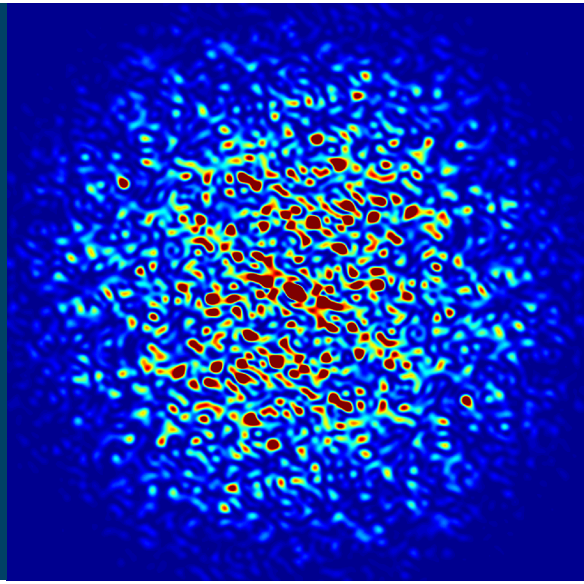
High Performance Data Acquisition for a Modern Accelerator



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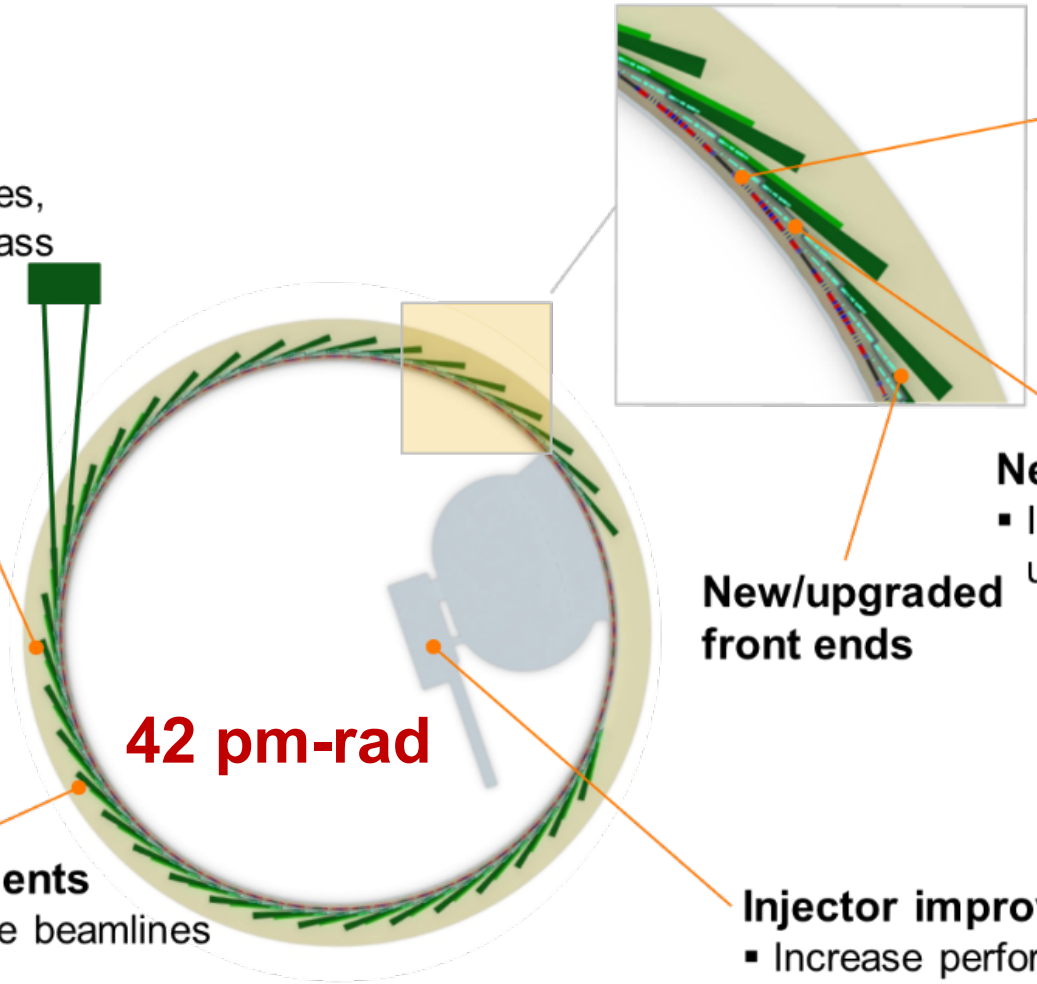
Advanced Photon Source
Argonne National Laboratory

