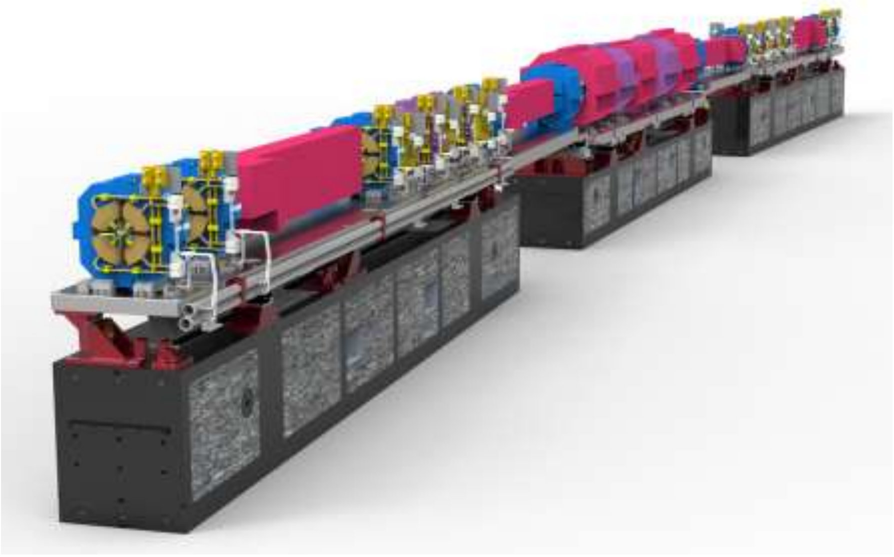
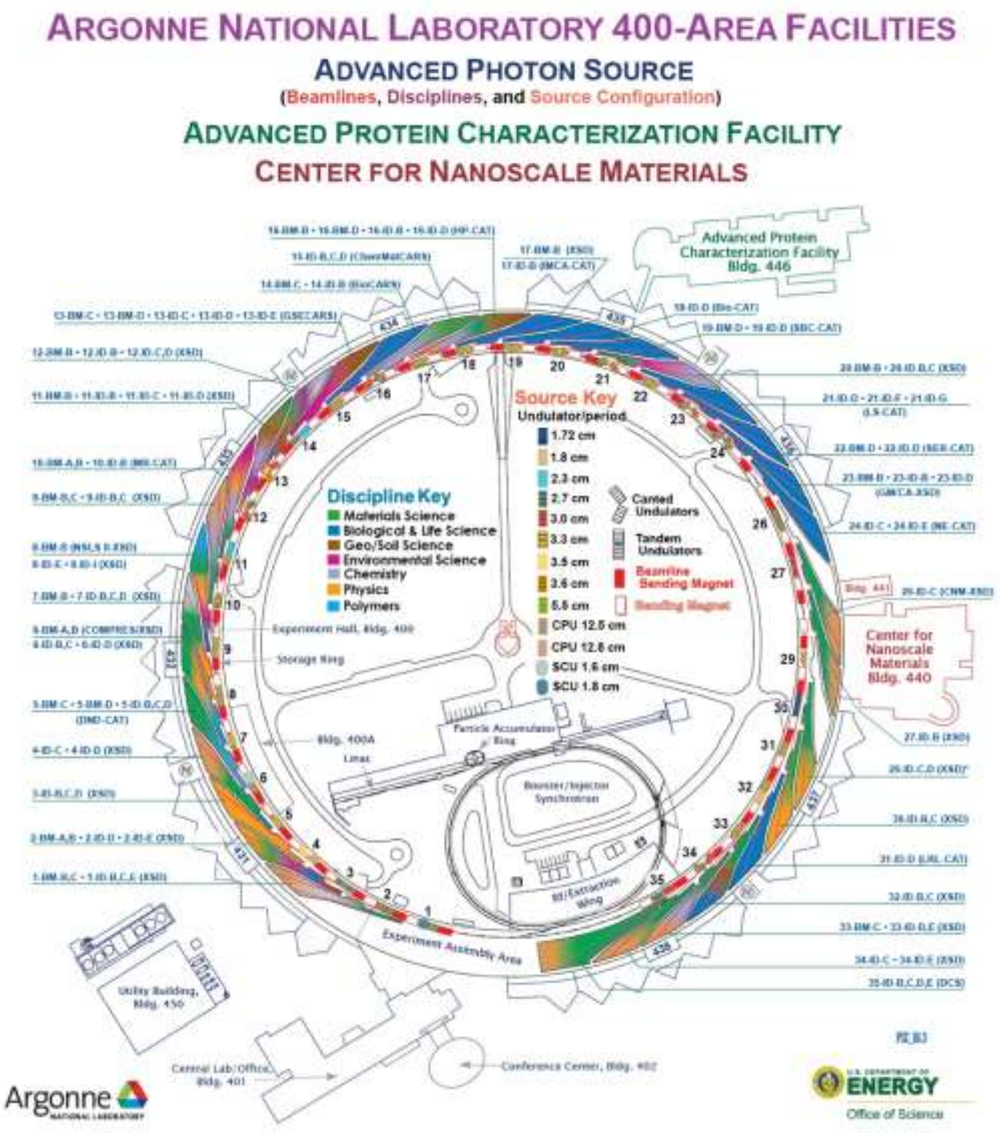
The APS Upgrade



John Carwardine
APS Upgrade
Deputy Associate Project Manager - Accelerator
Argonne National Laboratory

