APS Upgrade Status

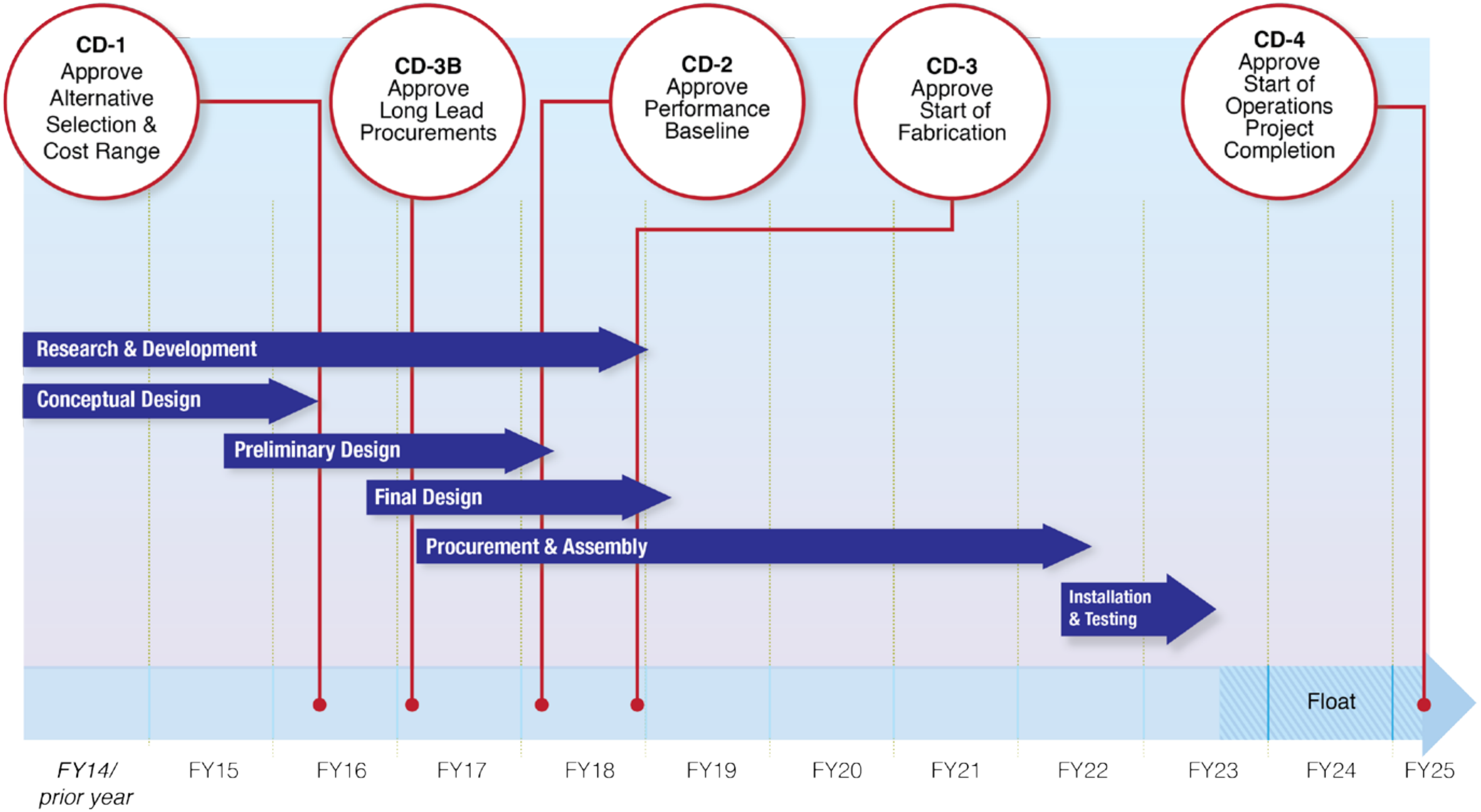
Glenn Decker, for the APS-U Team
APS-U Associate Project Manager - Accelerator
Argonne National Laboratory

BNL High-Brightness Synchrotron Light Source Workshop
April 26, 2017

Outline

- APS-U Design Overview
- R&D Activities / Results
- Summary

APS Upgrade Project Schedule



This schedule is based on a proposed funding profile

APS-U Storage Ring Lattice

- 67 pm H7BA* lattice presented in the Conceptual Design Report
- 41 pm lattice – Chosen for the Preliminary Design
  - Very similar to 67 pm lattice – same number of magnets
  - Q4, Q5, Q8 quadrupoles (6 per sector) get displaced horizontally by 2-4 mm to become transverse-gradient weakly-deflecting reverse-bend dipoles
  - 2.8 MeV energy loss / turn vs. 2.27 MeV for 67 pm
  - ID source position, angle constrained to present locations
    - Ring circumference changes slightly – Injector timing system impact

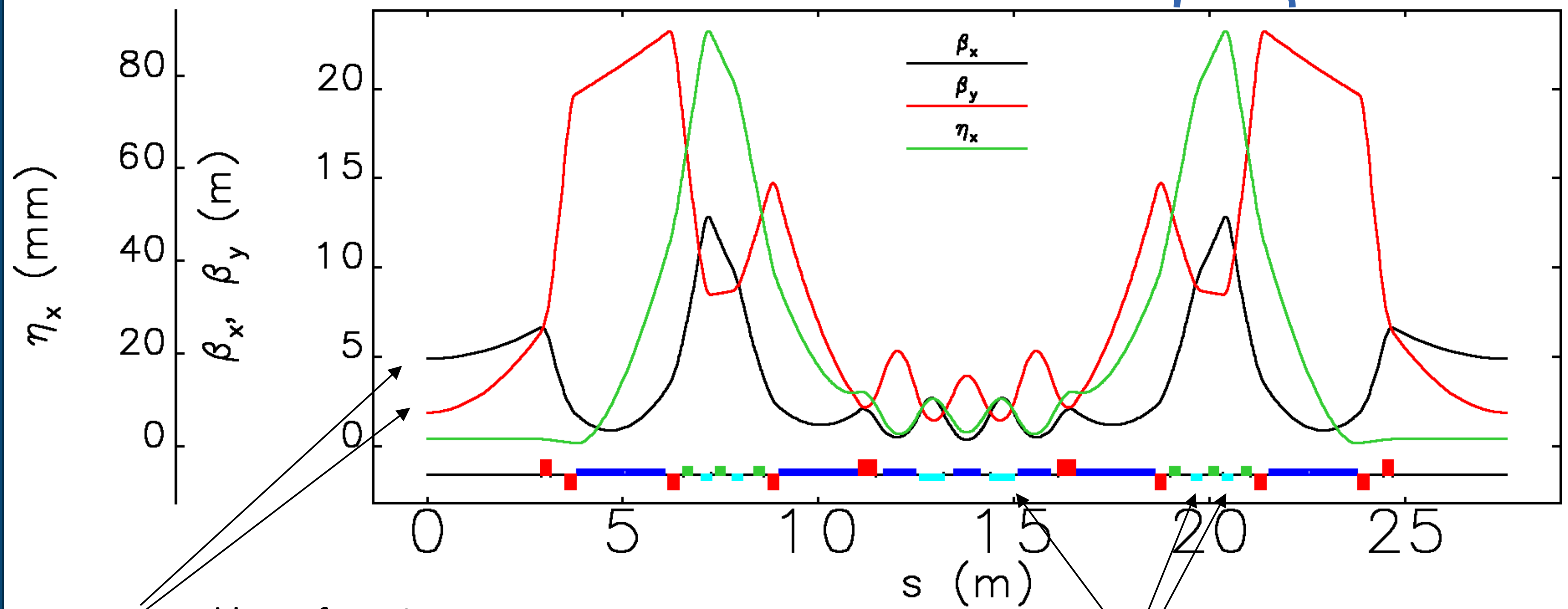
*Hybrid 7-Bend Achromat

41-pm Reverse-Bend Lattice[1]

Starting from H7BA, replace several quadrupoles with reverse-bend dipole magnets [2,3].

- Decouples dispersion and beta functions.