IBIC, 14-18 September 2020

APS-U Project Scope



Feature beamlines
- Suite of beamlines, including long beamlines, designed for best-in-class performance

New storage ring
- 6 GeV with 200 mA, 42 pm-rad emittance
- Hybrid 7BA lattice with reverse bends
- Improved electron and photon stability

New insertion devices
- Including superconducting undulators

New/upgraded front ends

42 pm-rad

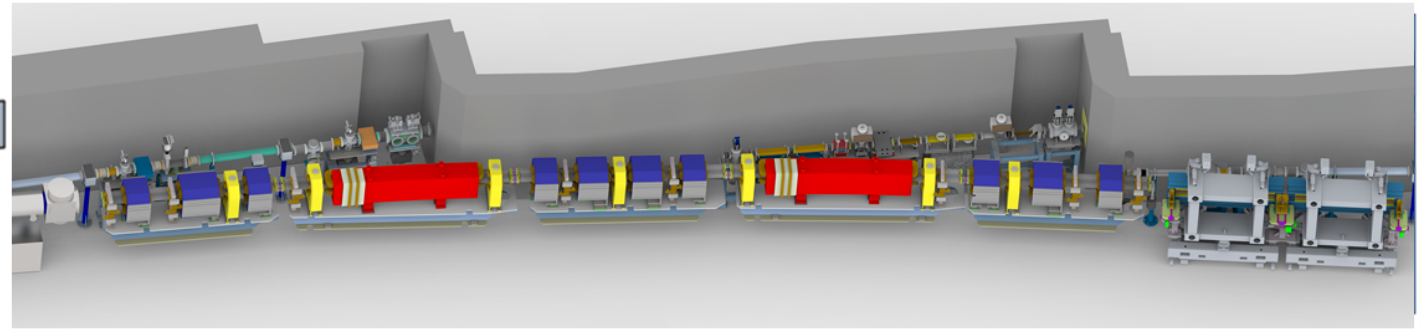
Beamline enhancements
- Improvements to make beamlines "Upgrade Ready"
- Existing beamlines are planned to come back on-line after the upgrade

