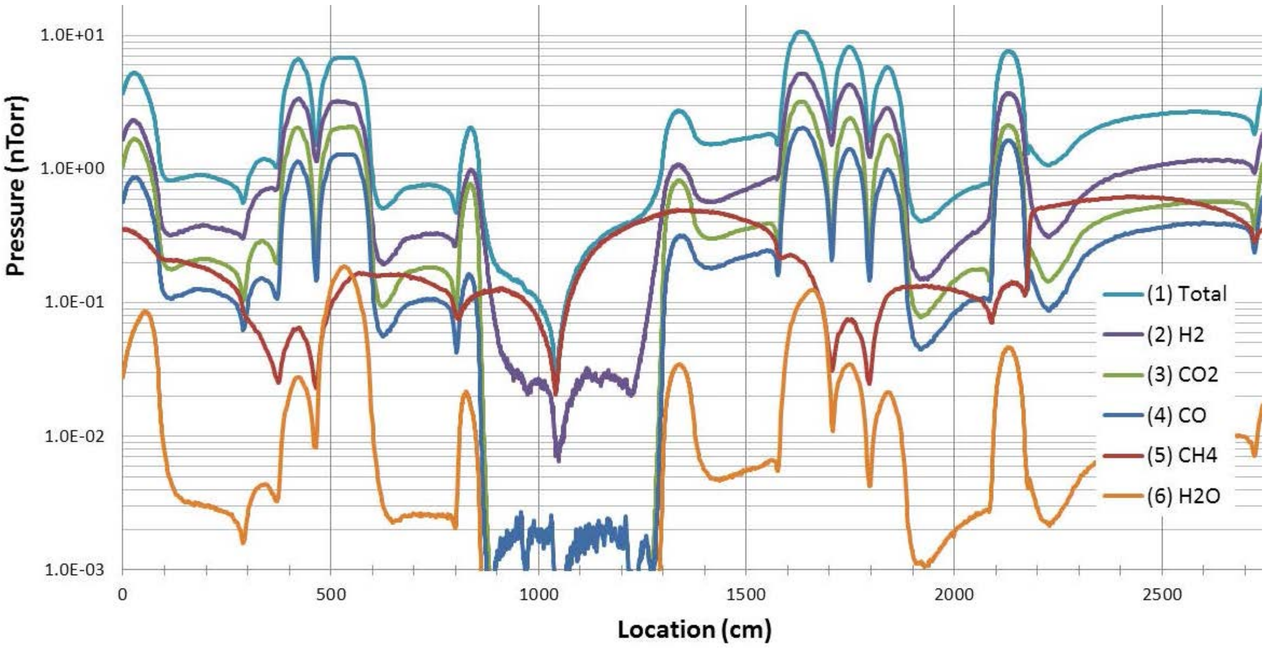
- 80 Quad doublet vacuum chamber strings
- 80 M1 magnet and 80 M2 magnet vacuum chambers
- 40 Upstream Multiplet, and 40 downstream Multiplet vacuum chamber strings
- 40 FODO vacuum chamber strings
- Chambers for photon extraction to Front Ends
- Vacuum strings include BPM assemblies and pump out ports

Courtesy of Vacuum team
B. Stillwell

Vacuum: Modeling

Vacuum Modeling

- Working with CERN and using CERN's simulation tools SynRad and MolFlow
  - Developing synchrotron radiation power distribution on absorbers and chamber walls
  - Developing pressure profiles

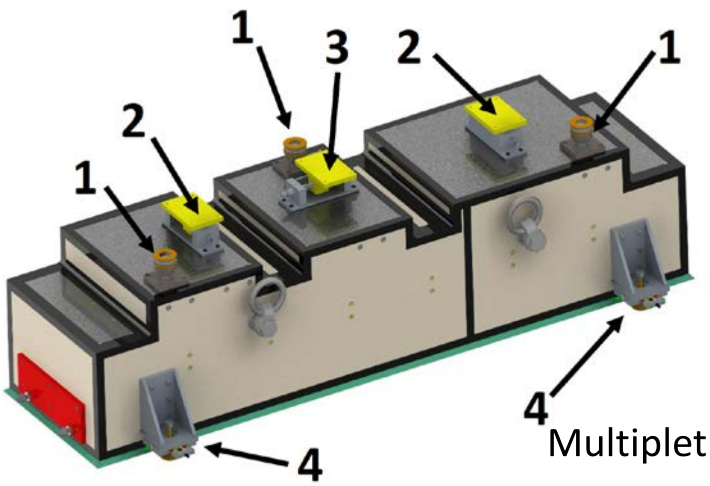


Supports and Alignment: Deliverables

Courtesy of Support team
J. Collins

Supports deliverables:
- 80 Quad doublet plinths with adjustment mechanisms
- 80 M1 magnet and 80 M2 magnet support bridges and adjustment mechanisms
- 80 Muliplet plinths with adjustment mechanisms
- 40 FODO plinths with adjustment mechanisms