Larger dispersion
Larger beta functions

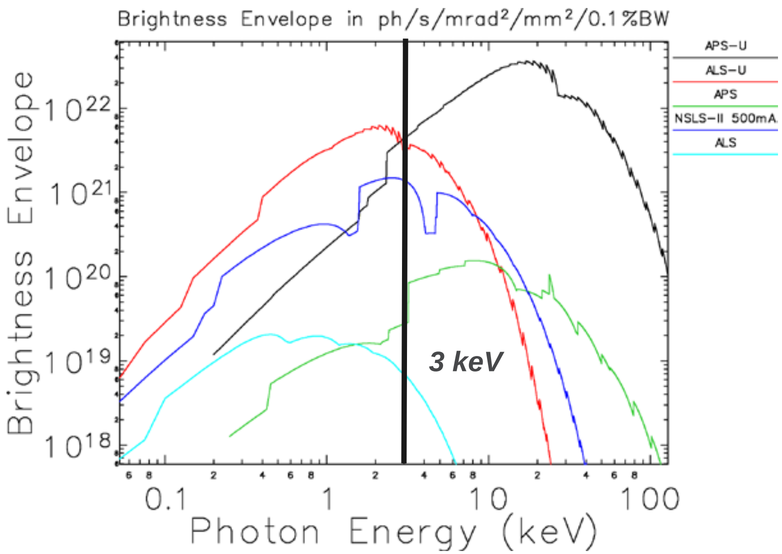


Improved beta functions

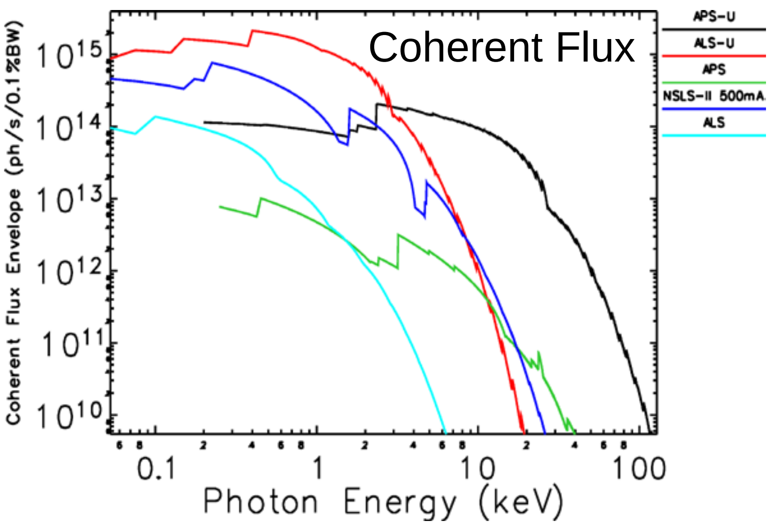
Reverse bends

1: M. Borland et al., NAPAC16, WEPOB01.
2: J. Delahaye et al., PAC89, 1611.
3: A. Streun, NIM A 737, 148-154 (2014).

Brightness and Coherent Flux



Brightness vs. x-ray energy at top beamlines among DOE-BES synchrotron light sources.



Coherent Flux vs. x-ray energy at top beamlines among DOE-BES synchrotron light sources.

APS-U will be the brightest storage ring-based light source in the U.S. for energies greater than ~3 keV

High-Level Lattice Parameters

Table 1: Comparison to prior MBA versions

	67pm-V6	42pm-V5r1	
Betatron motion			
ν_x	95.125	95.101	
ν_y	36.122	36.101	
$\xi_{x,nat}$	-138.580	-130.835	
$\xi_{y,nat}$	-108.477	-122.013	
Lattice functions			
Maximum β_x	12.9	13.0	m
Maximum β_y	18.9	22.9	m
Maximum η_x	0.074	0.090	m
Average β_x	4.2	3.7	m
Average β_y	7.8	9.5	m
Average η_x	0.030	0.033	m
Radiation-integral-related quantities at 6 GeV			
Natural emittance	66.9	42.3	pm
Energy spread	0.096	0.127	%
Horizontal damping time	12.1	7.3	ms
Vertical damping time	19.5	16.1	ms
Longitudinal damping time	14.1	20.1	ms
Energy loss per turn	2.27	2.74	MeV
ID Straight Sections			
β_x	7.0	4.9	m
η_x	1.11	0.57	mm
β_y	2.4	1.9	m
$\epsilon_{x,eff}$	67.0	42.3	pm
Miscellaneous parameters			
Momentum compaction	5.66×10^{-5}	3.96×10^{-5}	
Damping partition J_x	1.61	2.20	
Damping partition J_y	1.00	1.00	
Damping partition J_δ	1.39	0.80	

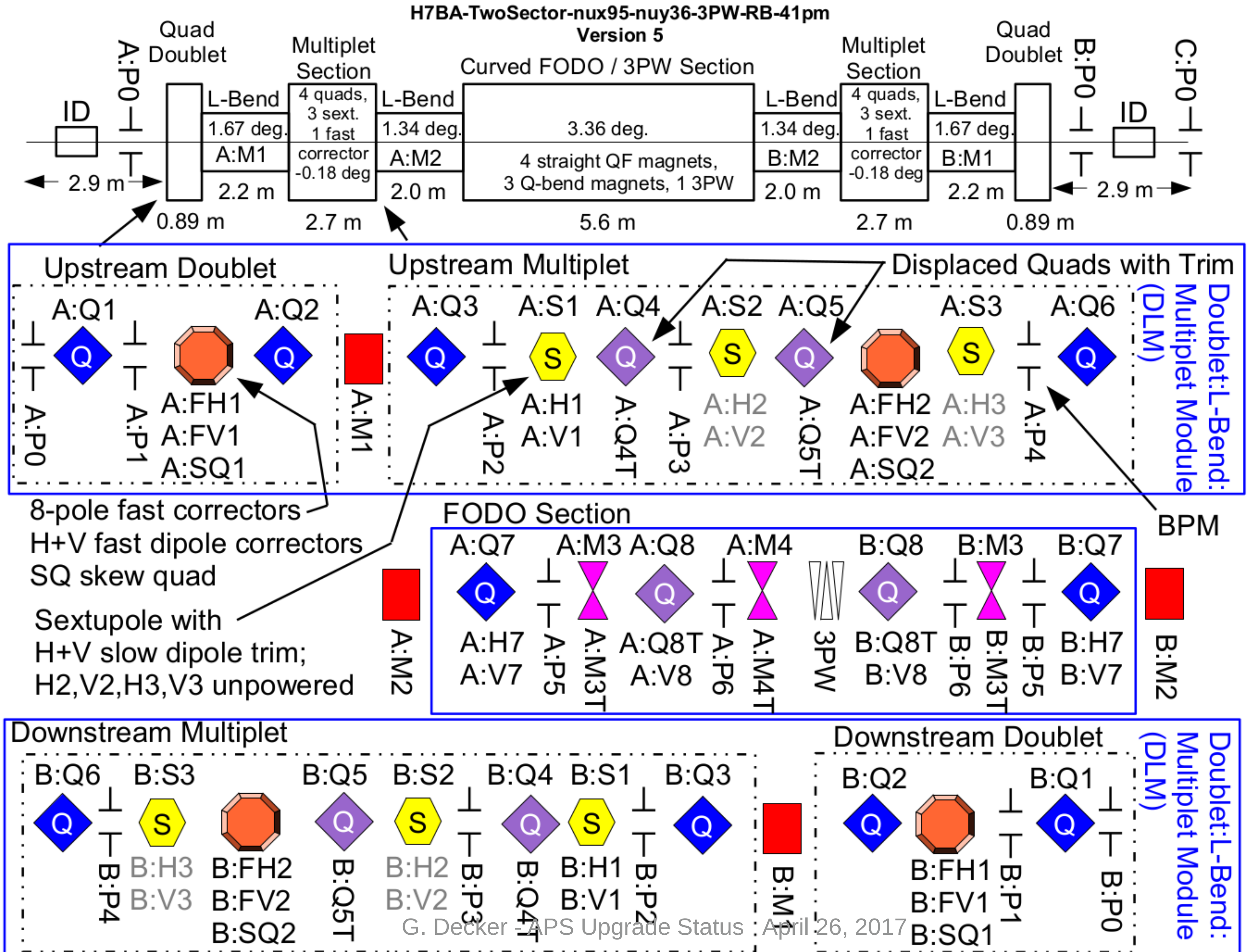
Beam Size Formula (horz.)