June 13, 2018

The Advanced Photon Source: BES's largest user facility

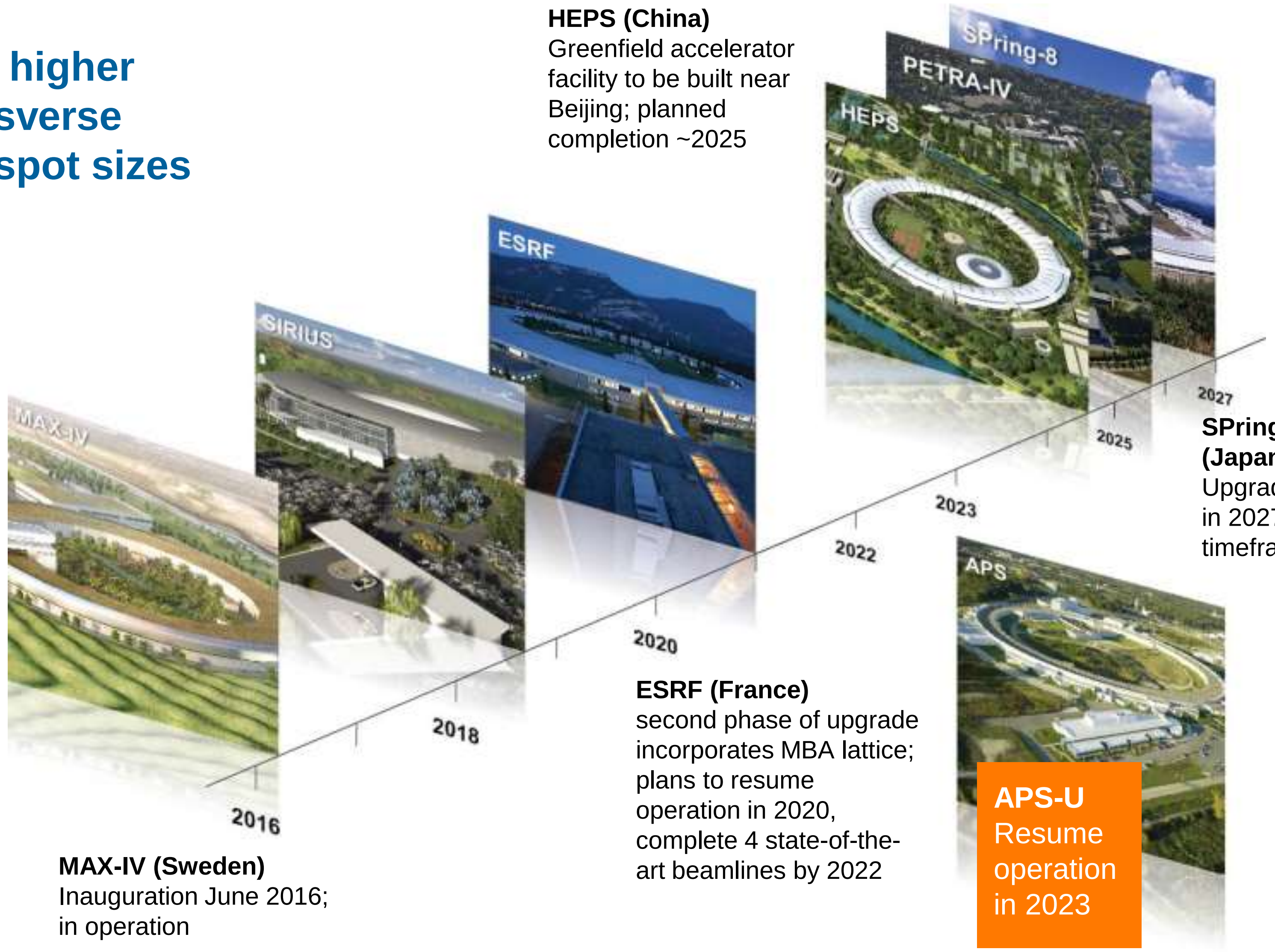


- APS is an xray microscope
  - In operation since 1995
  - 7 GeV electron synchrotron
  - 1104m circumference
  - Hard xrays: 1KeV – 100KeV
- 68 simultaneously operating end stations
- 5000 operating hours/year, 98% availability
- FY17: 5700 unique users, 700 institutions
- FY17 operating budget: $134M

To stand still is to lose ground

The push now is for higher brightness and transverse coherence, smaller spot sizes

HEPS (China)
Greenfield accelerator facility to be built near Beijing; planned completion ~2025



SPring-8 (Japan)
Upgrading in 2027 timeframe

ESRF (France)
second phase of upgrade incorporates MBA lattice; plans to resume operation in 2020, complete 4 state-of-the-art beamlines by 2022

APS-U
Resume operation in 2023

MAX-IV (Sweden)
Inauguration June 2016; in operation

Brightness and coherence scale inversely with emittance

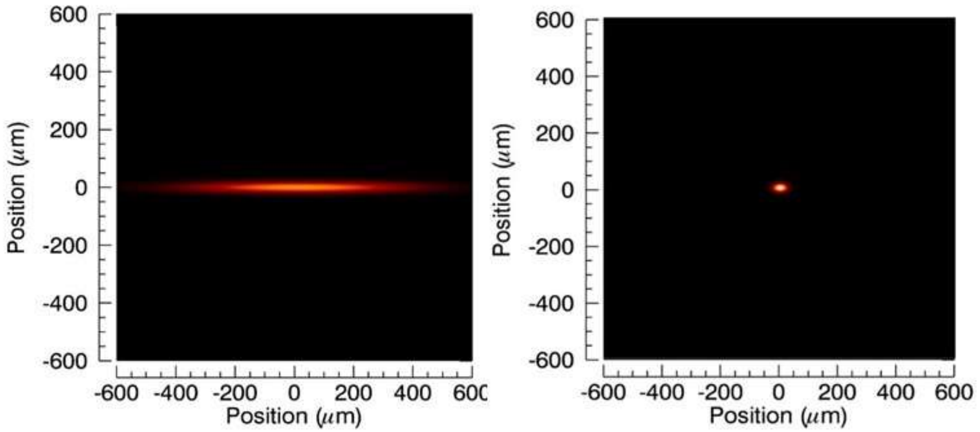
Reducing emittance from **3100** pm-rad (APS) to **42** pm-rad (APS-U)

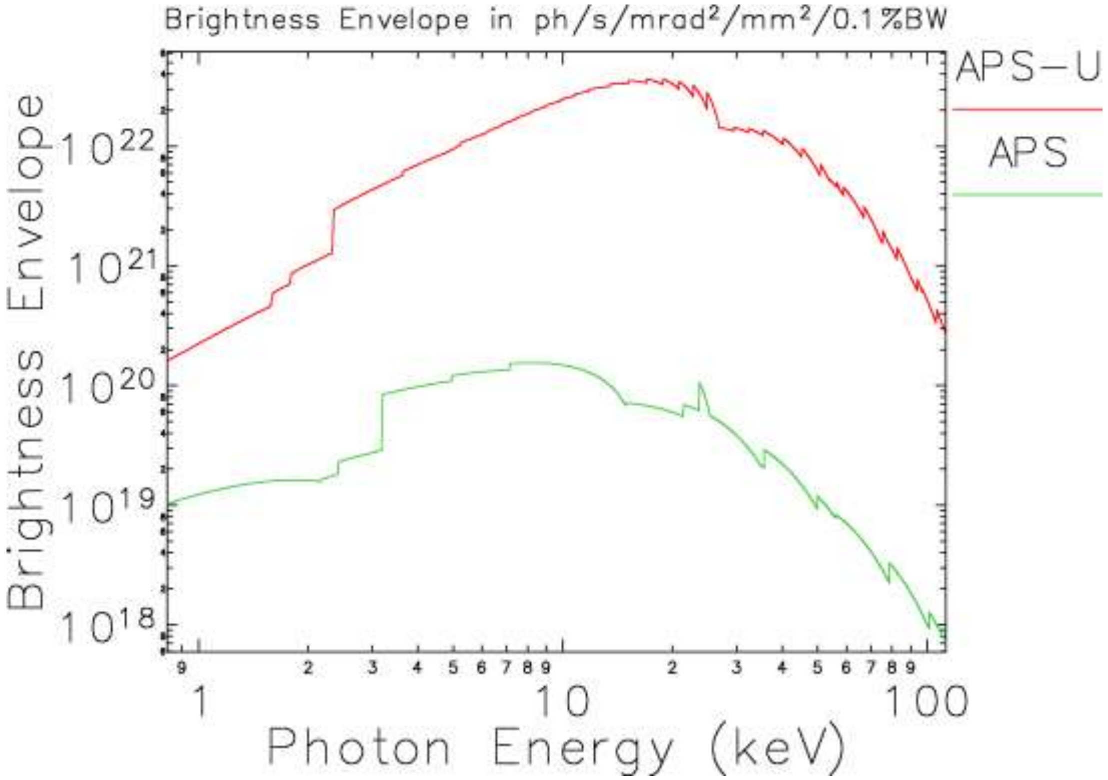
$\Rightarrow$ 2 orders of magnitude higher brightness and transverse coherence

$\Rightarrow$ smaller spot size for microprobes

$\Rightarrow$ round beams

$\Rightarrow$ **New science capabilities**





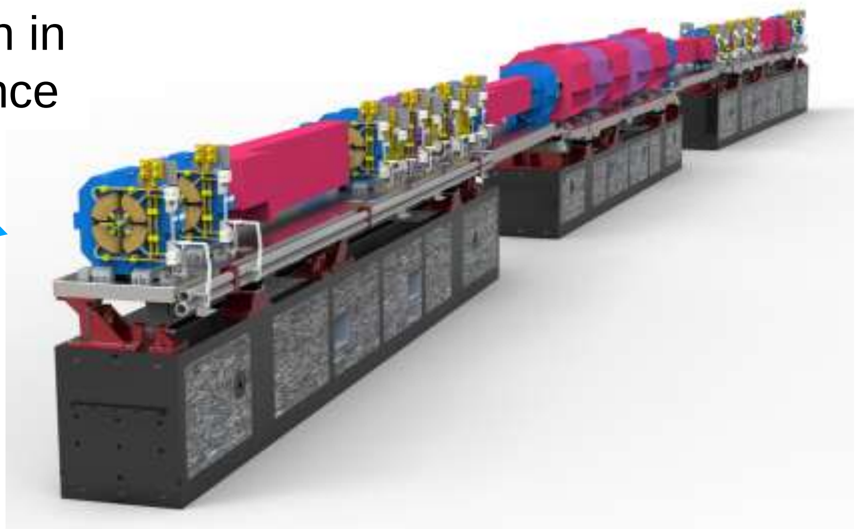
Emittance scaling

$$\varepsilon_x = C_L \frac{E^2}{N_D^3}$$

E = Beam energy (E = 6 GeV for APS MBA)
N_d = Number of dipoles per sector (N_d = 7 for APS MBA)