Injector improvements
- Increase performance beyond present capability

On-axis "swap-out" injection

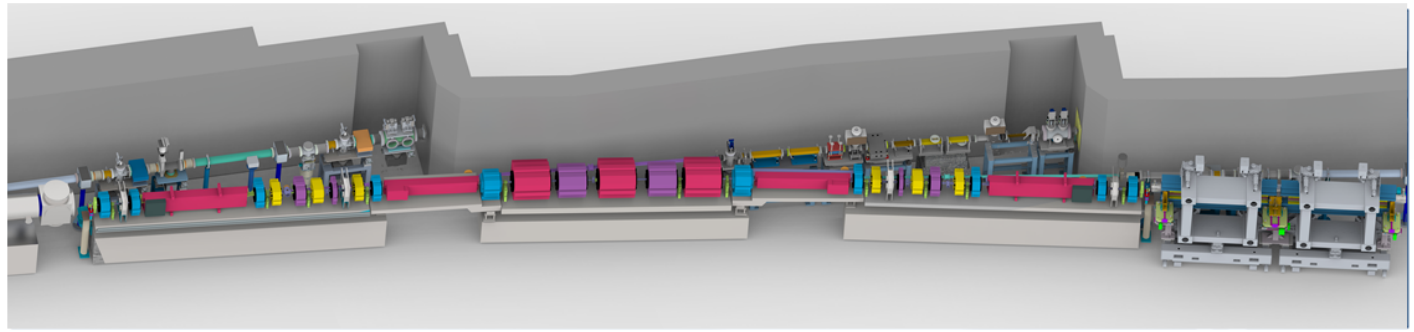
APS-U – High Brightness Storage Ring

APS double bend lattice

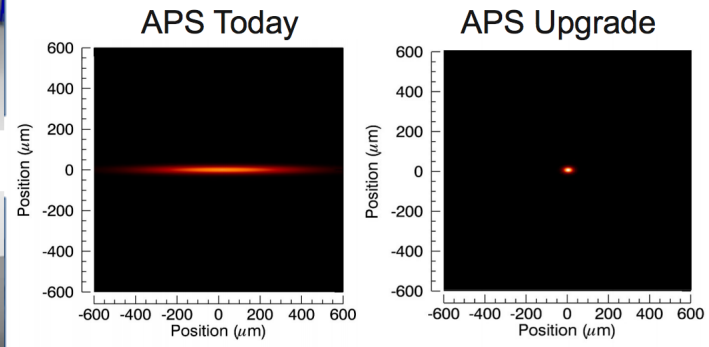


3000 pm-rad emittance

~70-fold reduction in horizontal emittance



42 pm-rad emittance



APS-U 7-bend achromat lattice

Hybrid 7BA lattice with longitudinal gradient, transverse gradient and reverse bend dipoles

$$\varepsilon \propto \frac{E^2}{(N_D N_S)^3}$$

N_D = # dipoles/sector
N_S = # sectors

MBA Accelerator Controls Scope

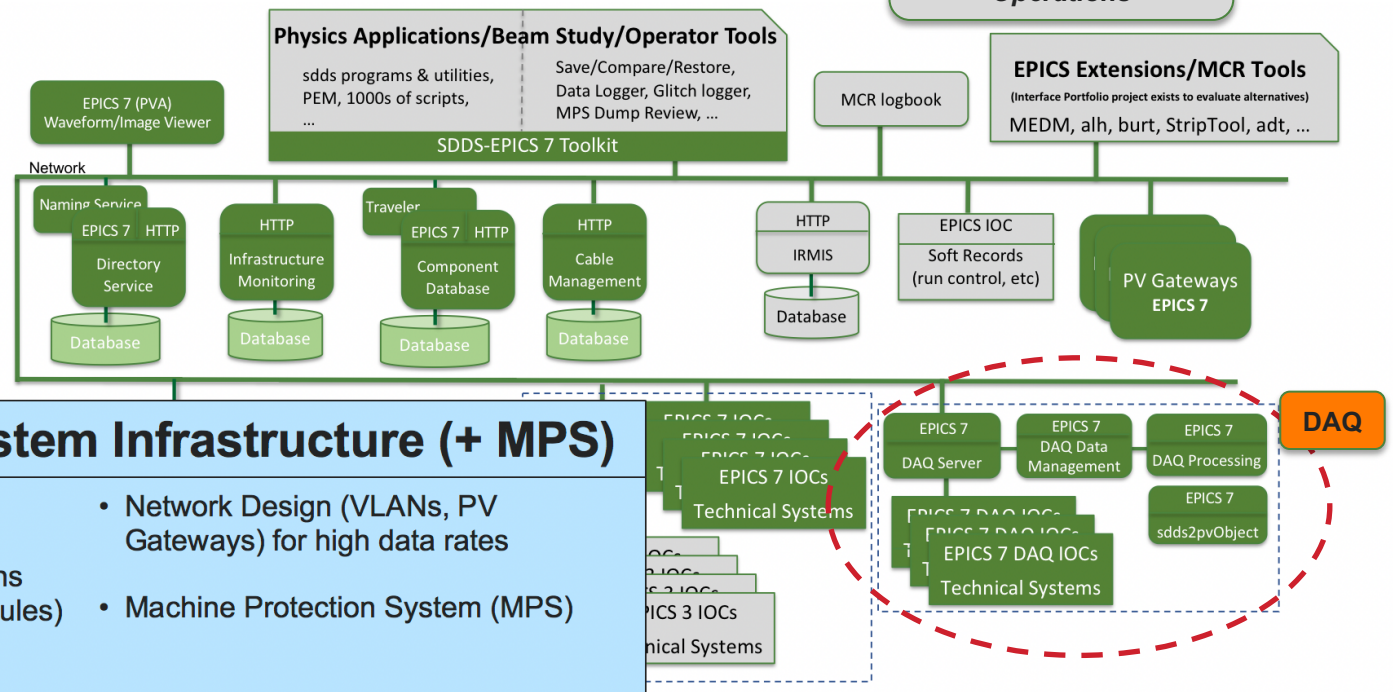
Gray items are supported/enhanced by "Operations"