Supports deliverables: needed for installation
- Grout, Grout frames, air casters…



Multiplet plinth

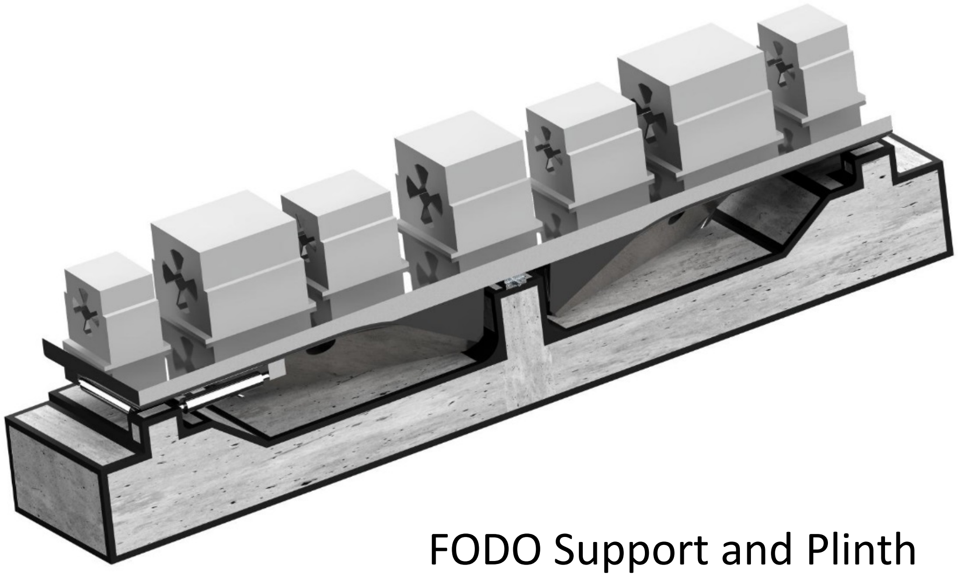
1. Vertical support adjustment mechanism
2. Lateral support adjustment
3. Longitudinal support adjustment
4. Support outriggers used to position module and plinth in the Storage Ring tunnel

Courtesy of Support team
J. Collins

Supports and Alignment: Conceptual Design

Design development

- Mounts through magnet support during transport
- Full length FODO plinth and support plate is feasible
  - Design optimization for gravitational sag, and first mode natural frequency
  - Magnet support clamped during transport
  - Testing planned in R&D
- Iterating with physics on alignment tolerances,
  - Loosening alignment tolerances in FODO section may help with design options.



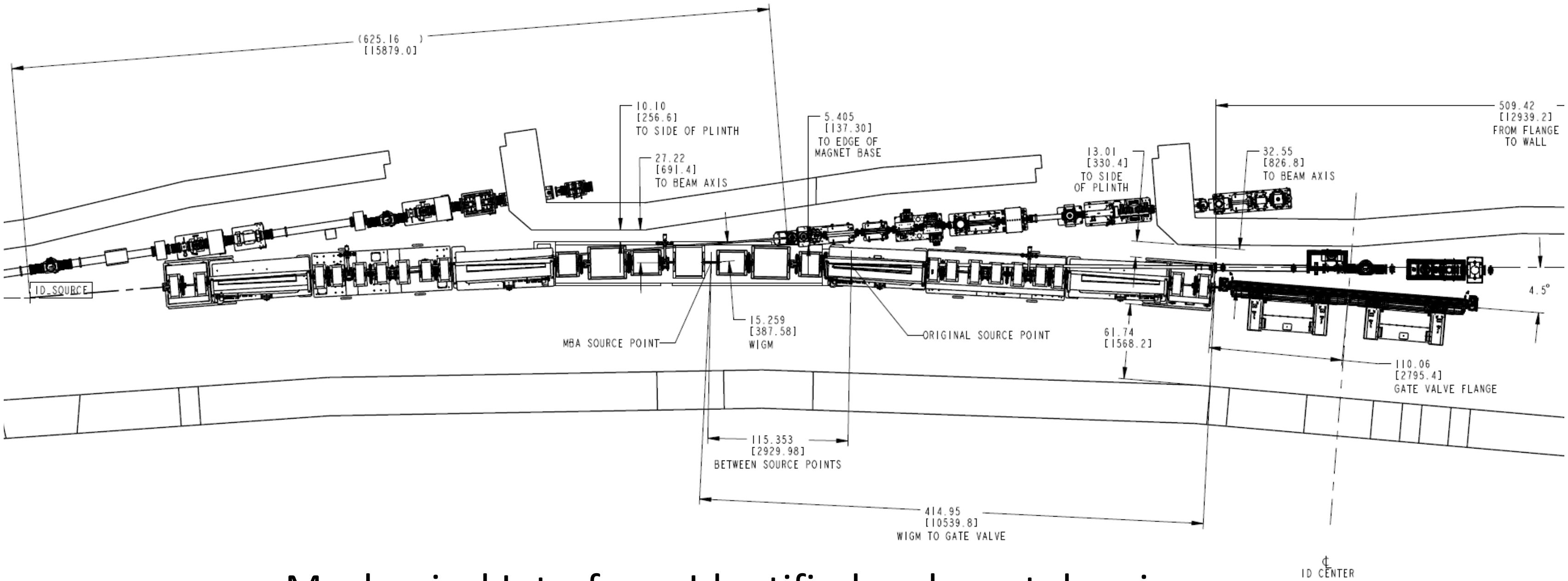
FODO Support and Plinth
Design Optimizations