APS - 7 GeV, 2-bend lattice

~70-fold reduction in horizontal emittance



APS-U - 6 GeV, 7-bend lattice

APS-U replaces this with this

APS-U Project Scope

All existing beamlines incorporated in plans to come back online at conclusion of APS-U

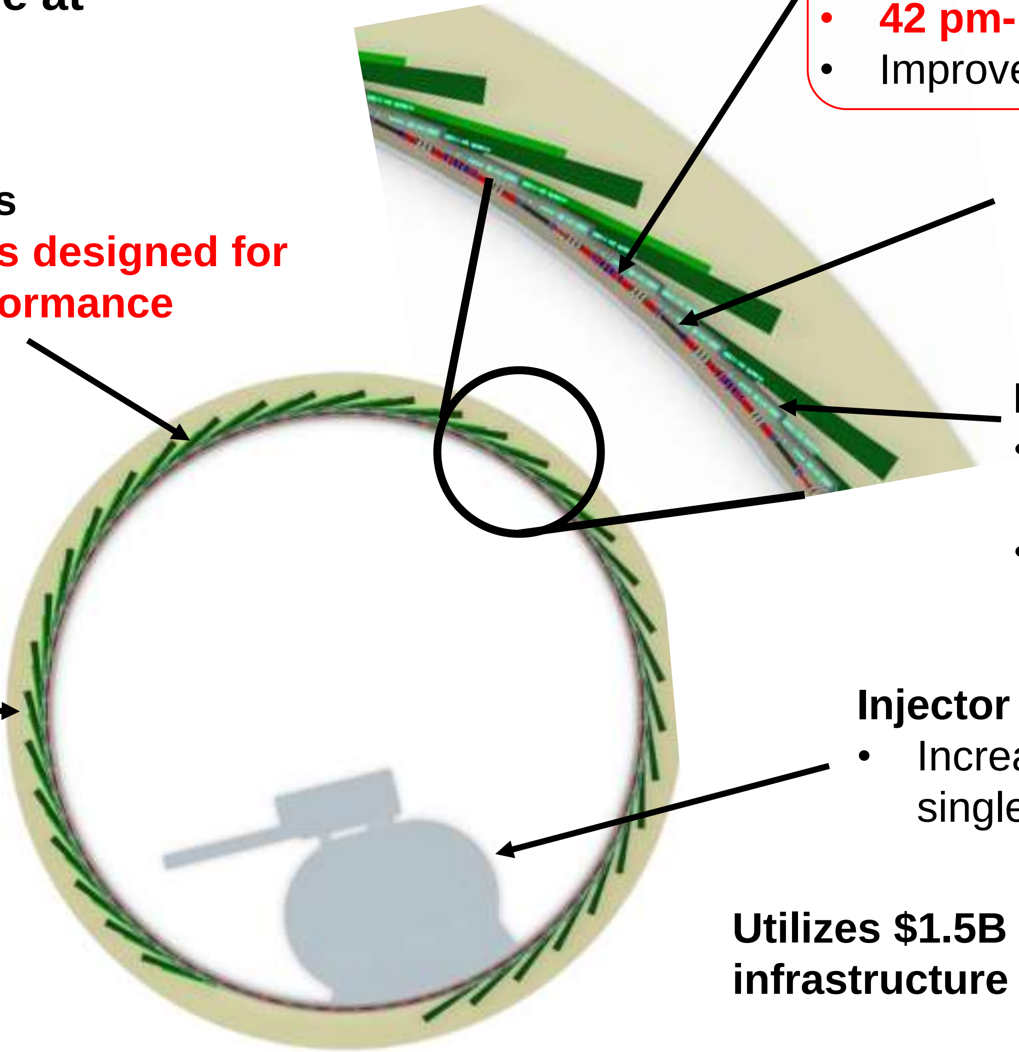
New Storage Ring
- 6 GeV MBA lattice
- **42 pm-rad emittance @ 200 mA current**
- Improved electron/photon stability

Feature beamlines
Suite of beamlines designed for best-in-class performance

New Insertion Devices
- Incorporate **SCUs** on selected beamlines

Beamline Enhancements:
improvements to make beamlines "Upgrade Ready"

"Do no harm"



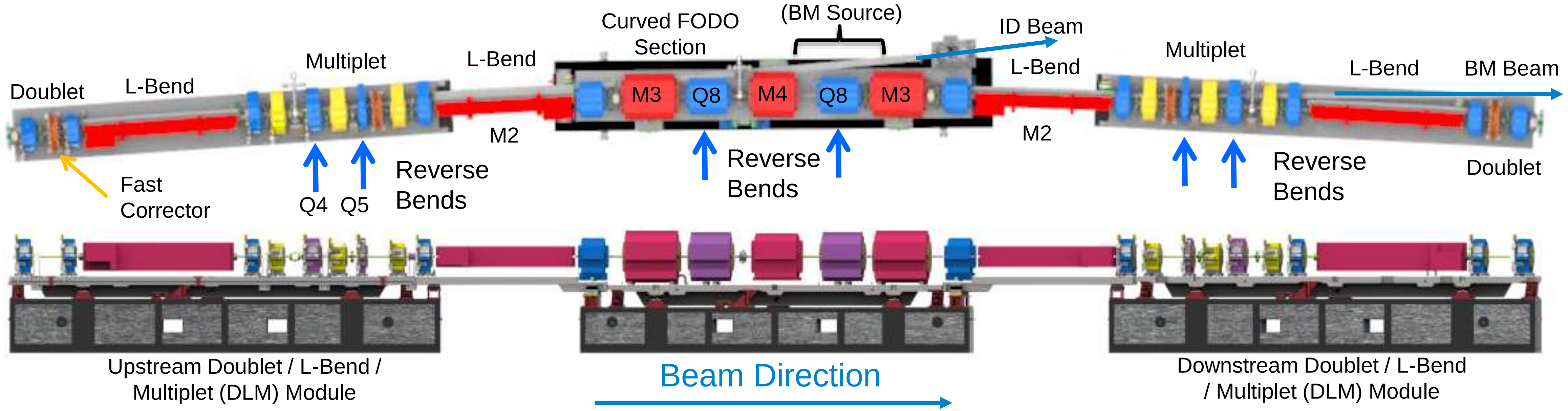
New/upgraded Front-ends
- Common design for maximum flexibility
- Integrated hard x-ray beam position monitors

Injector improvements
- Increased performance (high single-bunch charge)