APS-U Controls High Level Applications

- EPICS 7 Waveform/Image Viewer
- EPICS 7 sdds-epics toolkit enhancements
- Process Variable Directory & Name Service
- Infrastructure Monitoring
- High Level Applications for Specific Systems (e.g. orbit, synchronous PS setpoint, post-mortem, …)

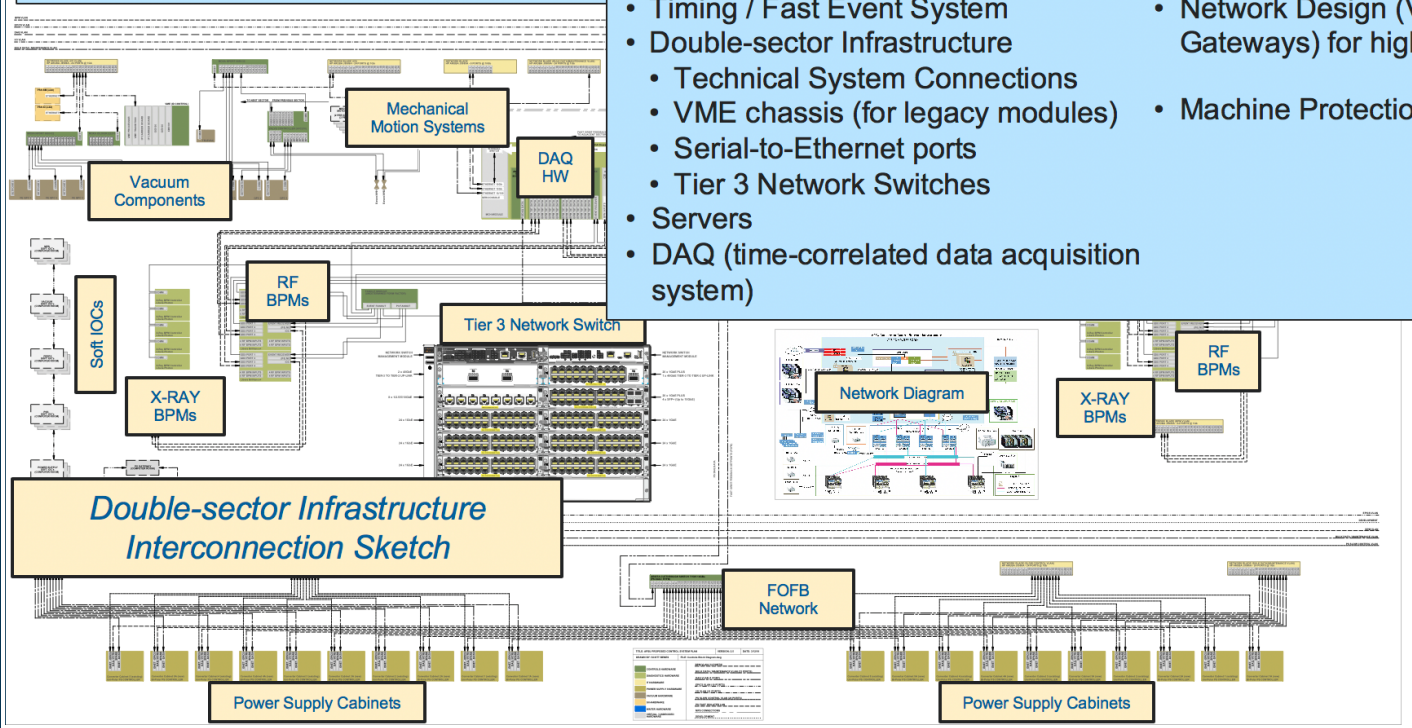
< Project-wide Tools >

- Component Database
- eTraveler
- Cable Management Application



APS-U Control System Infrastructure (+ MPS)