$$\sigma_x^2 = \varepsilon_x \beta_x + \eta_x^2 \sigma_\delta^2$$

Note: vertical beam size adjustable with skew quadrupoles

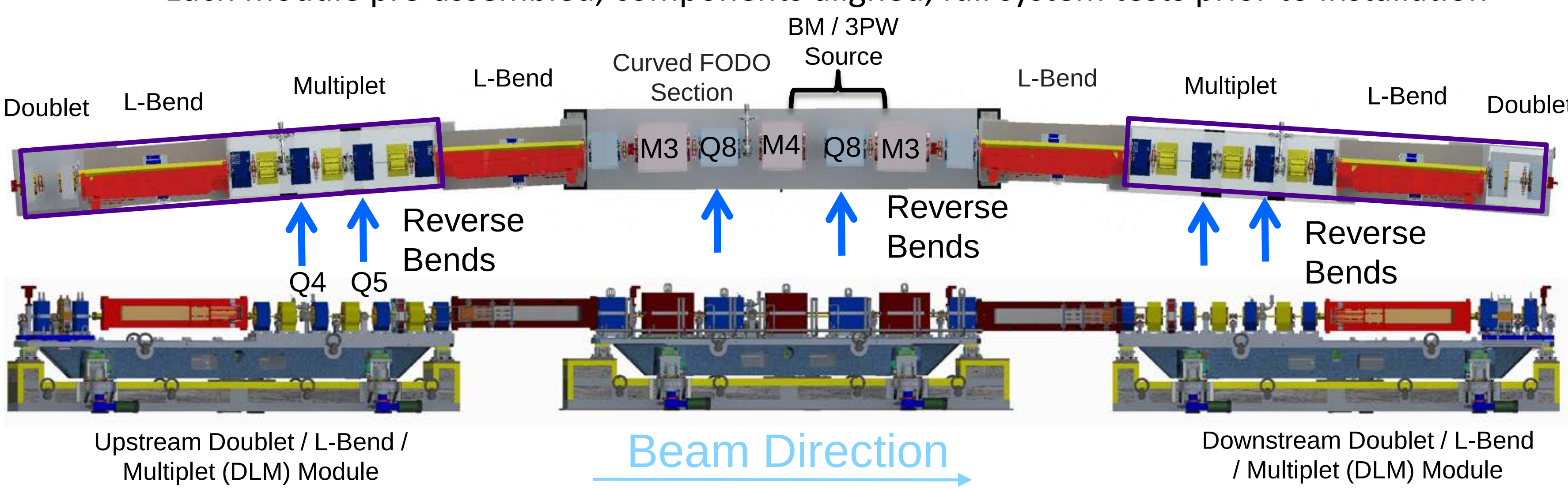
Table courtesy of Y. Sun APS/ASD

MBA Storage Ring Scope



APS-U Mechanical System Overview

- Storage ring consists of 40 Sectors. Each arc section identical. Length 27.6 m
- Sector arcs consist of nine modules, mounted upon three large support structures:
  - Two quadrupole doublets: Each with two quadrupoles and a fast corrector
  - Four longitudinal-gradient dipoles (L-bends)
  - Two multiplets: Each with 2 quadrupoles, 3 sextupoles, 2 reverse bends, and a fast corrector
  - Curved FODO section: 2 quadrupoles, 3 Q-bends, 2 reverse bends, and space for a 3PW source
- Vacuum systems integrated with magnets, supports, insertion devices, front ends.
- 5 Straight sections in Zone F (APS sectors 36 – 40)
  - Injection/extraction hardware, RF accelerating cavities and bunch lengthening system
- Assembly and installation readiness:
  - Each module pre-assembled, components aligned, full system tests prior to installation

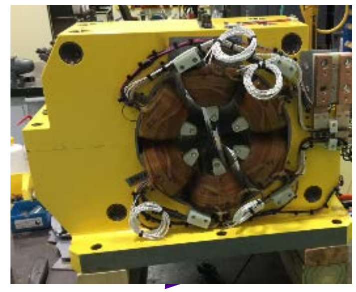


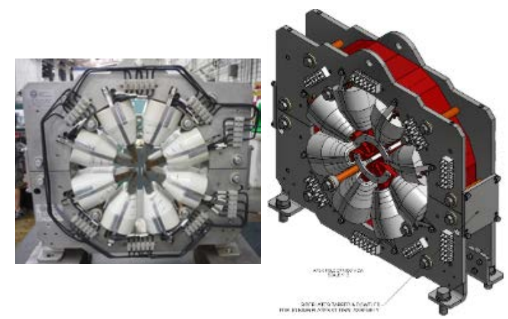
Graphic courtesy of H. Cease APS-U

Accelerator Mechanical Prototypes

- Demonstration Modular Multiplet (DMM)
  - Prototype quadrupoles (4),Prototype sextupole (1)
  - Prototype plinth, support structures to study alignment, vibration
  - Magnetic measurements, stretched / vibrating wire alignment techniques.
- Other magnets
  - Eight-pole corrector (8PC)
  - Three-magnet FODO(3MF)
- Vacuum system full-sector mockup
  - BPM prototypes
  - Flange testing
- Harmonic Cavity Components
  - Cavities, Couplers, HOM damper


DMM


DMM Sextupole

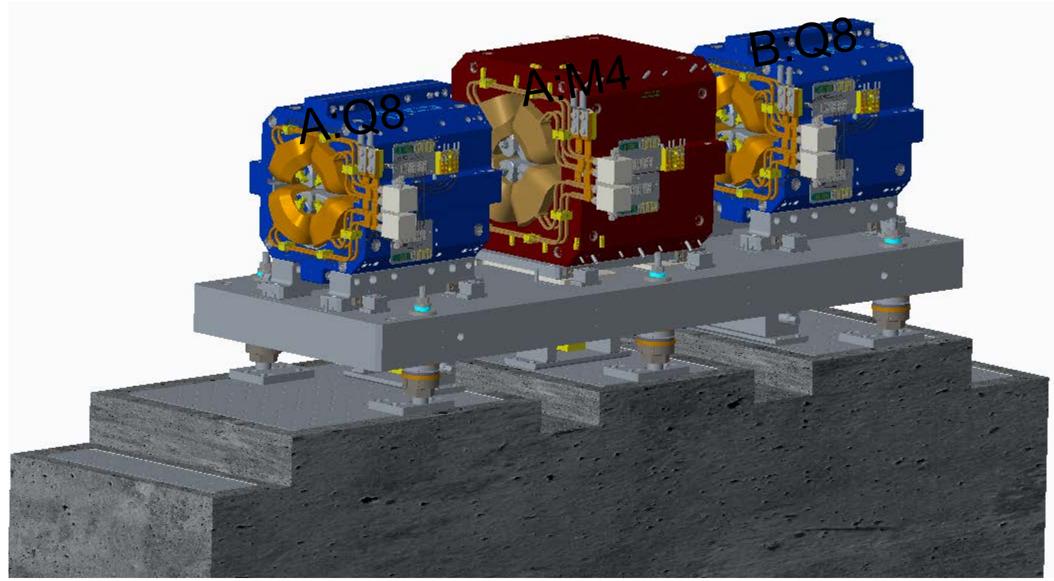

First 8PC prototype complete; at BNL


Prototype Aluminum Vacuum Chamber


Prototype 1.4 GHz Harmonic Cavities

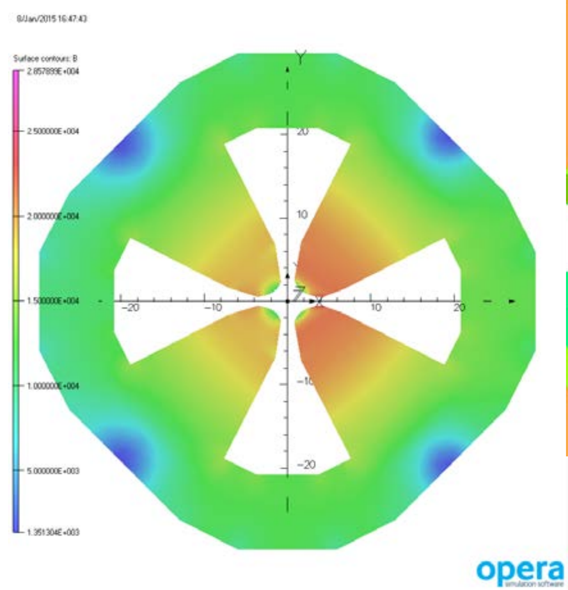
Magnet R&D: 3-Magnet FODO (3MF)

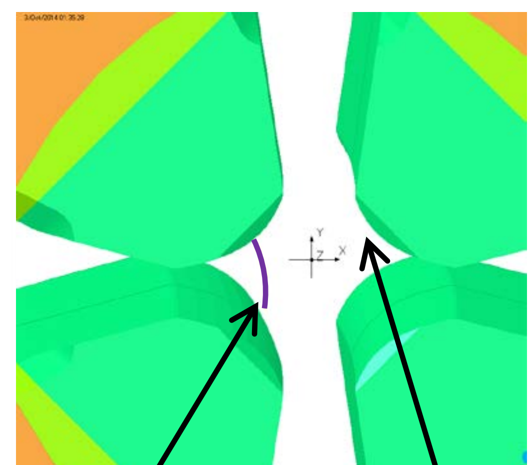
- Components
  - Two Q8 magnets
    - New 8-Piece-Yoke design
    - VP pole tips
  - One M4 magnet
    - Curved VP pole tips
- Goal
  - Test 8-Piece-Yoke design*
  - Test magnetic measurement method for FODO
  - Test alignment scheme