Support clamped
During transport

Mechanical System Overview: Interfaces

Interfaces with systems

- Sub-system scope and sub-system interfaces identified
  - Functional Requirements Document
- Front Ends and Insertion Devices
  - Solid models define mechanical interfaces
  - Sector layout drawing identifies interface locations
- Mezzanine
  - Sub-systems identify equipment controllers and scope

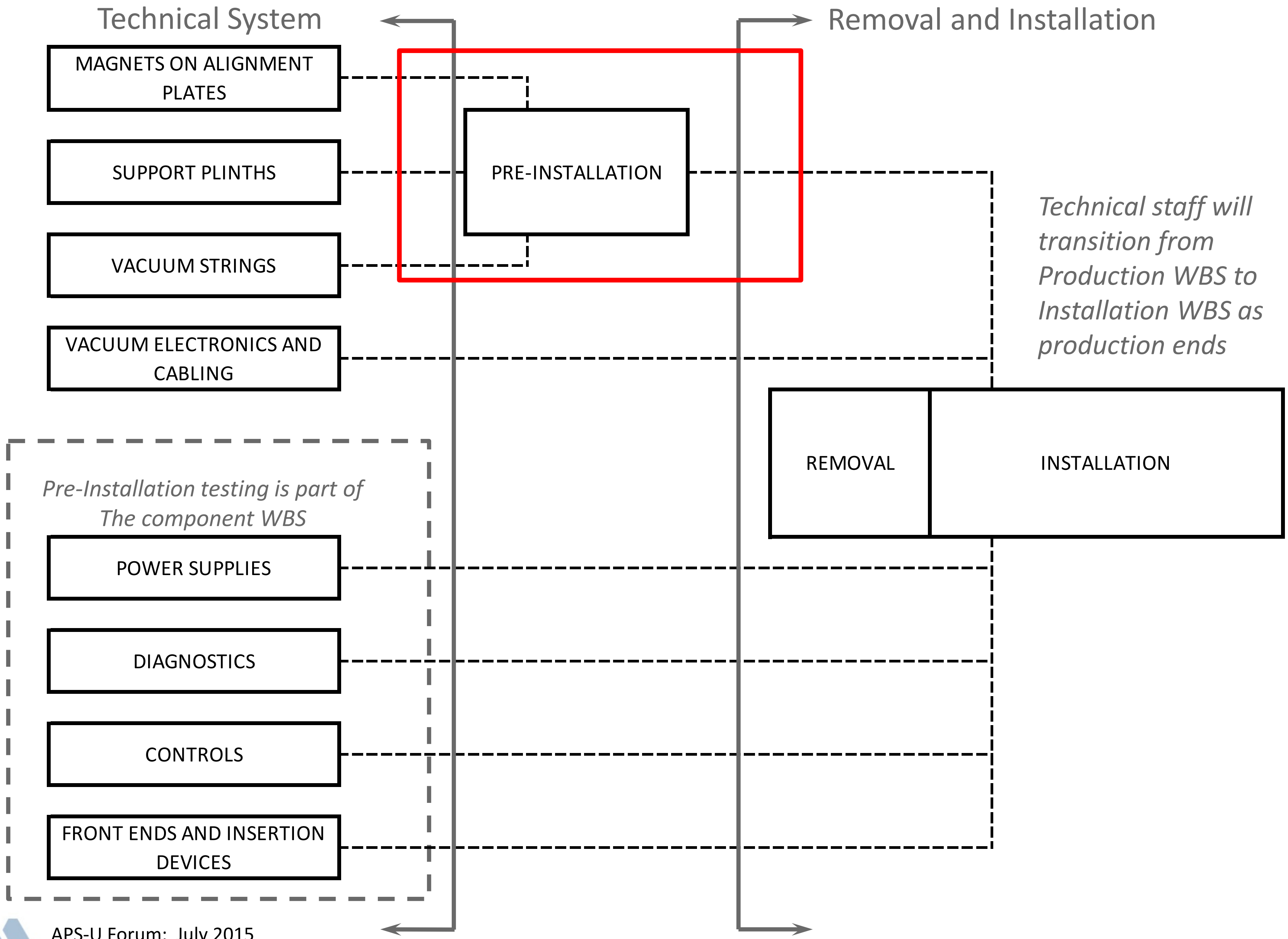


Mechanical Interfaces Identified on layout drawings

Interface matrix in Functional Requirements Document

Courtesy of Removal/Installation
C. Prokuski
T. Fornek

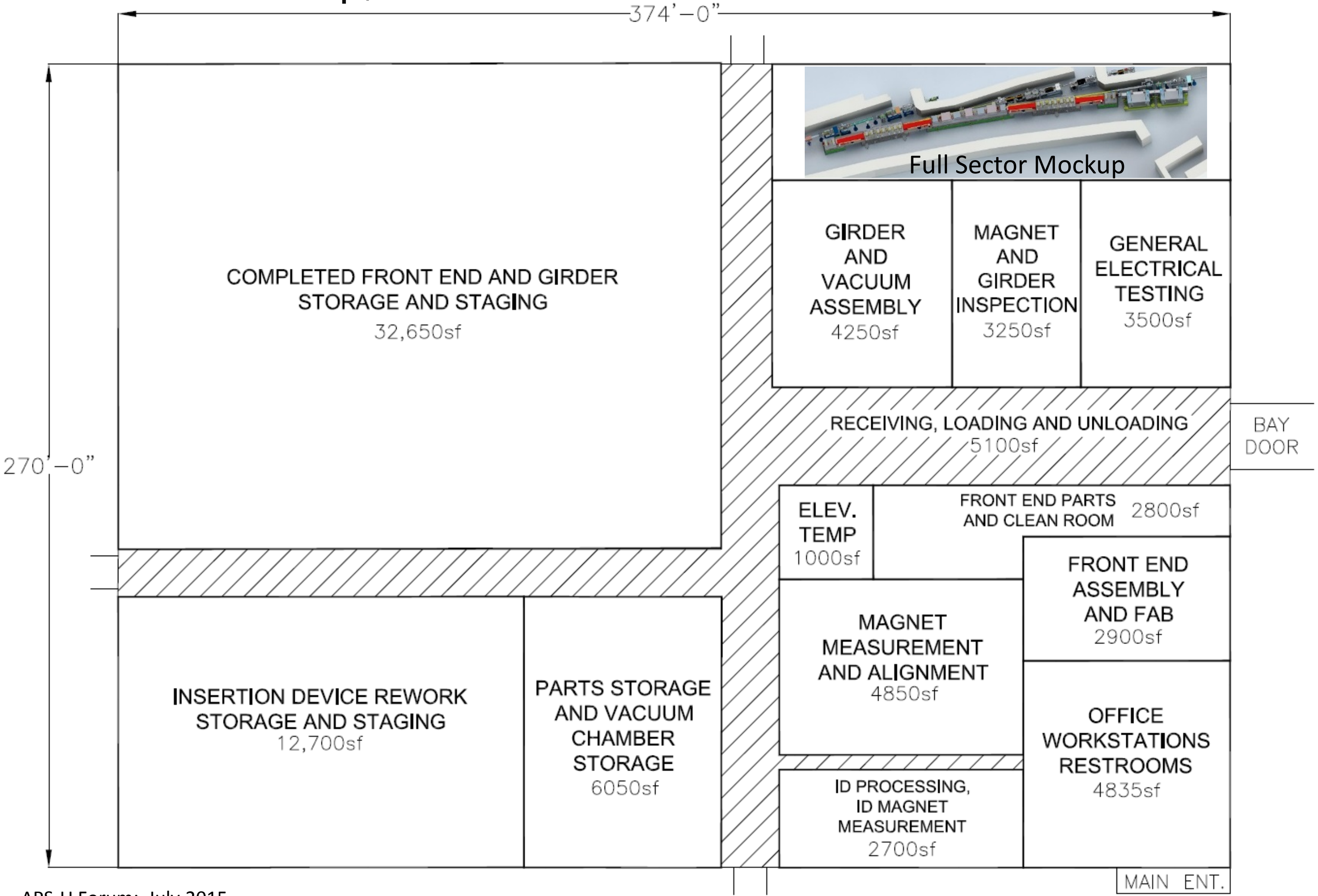
Pre-installation



Courtesy of Removal/Installation
C. Prokuski
T. Fornek

Accelerator integration: Pre-installation prep area, staging

- +100,000 ft^2
- Module Assembly and Testing space
- Magnet measurement and alignment
- Full sector mockup, with ratchet walls



Accelerator integration
Module Assembly and Test

Deliverables to Module Assembly and Test

- Received from technical sub-systems
  - Assembles completed and tested units from the technical subsystems
    - Magnets: Magnet modules mechanically aligned to a support
    - Vacuum: Strings of vacuum chambers assembled and leak tight
    - Supports: plinths and adjustment mechanisms
    - Diagnostics: BPM button electrons and cabling
    - Water systems: Water manifolds
- Module assembly and test
  - Builds and tests:
    - 80 Quad doublet modules
    - 80 Multiplet modules
    - 40 FODO module
    - 160 L-bend modules
- 19,000 hrs of assembly and testing, 52.7 FTE hrs per module.
  - Effort basis from NSLS-II