- Timing / Fast Event System
- Double-sector Infrastructure
  - Technical System Connections
  - VME chassis (for legacy modules)
  - Serial-to-Ethernet ports
  - Tier 3 Network Switches
- Servers
- DAQ (time-correlated data acquisition system)
- Network Design (VLANs, PV Gateways) for high data rates
- Machine Protection System (MPS)



Double-sector Infrastructure Interconnection Sketch

APS-U Technical System Interfaces

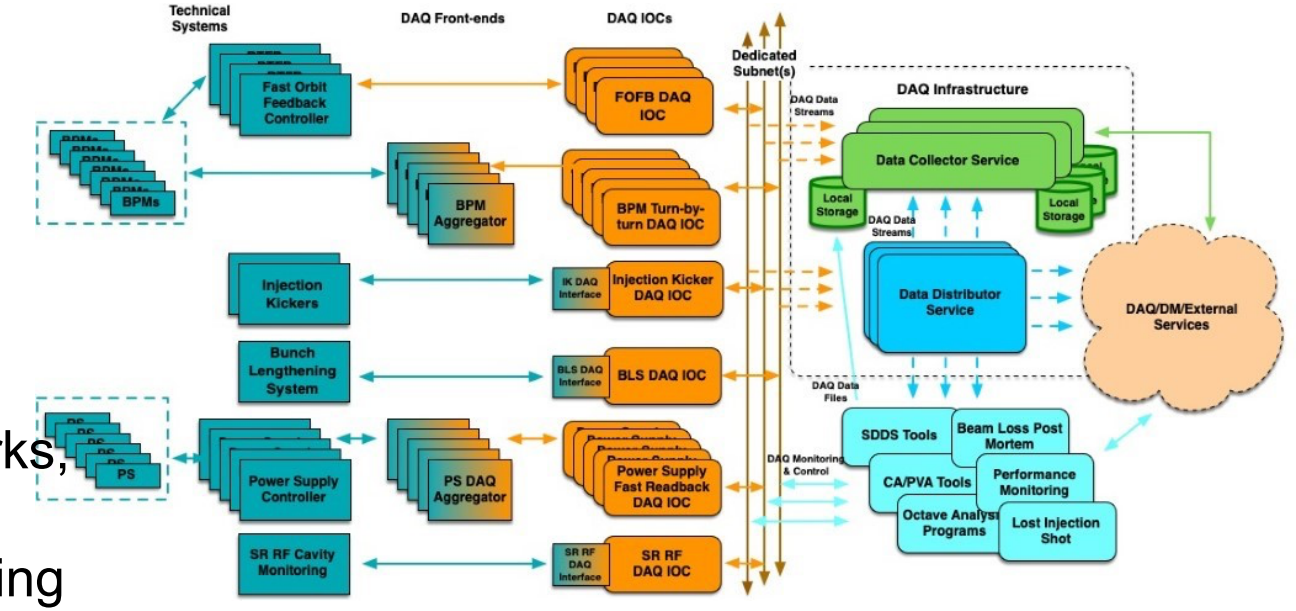
- Unipolar Power Supplies + DAQ
- Bipolar Power Supplies + DAQ
- Vacuum Systems + Beam Dumps
- Bunch Lengthening System Interlocks/LLRF + DAQ
- BLS Cryo-system + Distribution
- Injection/Extraction + DAQ
- RF BPM (Libera) + DAQ
- X-Ray BPM
- X-Ray Intensity Monitor
- BPLD
- Beam Size Monitor (absolute)
- Beam Size Monitor (relative)
- Mechanical Motion System
- DCCT
- Bunch Current Monitor
- Fast Orbit Feedback + DAQ
- Longitudinal Feedback + DAQ
- Transverse Feedback + DAQ
- Booster/SR 352MHz Timing
- Slow Abort Sequencer