Courtesy J. Downey APS-AES

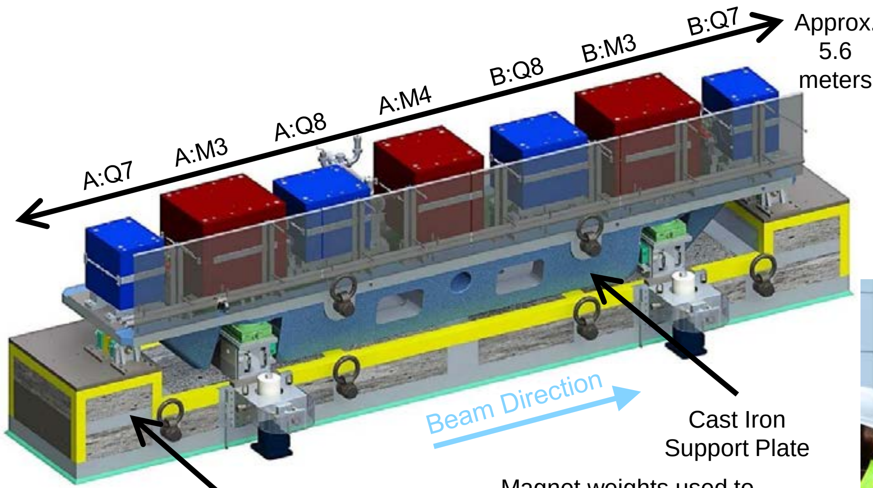
M4 Transverse-Gradient Dipole



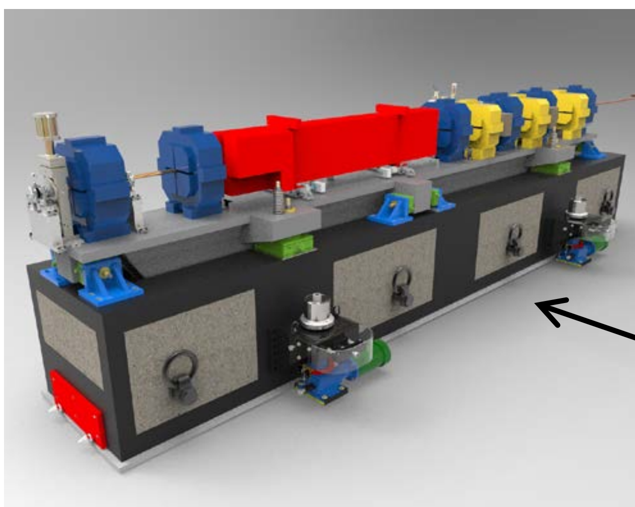


* 8-piece Q8 magnet delivered, measured, and meets requirements

Support Structure Design



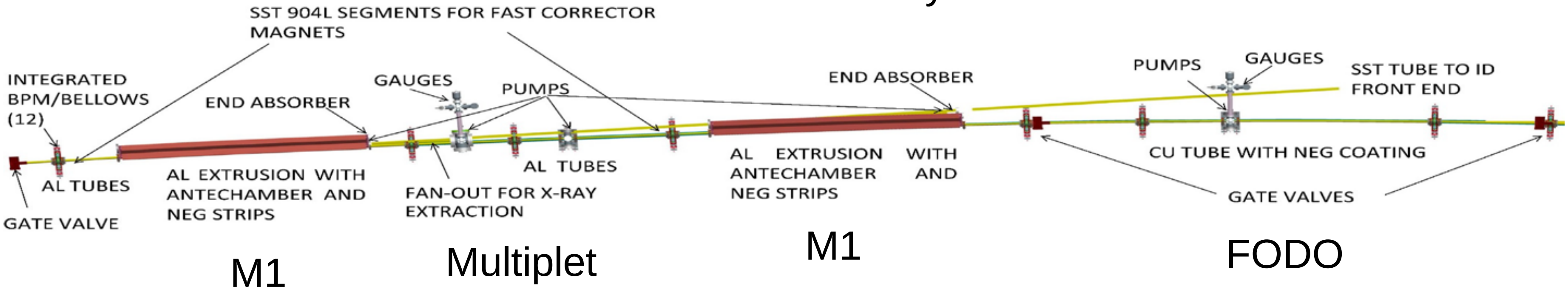
FODO Plinth / Support Structure Prototype



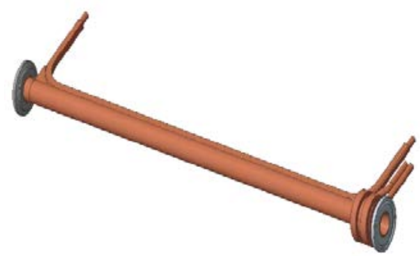
Doublet – L-bend – Multiplet Module (DLM)

Vacuum System Design

Arc layout

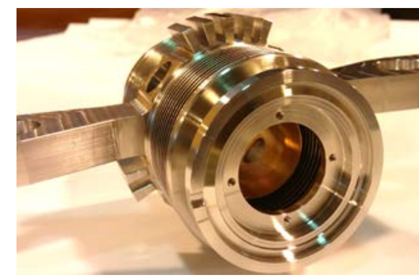


R&D doublet / multiplet chambers received



R&D FODO chambers on order, NEG heaters received.

R&D L-bend chamber extrusions received and bent. Demo welds made.

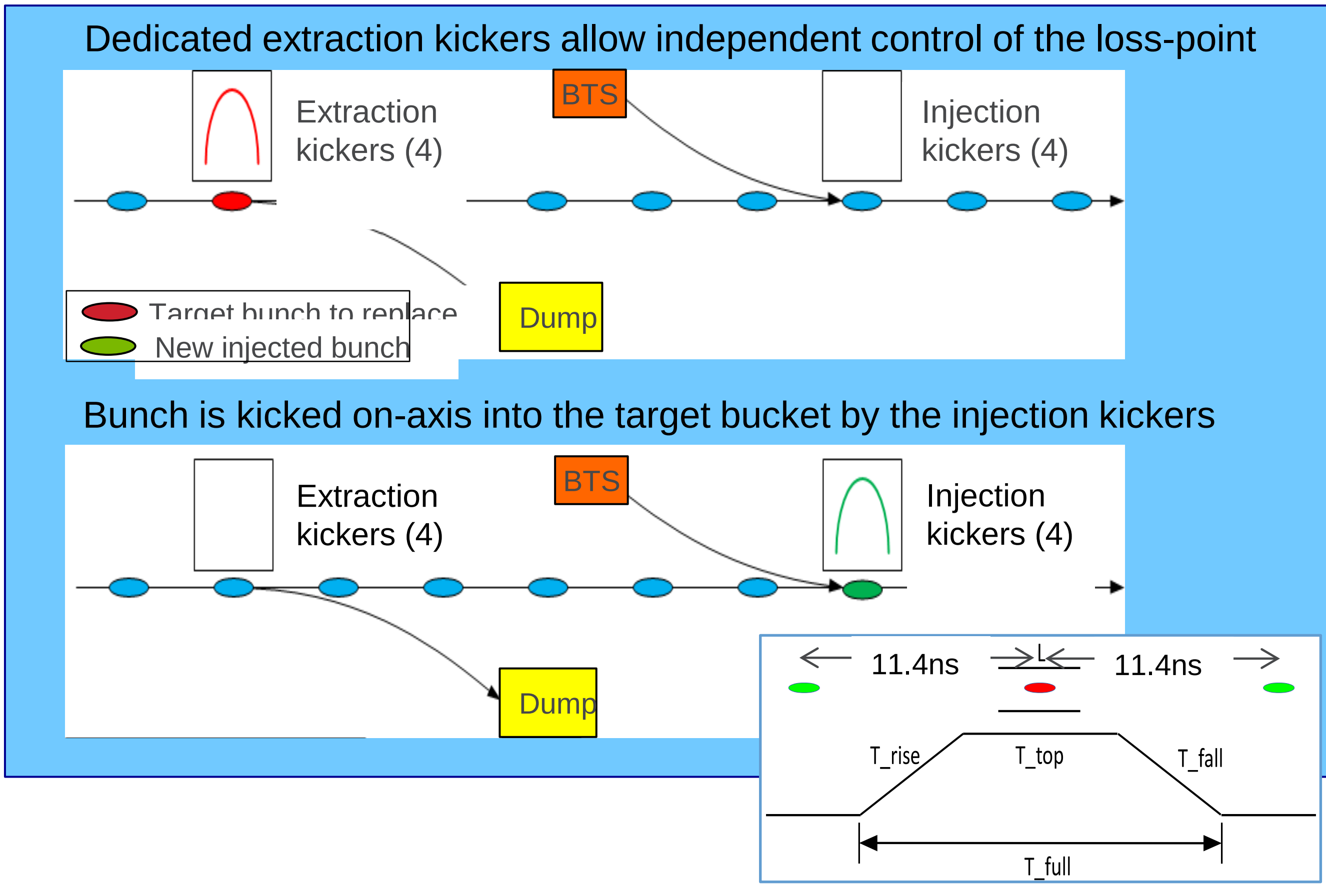


BPM/bellows R&D mockups received.

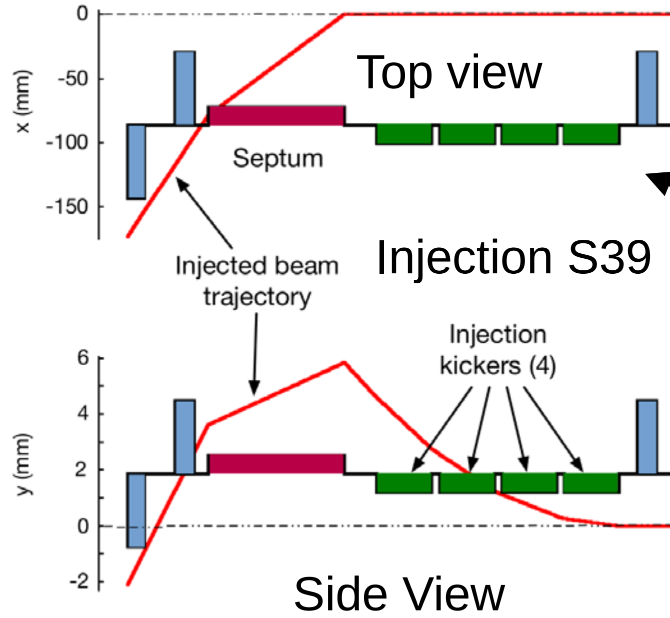
- Heat loads in FODO section for 41 pm lattice increase at 10% level vs. 67 pm
- Chamber inner diameter is 22 mm