Module Assembly and Testing

Module assembly:

- Subsystems deliver completed sections to the assembly area

Multiplet Module Assembly steps:

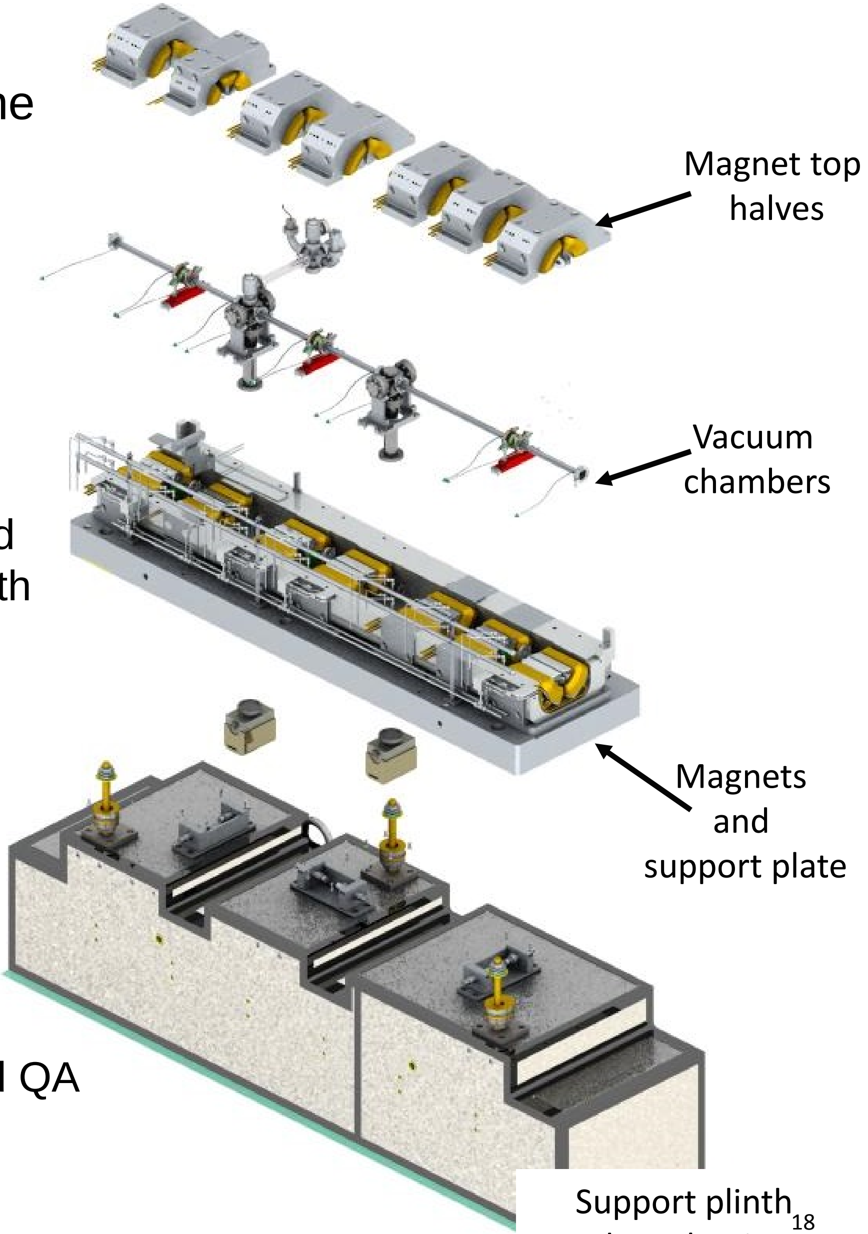
- Split magnets on magnet module
- Install and align vacuum chambers
- Assemble magnets
- Verify magnet alignment using stretched wire
- Install diagnostics, instrumentation, water manifold
- Mount Magnet and vacuum assembly on plinth with support mechanisms

Magnetic center alignment:

- Achieved with mechanical tolerances
- Verified using stretched wire techniques
- Shim any unacceptably misaligned magnet

Module testing:

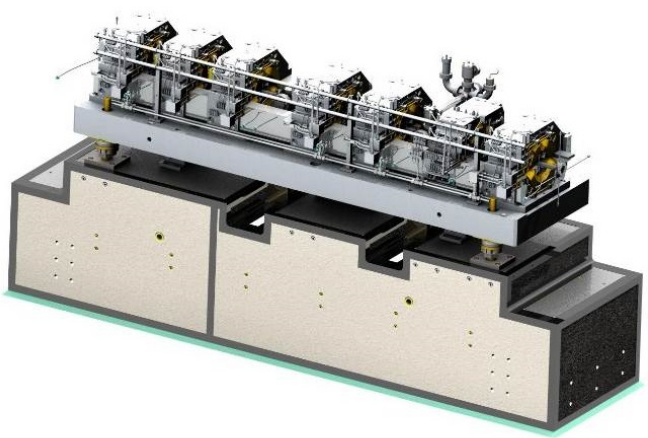
- Each assembled module undergoes systems and QA checks