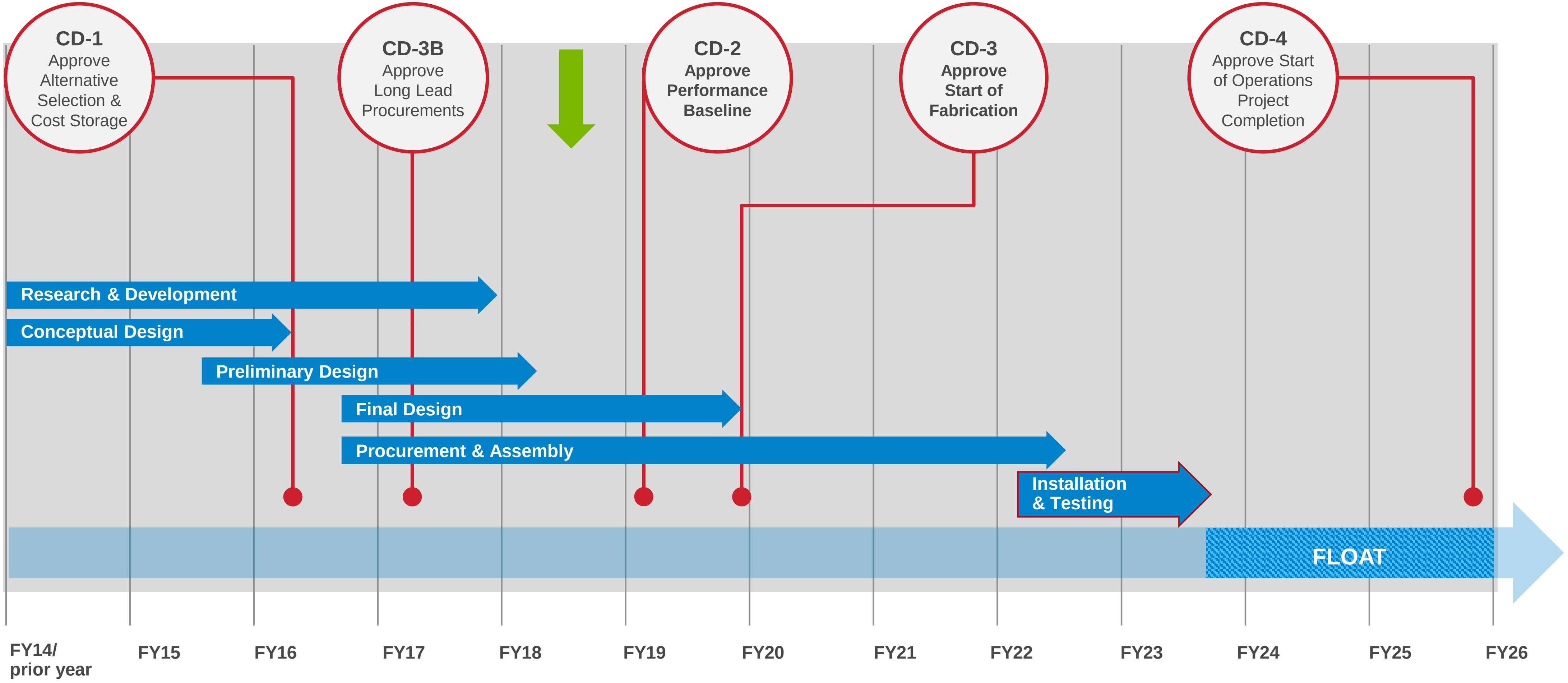
Utilizes $1.5B in existing infrastructure

APS-U 42-pm Lattice

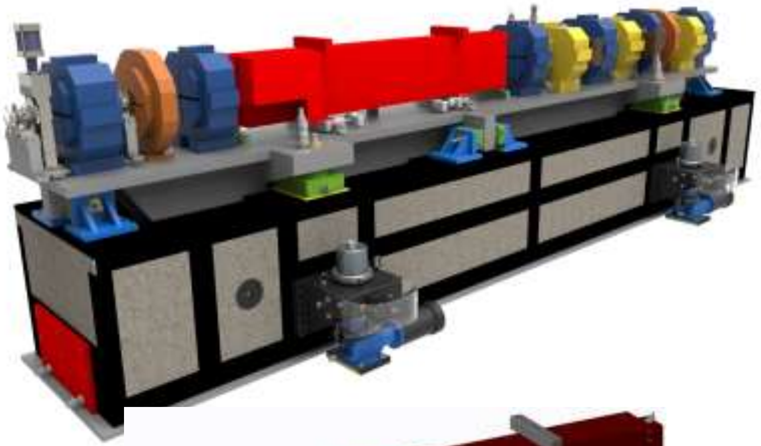
- Storage ring consists of 40 Sectors. Each with 33 arc magnets; 27.6 meters / sector
- Each sector is a hybrid 7BA with four longitudinal-gradient dipole bends, three transverse-gradient dipoles, and six reverse bends.
- Vacuum systems integrated with magnets, supports, insertion devices, front ends.

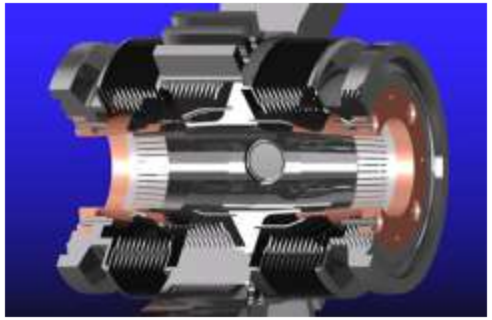


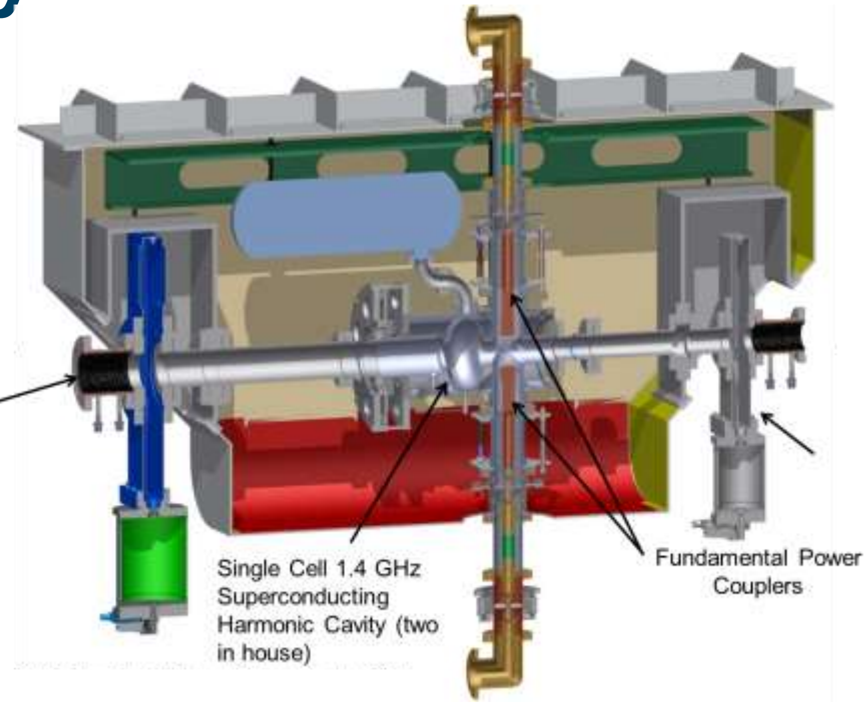
APS Upgrade Project Schedule



APS-U Technology

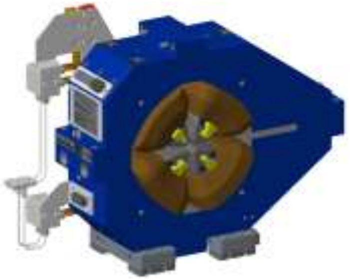




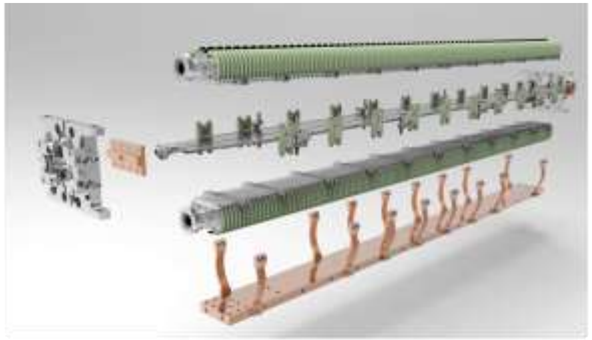


L-Bend Magnets (M1, M2)