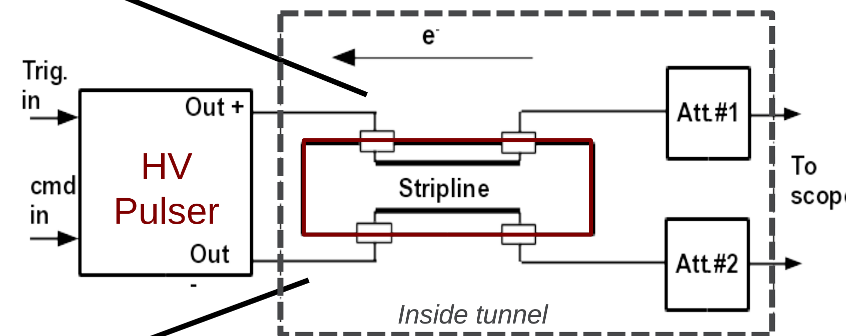
Swap-out Injection

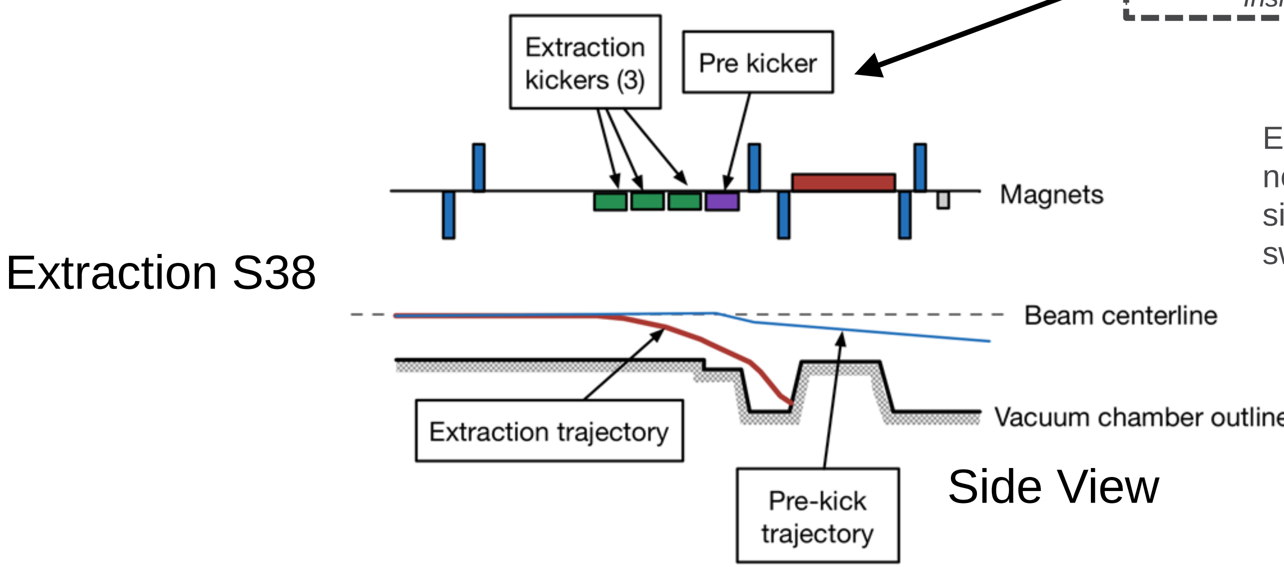
- Aggressive optics precludes conventional off-axis accumulation.
- On-axis swap-out injection scheme is planned:
  - Complete replacement of individual bunches
  - Fast (< 20 ns duration), high-voltage (15 kV+) kickers



Injection / Extraction Systems

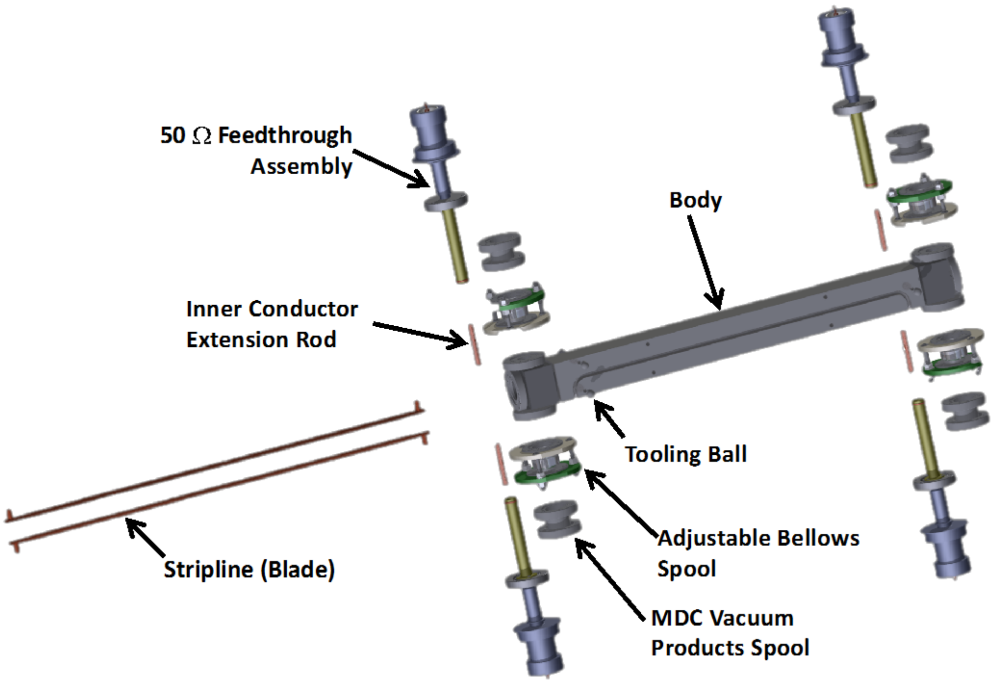


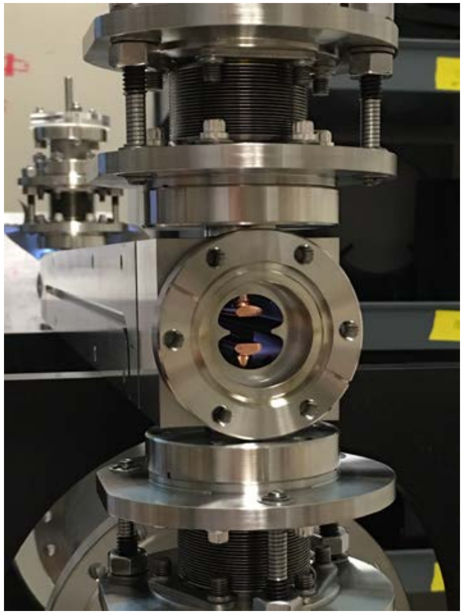


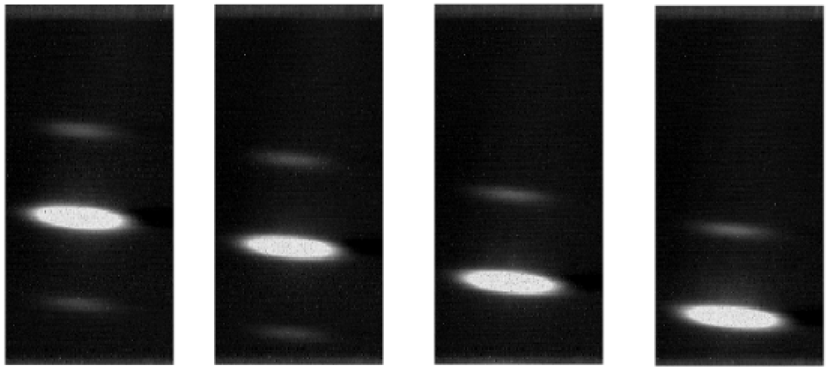


Extraction prekicker needed to increase beam size and avoid damage to swapout beam dump.