APS-U Data Acquisition (DAQ) System

- The need and specifications for a DAQ system are driven by the technical system implementations that use state-of-the-art technology of FPGAs, SoC, DSPs, and high bandwidth communication links. Such technology can capture GBs of data from the technical systems that must be “consumed” by the control system.
- ***DAQ Software: represents framework and tools that enable fast data collection for controls, statistics and diagnostics of the embedded controllers utilized by the APSU MBA***
- Must consider both the large data volume and fast data rates to scale systems appropriately. Prudence and “best practices” suggest isolating this data from the main controls network.
- Provide a “standard solution” for technical system DAQ implementations for code reuse and consistent interface for clients.

APS-U Data Acquisition (DAQ) System

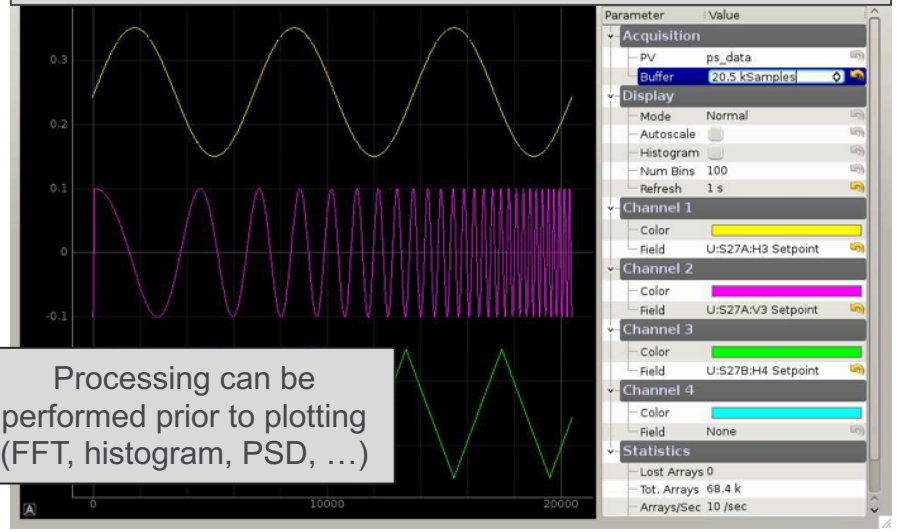
- **Key Aspects of the DAQ System:**
  - Capability to acquire time-correlated synchronously sampled data *from multiple subsystems at different sample rates* and correlate this data to within one beam revolution (3.6 μs) or better
  - Support for *continuous or triggered* data acquisition limited only by the available storage.
  - DAQ data includes a timestamp for each sample acquired allowing immediate plotting of data from various systems onto a common time-axis
  - The ability to route the data to any number of applications
  - Use of EPICS PVA objects to encapsulate numerous fast data signals, parameters, and slow data in an atomic data packet (ensures data synchronicity to the same event)
  - Scalability by partitioning the heavy traffic to multiple dedicated subnets and servers
  - Separation from operational systems (networks, processors, servers) to allow trouble-shooting/enhancements/reconfigurations during user operation