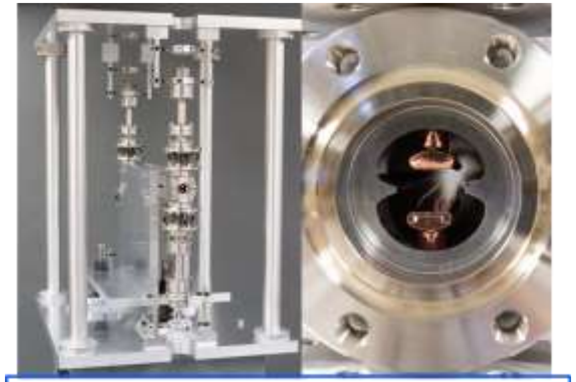
In-House Design
Fast Bipolar Power Supply*



Q-Bend Magnets M3,M4

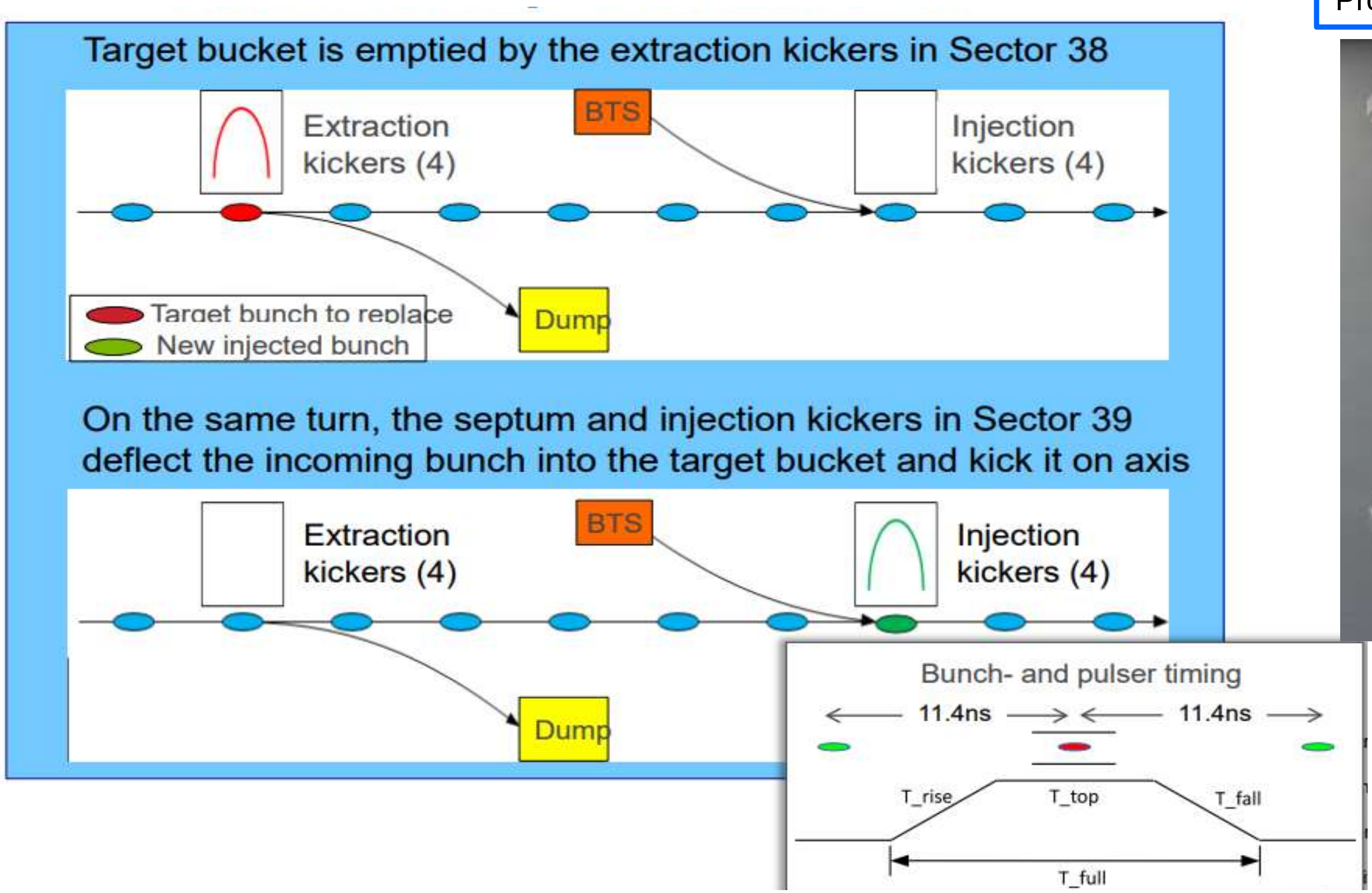


Exploded view of planar SCU design model with vacuum chamber

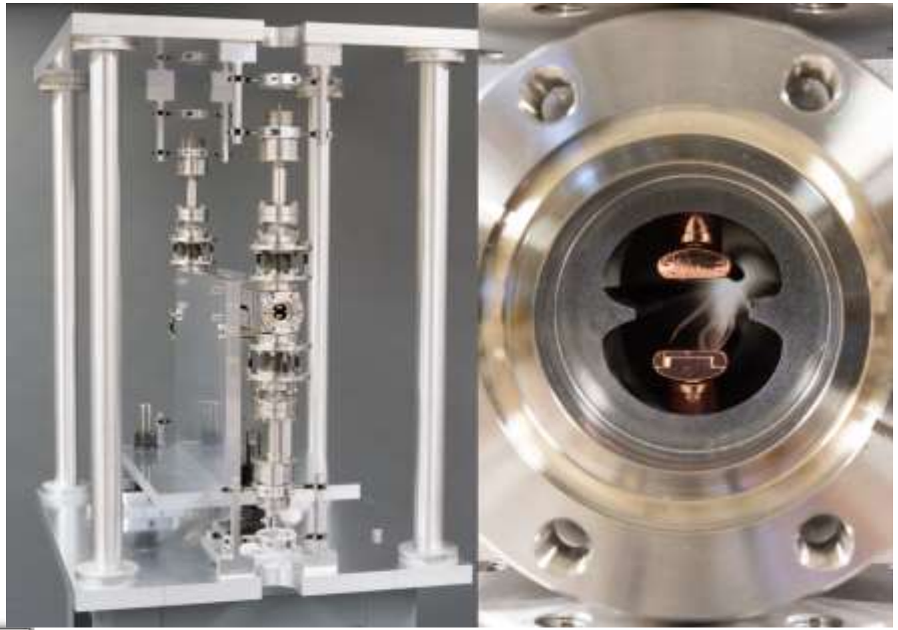


Prototype Stripline Kicker used for successful BTX Beam Tests

Fast Bunch Swap-Out Injection



Prototype Stripline Kicker* used for successful BTX Beam Tests



Operation demonstrated with beam to 30 kV; double the original requirement.