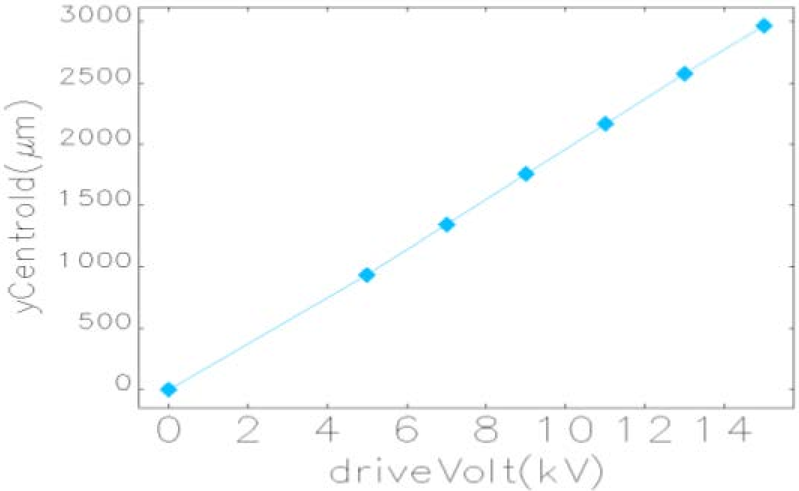
Stripline Kicker Prototype Beam Test



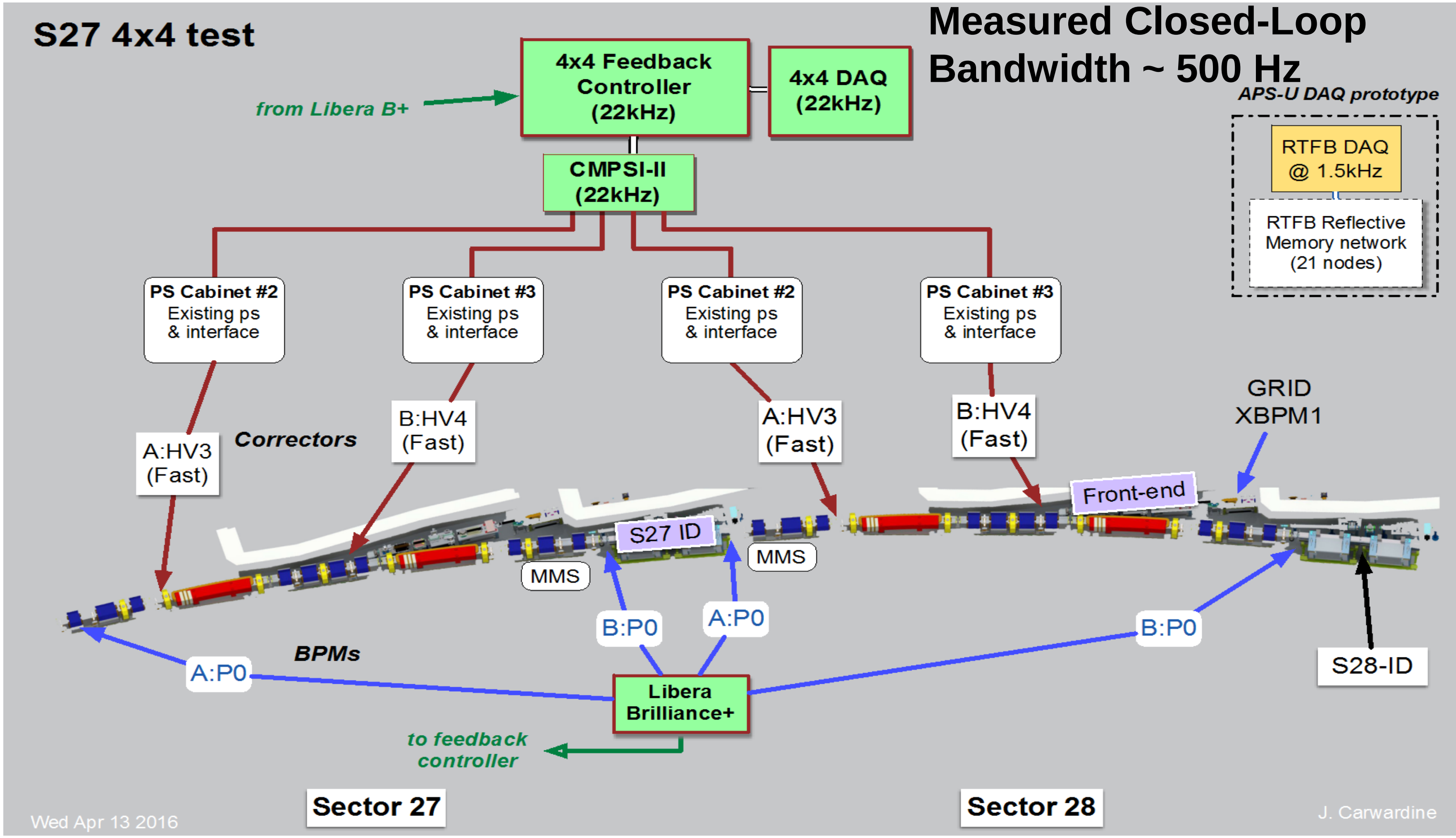




1 mrad / meter confirmed

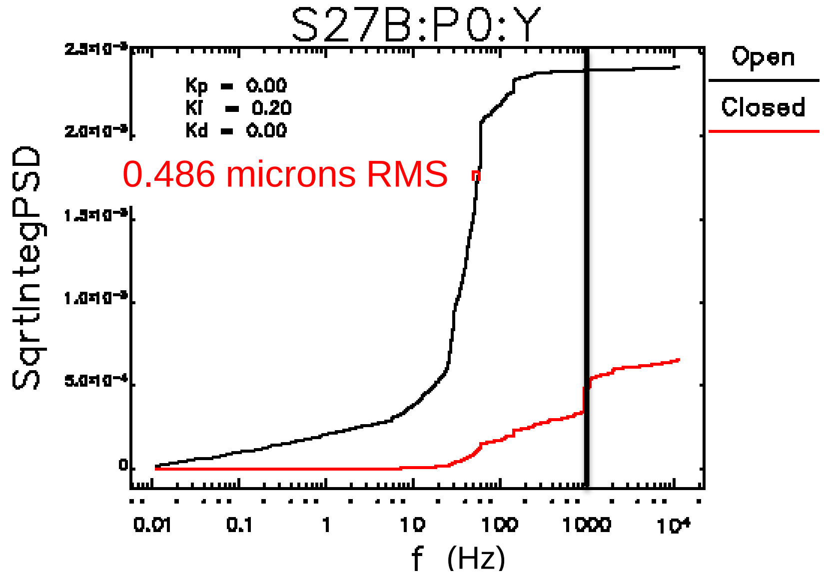


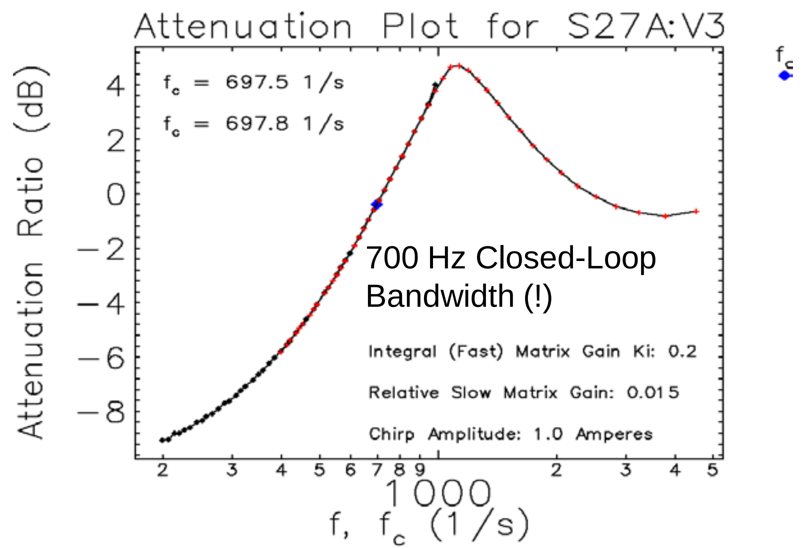
APS-U 4x4 Prototype Fast Orbit Feedback Test - April, 2016
- First demonstration of Fast Orbit Feedback at 22.6 kHz

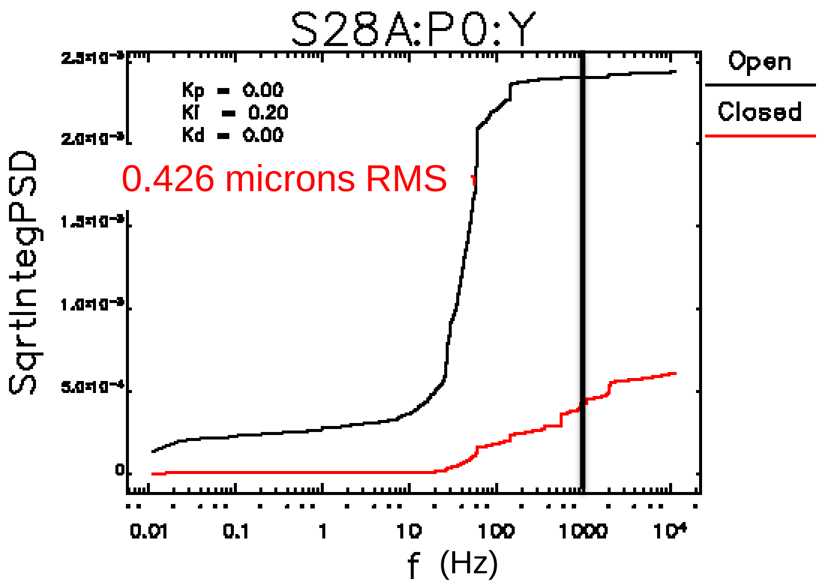


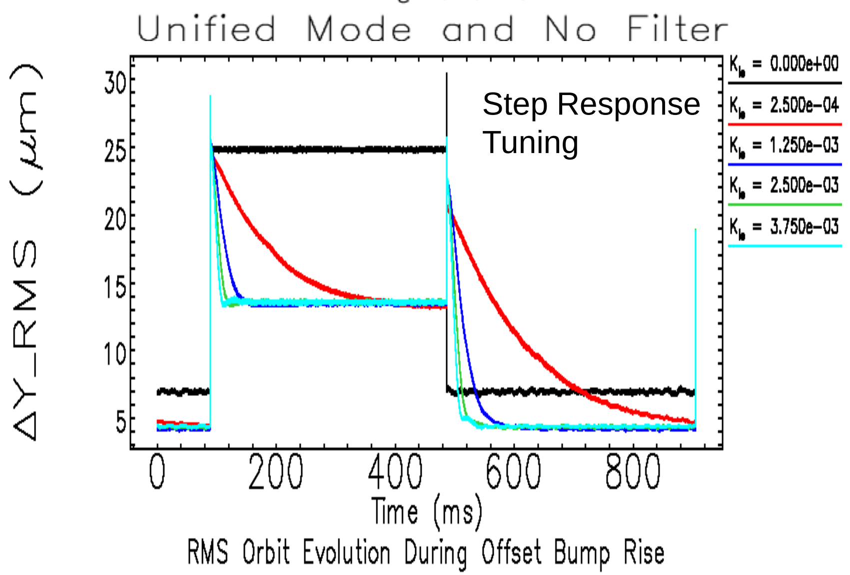
Integrated Beam Stability tests (16 BPMs, 8 new fast power supplies, two feedback controllers) now being tested in sectors 27, 28.