Accelerator integration
Module Assembly and Test

Module Test

- Magnets:
  - Magnetic centerline verified
  - Water leak test, hipot, test temperature sensors and thermal switches
- Vacuum:
  - Water leak test, vacuum leak test
- Supports:
  - Center magnet and vacuum assembly on the plinth
- Diagnostics:
  - Connect BPM signals to filter/comparator box and check signals.
- Controls:
  - Label connections to control systems
- During storage, some tests repeated

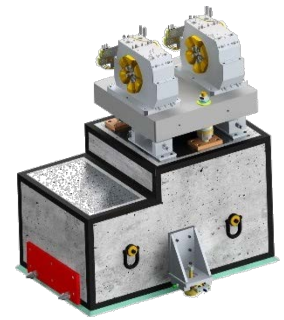


Assembled
Multiplet Module

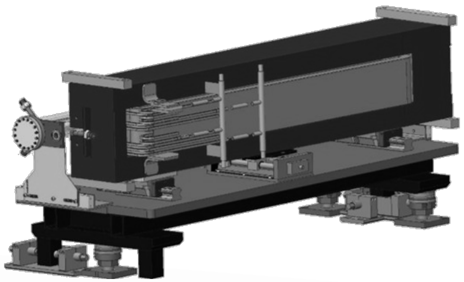
Accelerator integration
Module Assembly and Test

Deliverables to Installation queue storage area

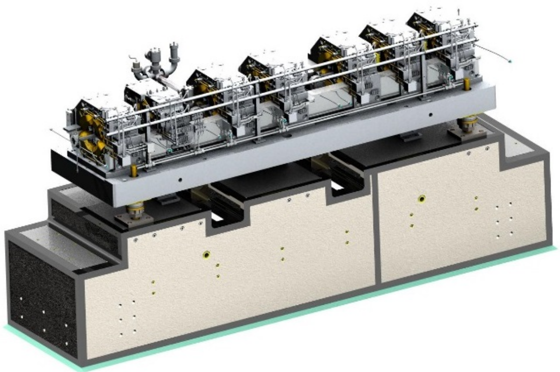
- Fully assembled and tested modules
  - Two quad doublet modules per sector
  - Four L-bend modules per sector
  - Two Multiplet modules per sector
  - One FODO module per sector
- Electronic systems
  - Power supplies
  - Diagnostics