* Courtesy Z. Conway etal, ANL-PHY

MBA Control System constraints and challenges

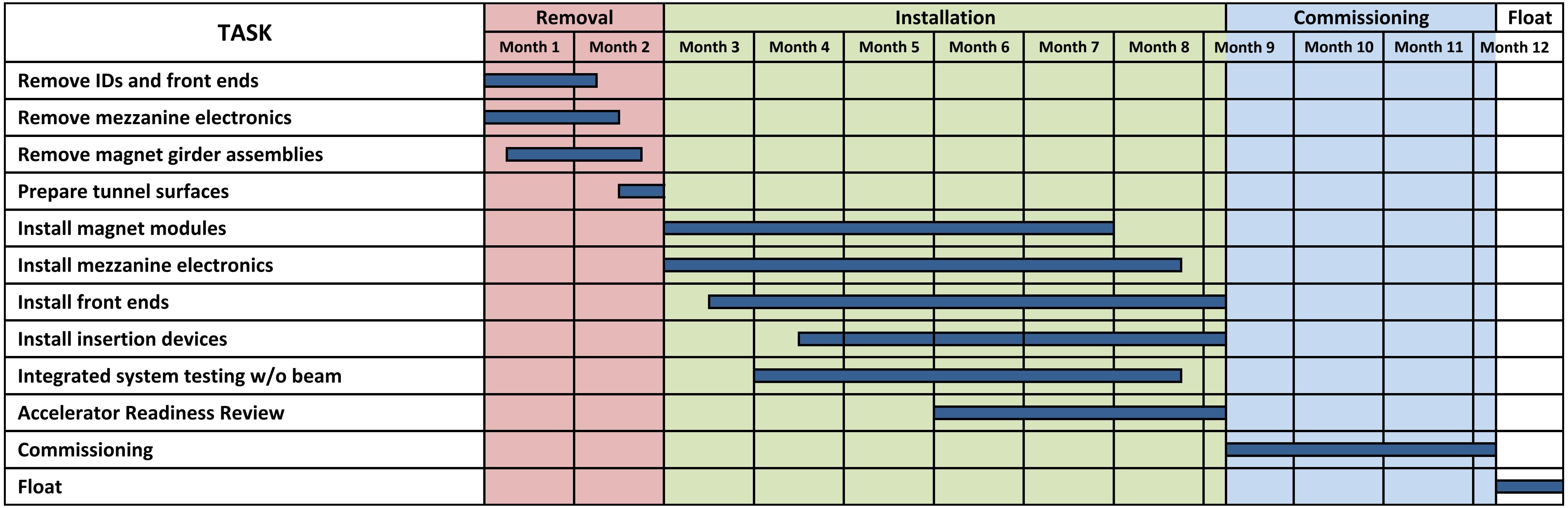
- Control system design **retains the underlying APS controls infrastructure**

- Enhancements are driven by APS-U technical system needs
  - Ubiquitous embedded IOCs, FPGA-based controllers, network appliances
  - Substantial increase in number network ports
  - Substantial increase in data volume and throughput requirements

- Commissioning time is short for Controls + Integrated Tests + full MBA
  - Must be completely integrated/tested/debugged very soon after installation
  - All tools must be debugged and ready
  - Requires expedient troubleshooting tools
  - Early deployment of “virtual accelerator systems” with production PV names
  - Early development of integrated tests (using the virtual accelerator and test stands)

- Will need to draw upon the numerous ‘modern’ tools developed by the EPICS community

Major challenge – 12-month dark-time schedule



- 3-month beam commissioning phase begins in Month #9
- Control System will be expected to be ready from the moment it’s needed
- Transferring Controls interfaces from existing technical systems to new will be a daunting task (~500,000 PVs, over 21 new systems)

From PDR

MBA Control System Scope

Control System Engineering Applications & Services

Technical System Database (magnet measurements, calibration data, installed equipment, etc)

Subsystem Performance Monitoring

BPM / Orbit Server

Process Variable Database

Subsystem Integration Tests

Power Supply Synchronous Setpoint Control

Short Term Data Logging

Data Acquisition (DAQ) Services

APIs to other toolkits (e.g. Matlab, Octave, python)

Post-mortem analysis

Physics Applications & Operation Tools

Interactive Tools

Convenience Tools for Operators

Injection Sequencer

Alarms

sdds tools

Long Term Data Logging

AOP Applications

- 1000's of scripts
- MPS Data Review
- Knobs (weights/limits)
- Glitch Logger
- PEM
- sddsexperiment
- BPM Histories

EPICS

Data Acquisition (DAQ)

Timing, Bulk Data, Maintenance, …

Accelerator Control

Controls Hardware & Software Infrastructure

Interface(s) to Technical Equipment

MPS

Fast Orbit Feedback

Unipolar Power Supplies

Bipolar Power Supplies

Vacuum Systems

Transverse Feedback System

Longitudinal Feedback System

Diagnostics
BPMs
X-ray Intensity Monitors
BPLD
Beam Size Monitors
Mechanical Motion System
Current Monitors

RF Upgrades

RF Bunch Lengthening System

Booster / SR 352MHz Sync

Injection / Extraction Timing

Beamline Timing

Water Systems

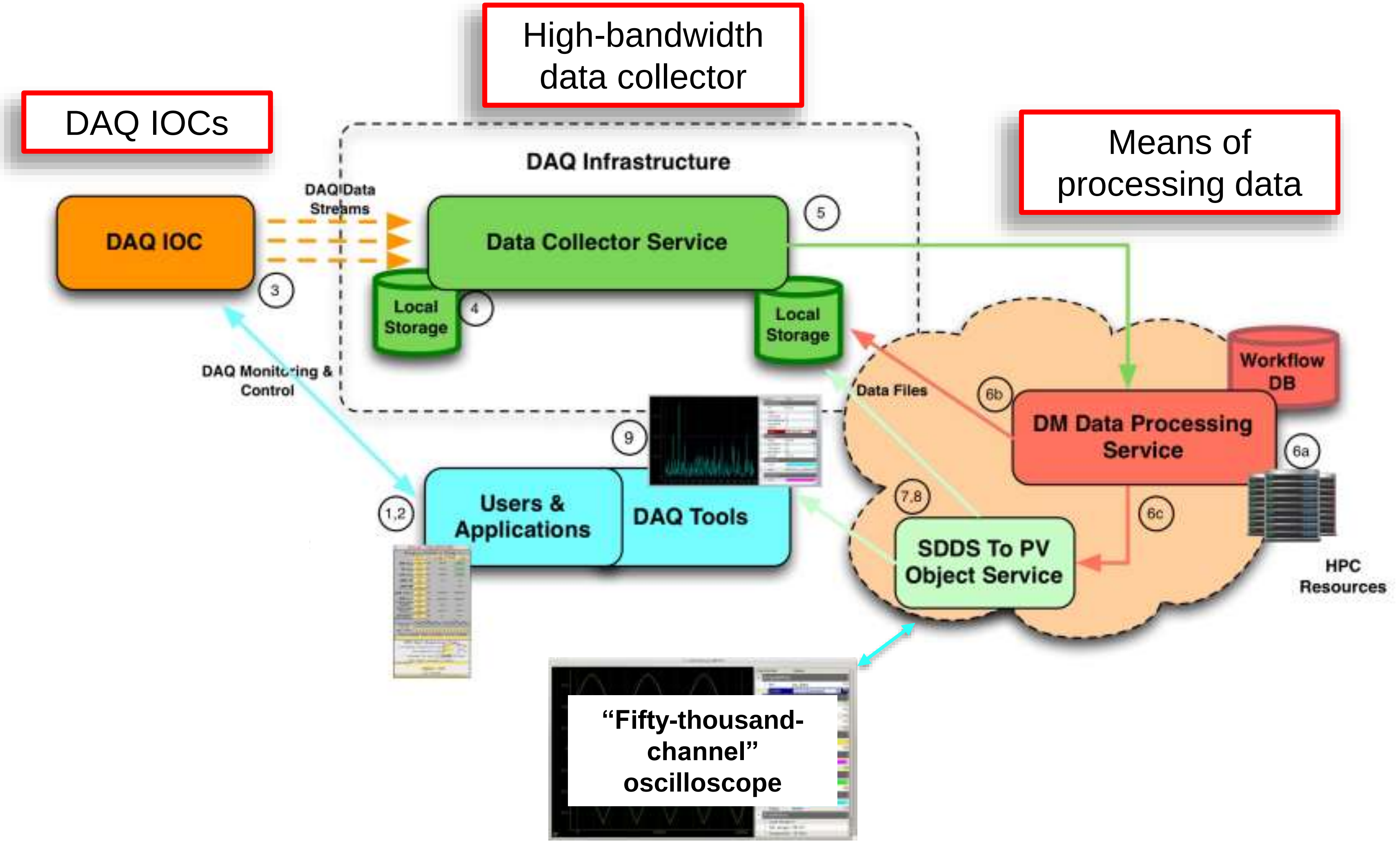
Cryo Plant

Absorbers

Existing Systems to Remain
Oscilloscopes
Video Distribution
DCCTs
LNDS
BACNET
Top-off Monitor
Injectors PSS/ACIS