Unified / Integrated Vertical Orbit Feedback
RMS Motion 0.01 – 1000 Hz; (4x4 Fast + 4x16 Slow)









Courtesy N. Sereno etal., APS-ASD

Preliminary Insertion Device Selection

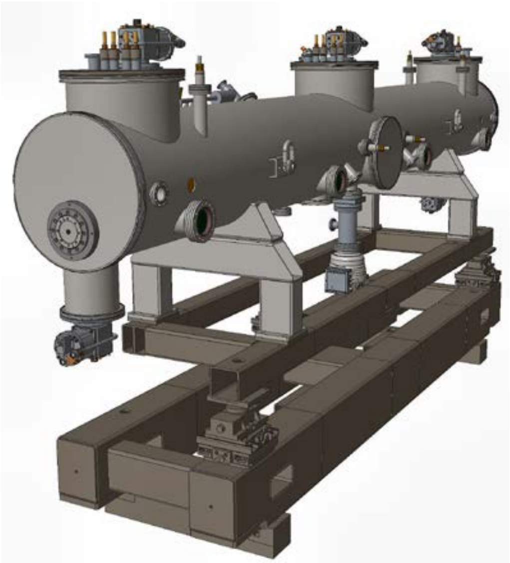
Device	Preliminary Selection	Comments
HPM Planar	32 + (7)	Nominal 2.8cm period. Additional new periods are 2.5cm, 2.1cm and 1.35cm Will reuse all 2.7cm and 2.3cm period devices
HPM Revolver	8 + (1)	Only two headed revolvers (Reuse one existing revolver)
SCU	8 + (1)	2 devices of 1.8m each in one cryostat - 2 locations 2 devices of 1.2 to 1.5 m with canting magnets - 2 locations 1 existing device - located co-linear with HPM Planned periods are 1.65cm and 1.85cm
EMVPU	(1) + (1)	Reuse both IEX and CPU
Variable Polarization SCU (SCAPE)	2	2 devices in one cryostat for polarization switching studies for hard x-rays

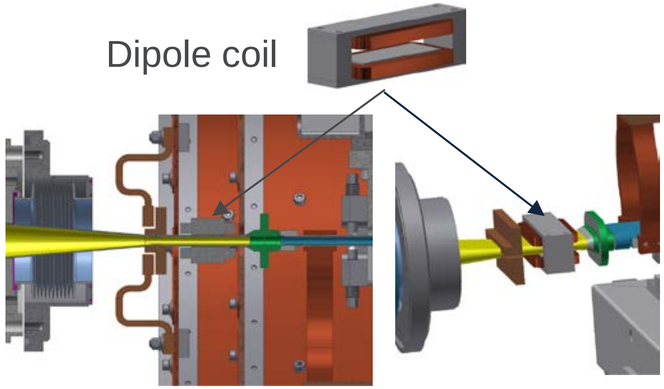
Nominal length of PM devices are 2.4m (2.1 m in canted configurations) and SCU are 1.8m (1.2-1.5 m in canted configurations)
Hybrid Permanent Magnet (HPM) Planar is for one set of magnets
HPM Revolver is two sets of magnets and a revolver mechanism
Both HPM Planar and Revolver will reuse the existing gap separation mechanisms
Device count in () is existing and may need minor modifications

Beamlines requesting dual in-line undulators (2 x 2.4 m long) will be provided with phase tuning

Super Conducting Undulator

- New cryostat is modular and length can be expanded to 4.5m
- Single cryostat to accommodate multiple devices in same straight section
- For devices in tandem a phase shifter , corrector and a BPM in the middle is planned
- For canted configuration ID length will be restricted to maximum of 1.5m
  - Need to have canting magnets both upstream, downstream and middle
  - Corrector and BPM in the middle





Vacuum Chamber Transition

Summary

- The APS-U 41-pm reverse-bend lattice promises orders of magnitude brightness improvement.
- Preliminary Design Report is a key FY17 deliverable.
- The APS-U R&D program is yielding excellent results.
  - Magnet design validation
  - Demonstration of alignment
  - High-speed kicker technology
  - Beam stability and control
  - Superconducting undulator development
- The future looks very bright.

Backup Material

▪

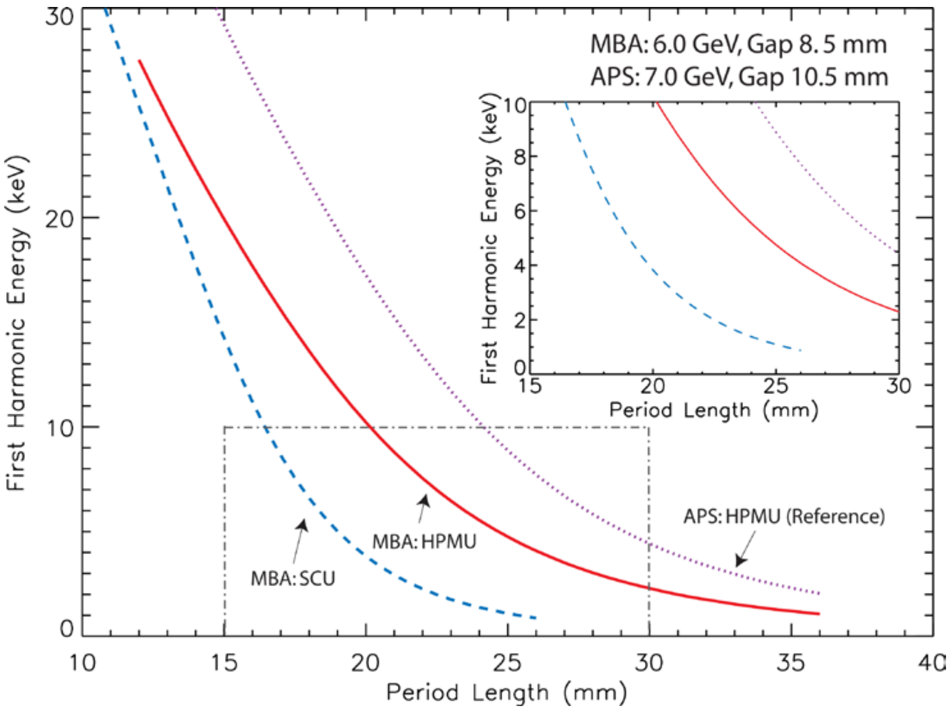
APS Upgrade User Needs

- Maximize brightness and flux
- Balance between tuning range and maximizing the performance at specific photon energies
- Balance between power, power density with flux through an aperture

- Make period length as short as possible for maximum performance
- Typically shorter periods than today will be required.
- For the HPMUs most commonly requested periods are 2.1 – 2.8 cm (SCUs periods 1.5 – 1.9 cm)

APS UA (3.3 cm):
3.0 keV (10.5 mm gap)

APS-U HPMU 2.7 cm:
3.5 keV (8.5 mm gap)