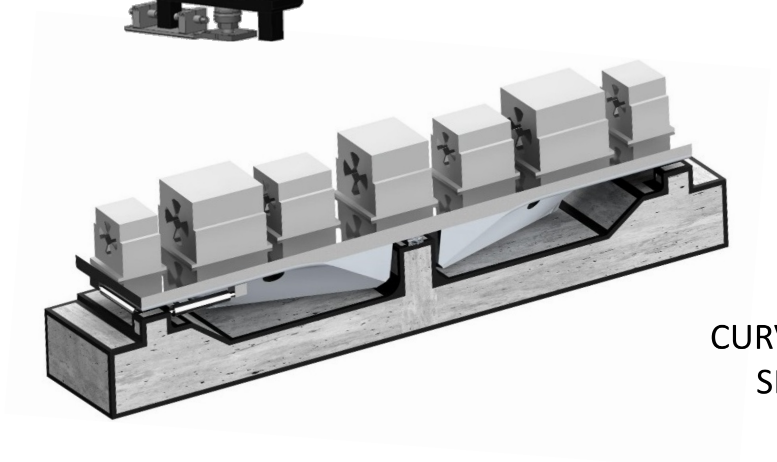
QUAD DOUBLET



L-BEND



STRAIGHT MULTIPLET



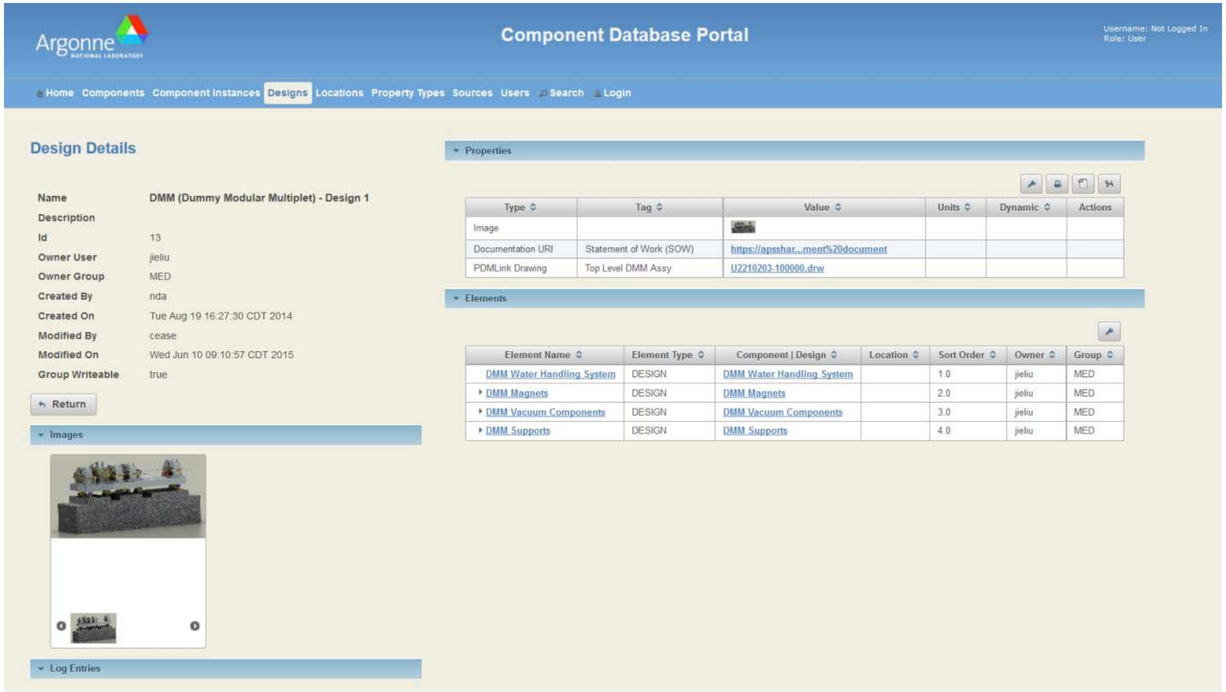
CURVED FODO SECTION

Module Assembly and Testing
Component Database

Courtesy of Controls team
N. Arnold

Tracking of components, data, travelers:

- Engineering applications are developed in the R&D phase
- Component Database Tracking:
  - Components
  - Reference documents, manuals, drawings….
  - Procurement information
  - QA and procedure travelers, including magnetic measurements



Database software developed in Electrical Systems WBS

Design Challenges

Integration risks

- Alignment and stability
  - Repeatability in assembly of magnets top/bottom half
  - Maintaining magnet alignment before and after module transport
  - Temperature induced motions causing alignment issues
  - Alignment of components and stability of critical vacuum components and BPMs
  - Meeting vibration specifications
  - Magnet alignment in the FODO section
- Moving large assemblies: Magnet modules
- Equipment availability for installation