Timing & Synchronization

Requirements for high data rates + *Time-correlation of data from disparate systems* → *Structured data (EPICS V7)* → ***APS-U DAQ***



Real-time processing workflow

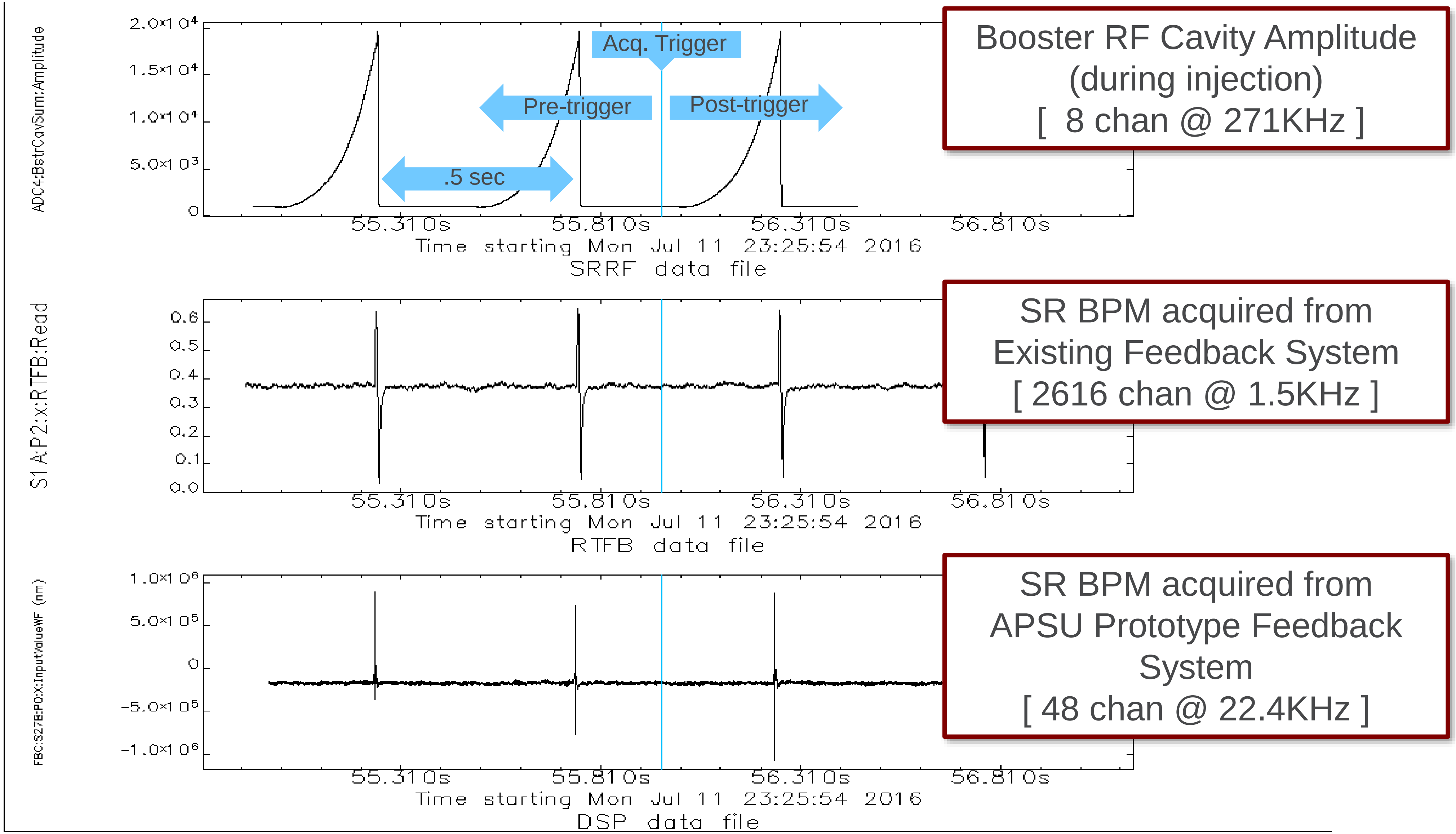
1 : DAQ Setup
2 : Start Data Acquisition
3 : Stream DAQ Data to Data Collector
4 : Save Files to Local Storage
5 : Initiate Real-Time Processing Workflow
6a: Process Data
6b: Save Processed Files
6c: Notify SDDS To PV Object Service
7 : Convert SDDS Files to PV Objects
8 : Update PVA Channels
9 : Receive PVA Updates

OrbitVectorServices
[method = ACLockin]
[event = beam-loss]