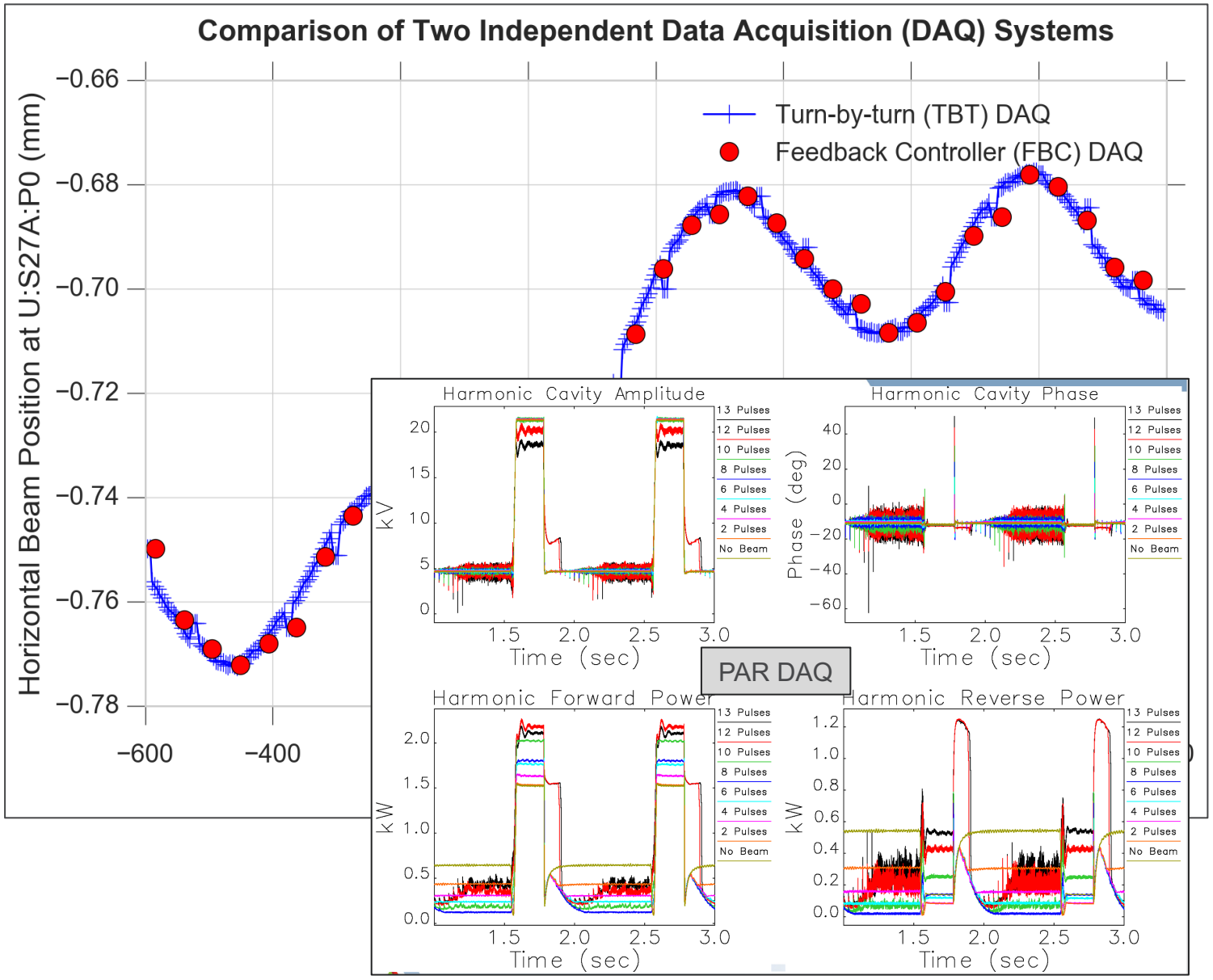
APS-U DAQ System: R&D Activities

- **Data Acquisition System**
  - Time-correlated acquisition across different subsystems (with different F_s)
  - Services: Real-time viewing, save to file, in-line processing, …
  - Five DAQ IOCs deployed during R&D
  - Additional DAQ IOC deployed in PAR for Injector studies

"Scope-like-app" displays streaming DAQ data
-- Corrector Drive (w AFG) within Fast Orbit Feedback --