R&D plans in place to help manage risks and develop designs

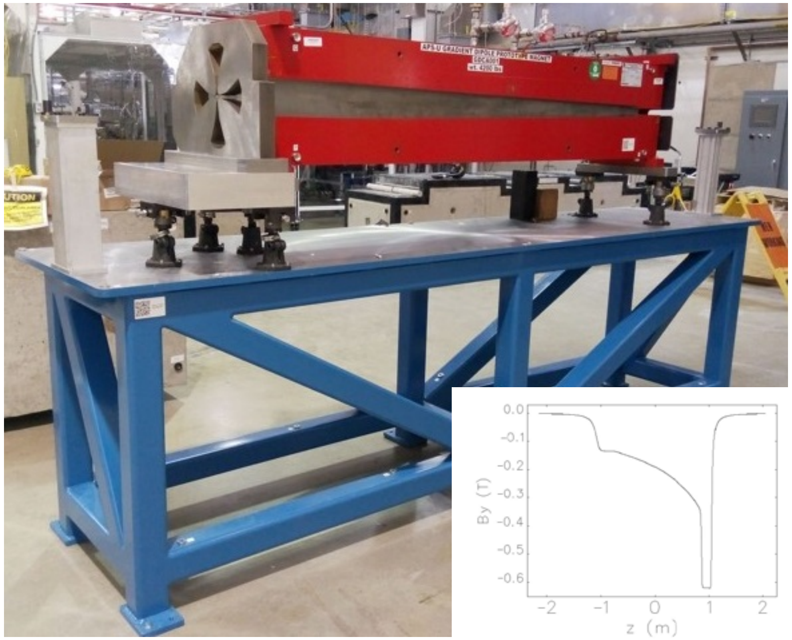
R&D plans

Early R&D assemblies

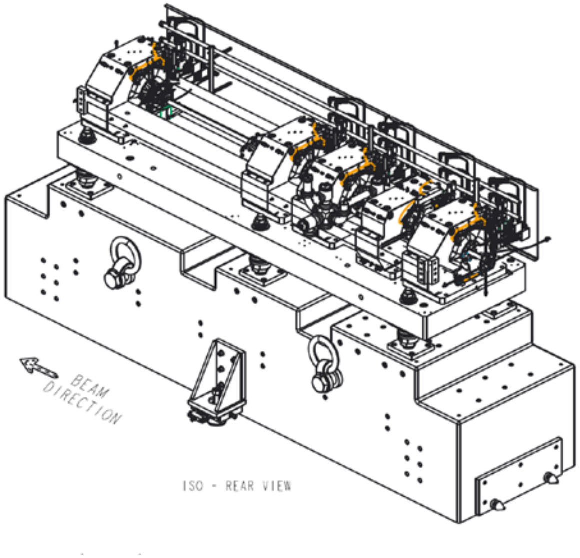
Will measure alignment, stability, repeatability, magnetic measurements, magnet alignment….

- Multiplet module
- L-bend module
- FODO module, full length concept
- Fast corrector with vacuum chamber

R&D DMM Multiplet Concrete Plinth



Initial magnetic measurements performed at FNAL and in MM1

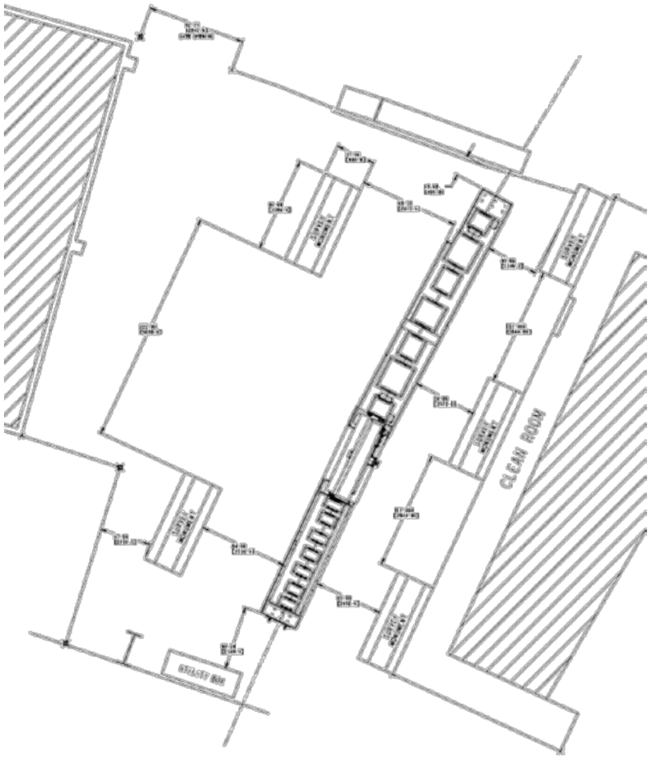


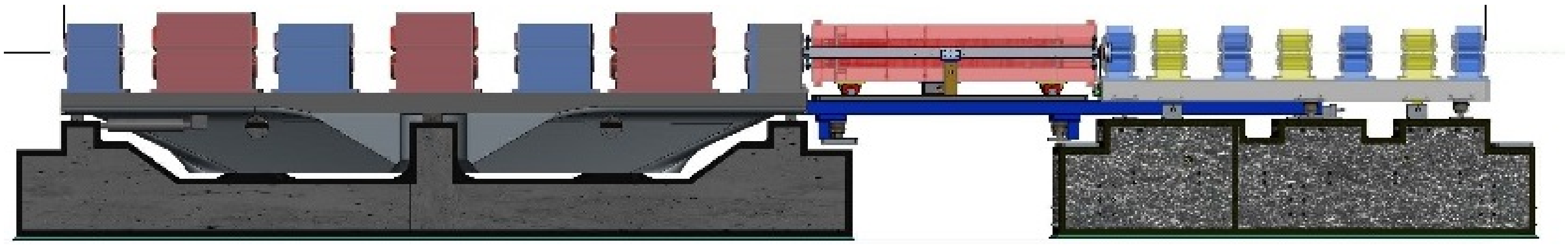
R&D DMM Multiplet Module

Integrated R&D plans

Integration activities and R&D plans to be completed in FY17

- Partial Sector mockup R&D program
  - Integrated assembly of Multiplet, L-bend, and FODO module in EAA.
- Component Database
  - Tracking of components, assemblies
  - Travelers, data, parameters, vendor information.
- Full Sector mockup (WBS U2.03.05.03.01)
  - Full sector, starting with components from the partial sector mockup and first articles.





Summary

Conceptual Design leverages previous history:

- Communicating with other facilities
- Lessons learned

Design drivers and requirements addressed:

- Scope, design drivers, and requirements reviewed
- Requirements defined and interfaces identified:
  Functional Requirements Document

Risks are identified, R&D plans:

- R&D plan addresses many of the risks
- R&D plan allows down selection of designs
- Integration issues will be discovered and mitigated early

Scope, cost and schedule developed with BOEs