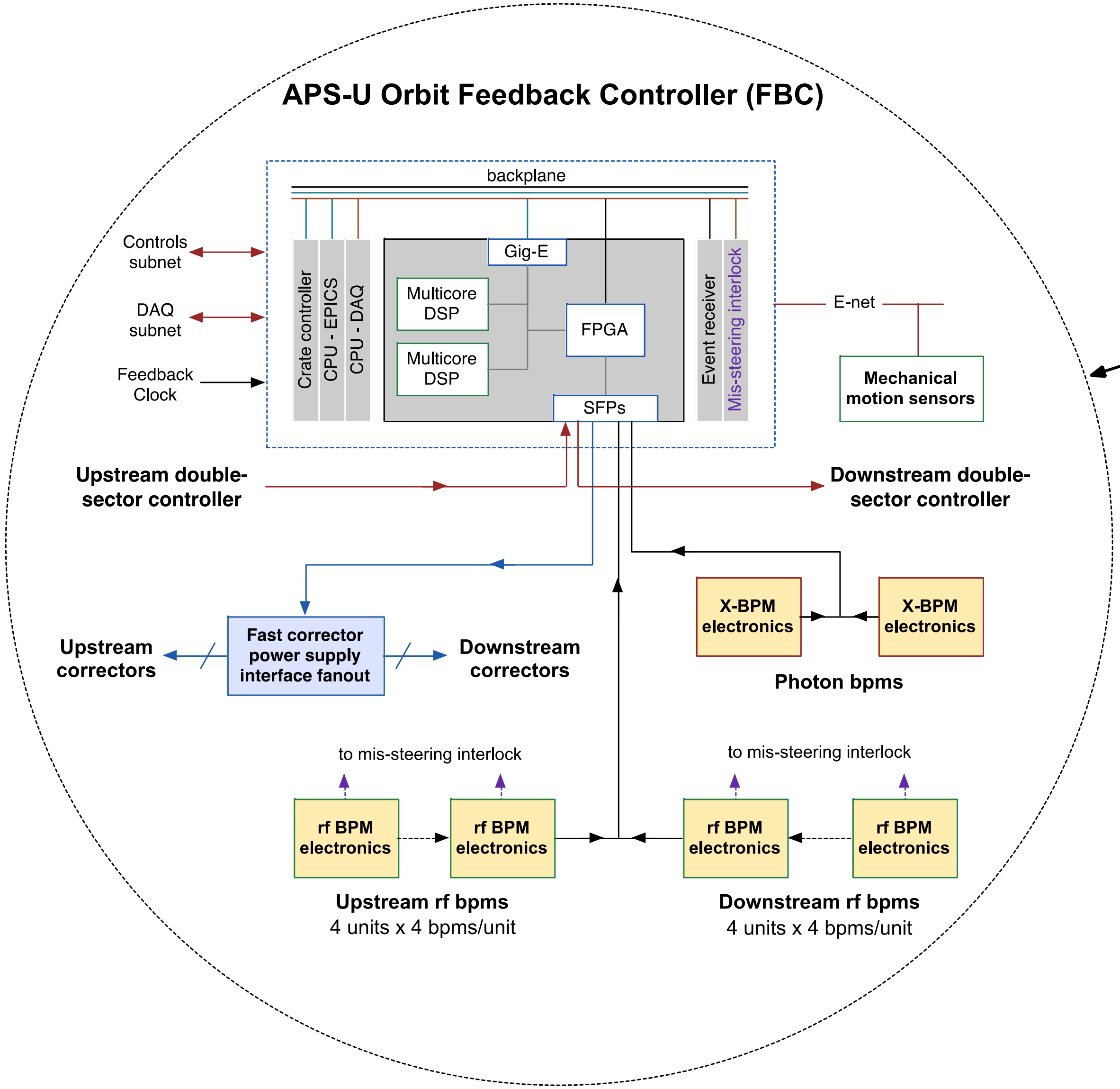
Courtesy S. Veseli

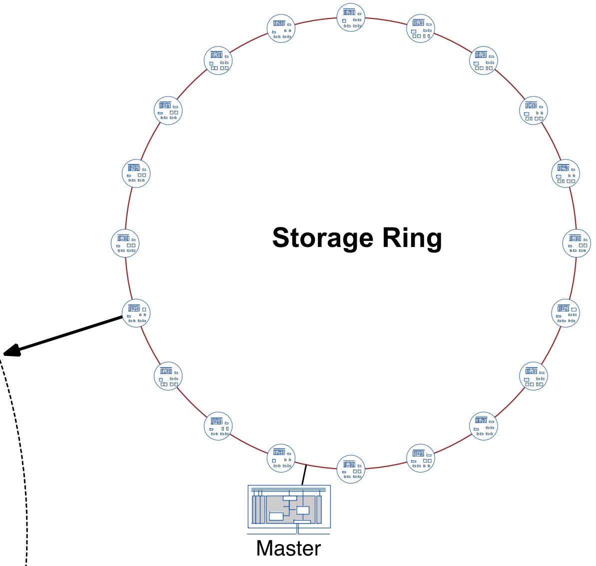
The APS Upgrade (J. Carwardine) - EPICS Collaboration Meeting, June 2018

DAQ Use Case: Monitoring SR Injection



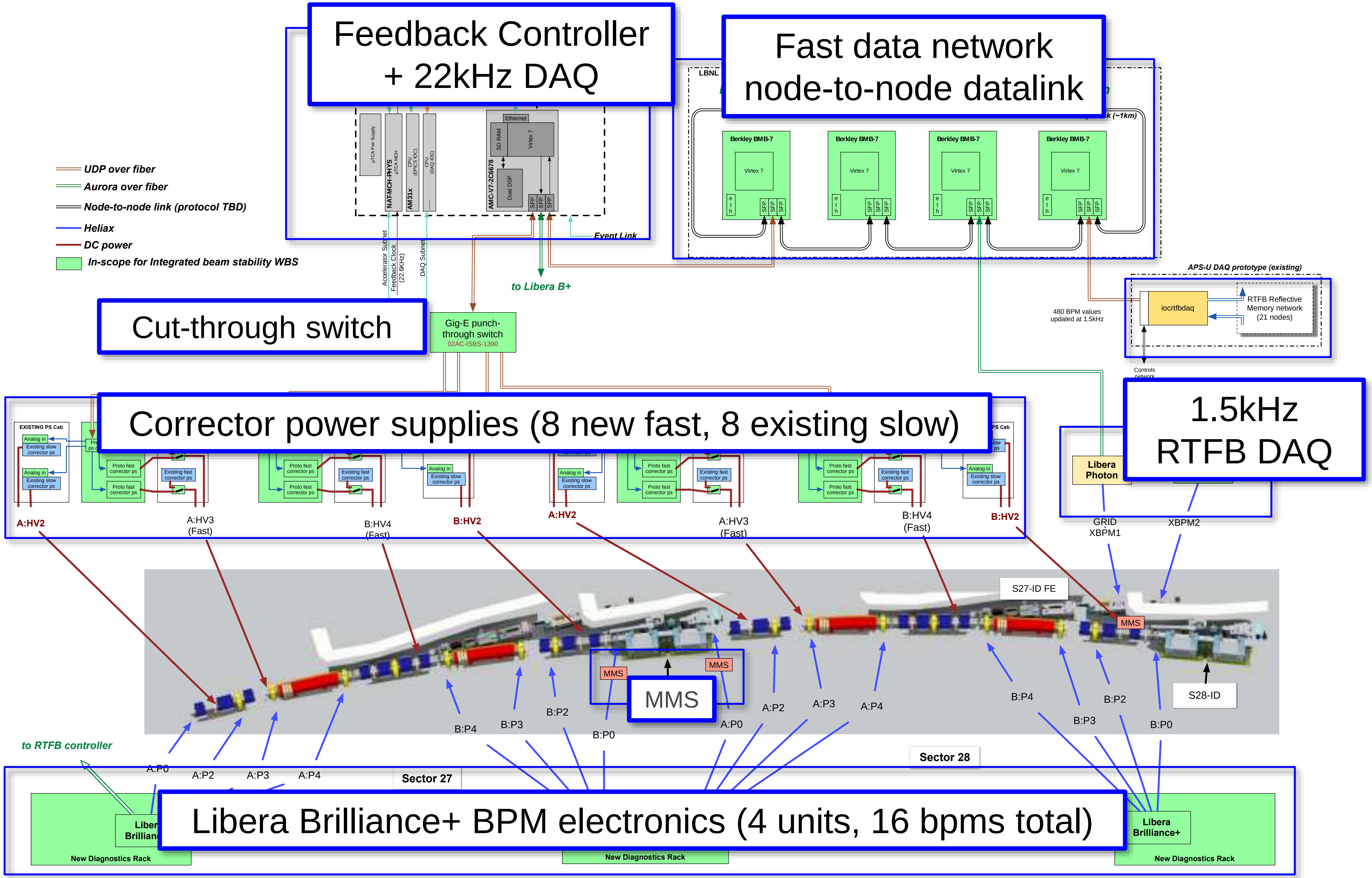
APS-U fast orbit feedback





- The APS orbit feedback system was the first digital truly global fast orbit feedback system to be implemented at a light source
  - In operation since 1995
- APS-U fast orbit feedback follows the same architecture and design philosophy (it just uses ‘modern’ technology)

APS-U Orbit feedback Integrated R&D



Argonne NATIONAL LABORATORY

J. Carwardine, N. Sereno, N. Arnold

Fast orbit feedback system parameters

Present system (circ. 1995)

Parameter	APS-U design	'Datapool'	RTFB
Algorithm implementation	'Unified feedback' algorithm ✓	Separate DC and AC systems for slow and fast correctors	
BPM sampling & processing rate	271 kHz (TBT) ✓	10 Hz	1.5 kHz
Orbit correction update rate #	22.6 kHz ✓	10 Hz	1.5 kHz
Signal processors (20 nodes) (one node demonstrated)	DSP (320 GFLOPS) + FPGA (Virtex-7)*	EPICS IOC	DSP (40 MFLOPS)
Num. rf bpms / plane	570 *	360	160
Fast correctors / plane	160 *	-	38
Slow correctors / plane	320 *	282	-
Fast corrector ps bandwidth	10 kHz ✓	-	1 kHz
Fast corrector latency	<10 us ✓	-	~250 us
Closed-loop attenuation bandwidth	DC to 1 kHz**	DC - 1 Hz	1 Hz - 80 Hz

Highest demonstrated at any light-source to date

✓ Demonstrated

* Full double-sector demonstrated

** >800 Hz has been demonstrated

Wrap-up

- The APS-U lattice design has the lowest horizontal emittance of all synchrotron light sources currently under consideration (42 pm-rad)

- APS will continue operating until mid FY2022
- APS-U is due to come on line in FY2023 after a 12-month shutdown

- APS-U R&D program has been very successful (for Controls and others)
- Early procurements are underway (magnets, power supplies,…)

- There are many challenges (for Controls and others)

- We have funding (FY2018 budget = $93M)