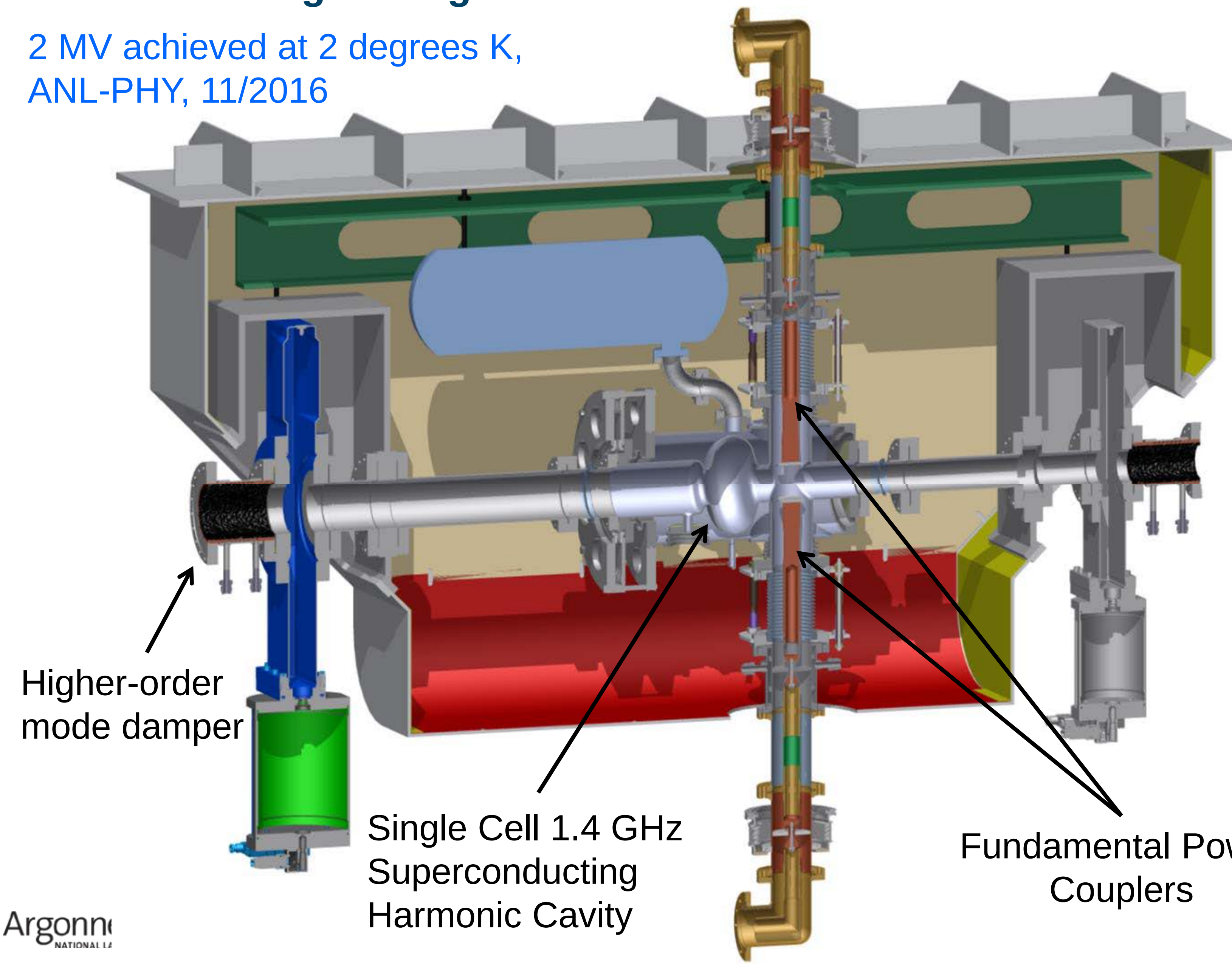


First harmonic energy vs period length for HPMUs and SCUs for 6 GeV and 8.5 mm magnetic gap

Argonne NATIONAL LABORATORY

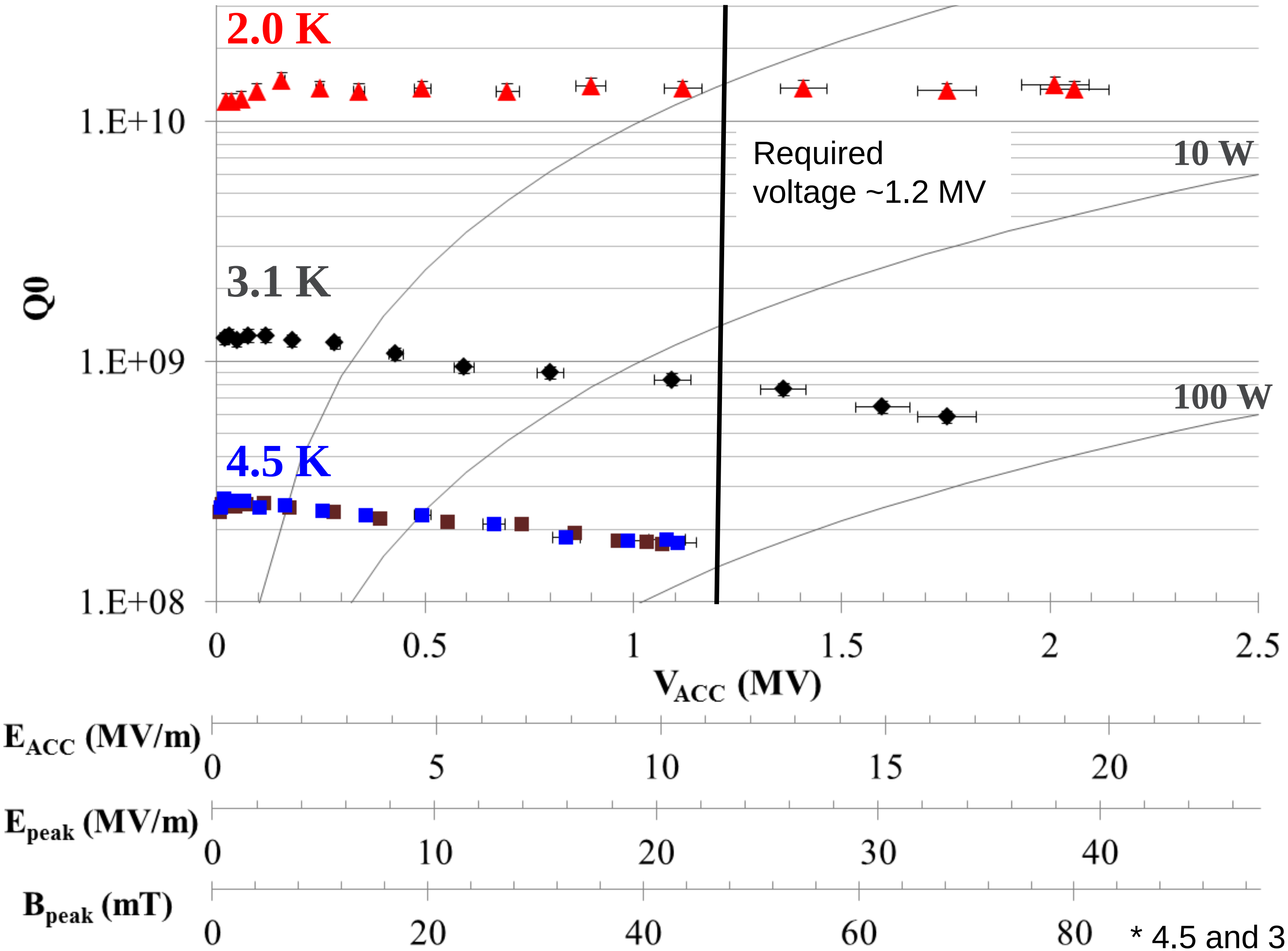
Superconducting 1.4 GHz Higher-Harmonic Cavity (HHC) For Bunch Lengthening

2 MV achieved at 2 degrees K,
ANL-PHY, 11/2016



Argonne NATIONAL LA

Cold Tests of Superconducting Higher-Harmonic Cavity (HHC) November, 2016



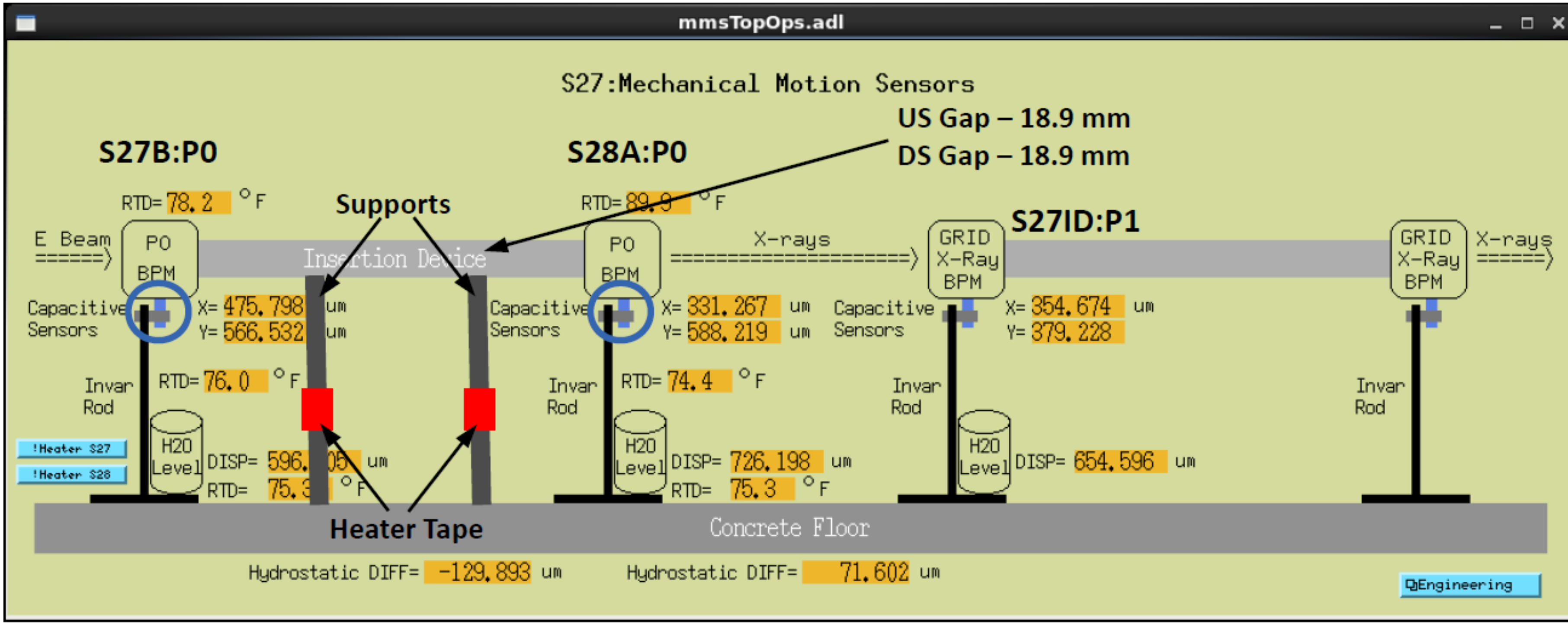
Data Courtesy of S.H. Kim, M. Kelly, ANL-PHY

* 4.5 and 3.1 K limit due to RF power amplifier

Argonne NATIONAL LABORATORY

Long-Term Beam Stability Tests

- Use of capacitive proximity sensors and hydrostatic level system (HLS)



Long-term beam stability studies have demonstrated 1.4 microns rms stability over several days after compensating for ground motion (HLS) and thermally-induced mechanical motion of beam position monitors.