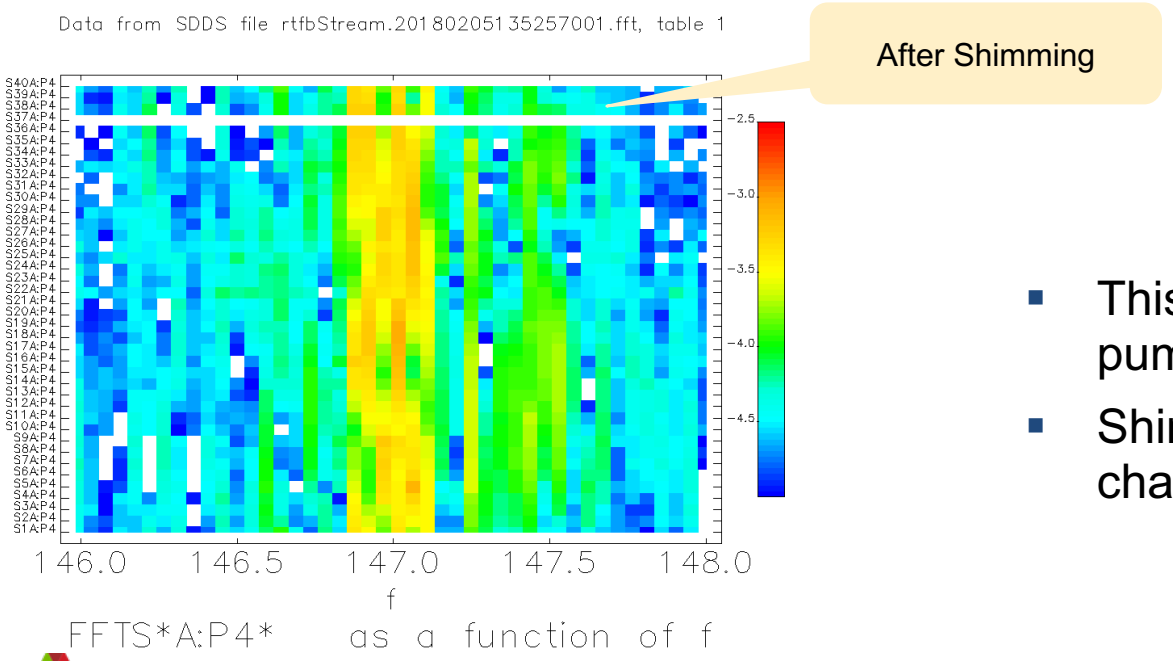


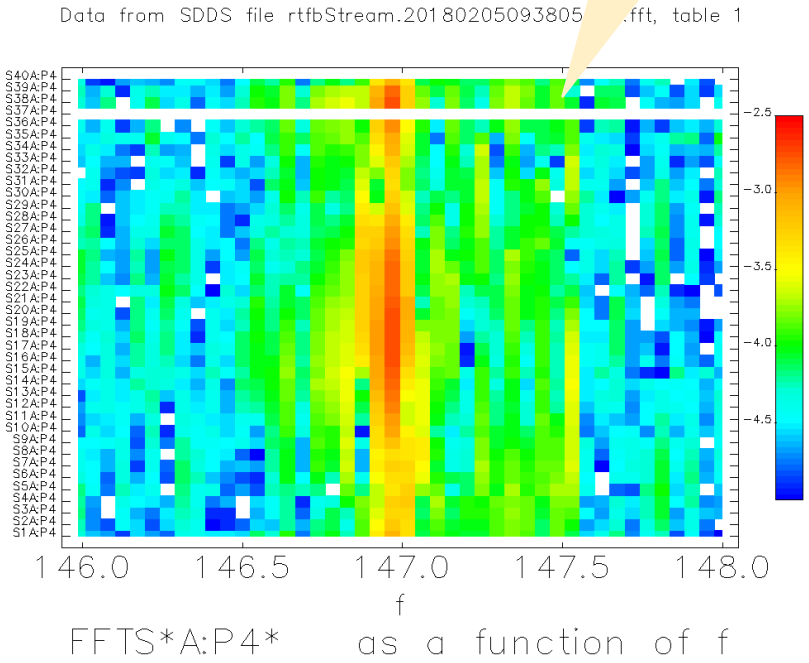
Processing can be performed prior to plotting (FFT, histogram, PSD, …)



Diagnostics with DAQ (L. Emery)

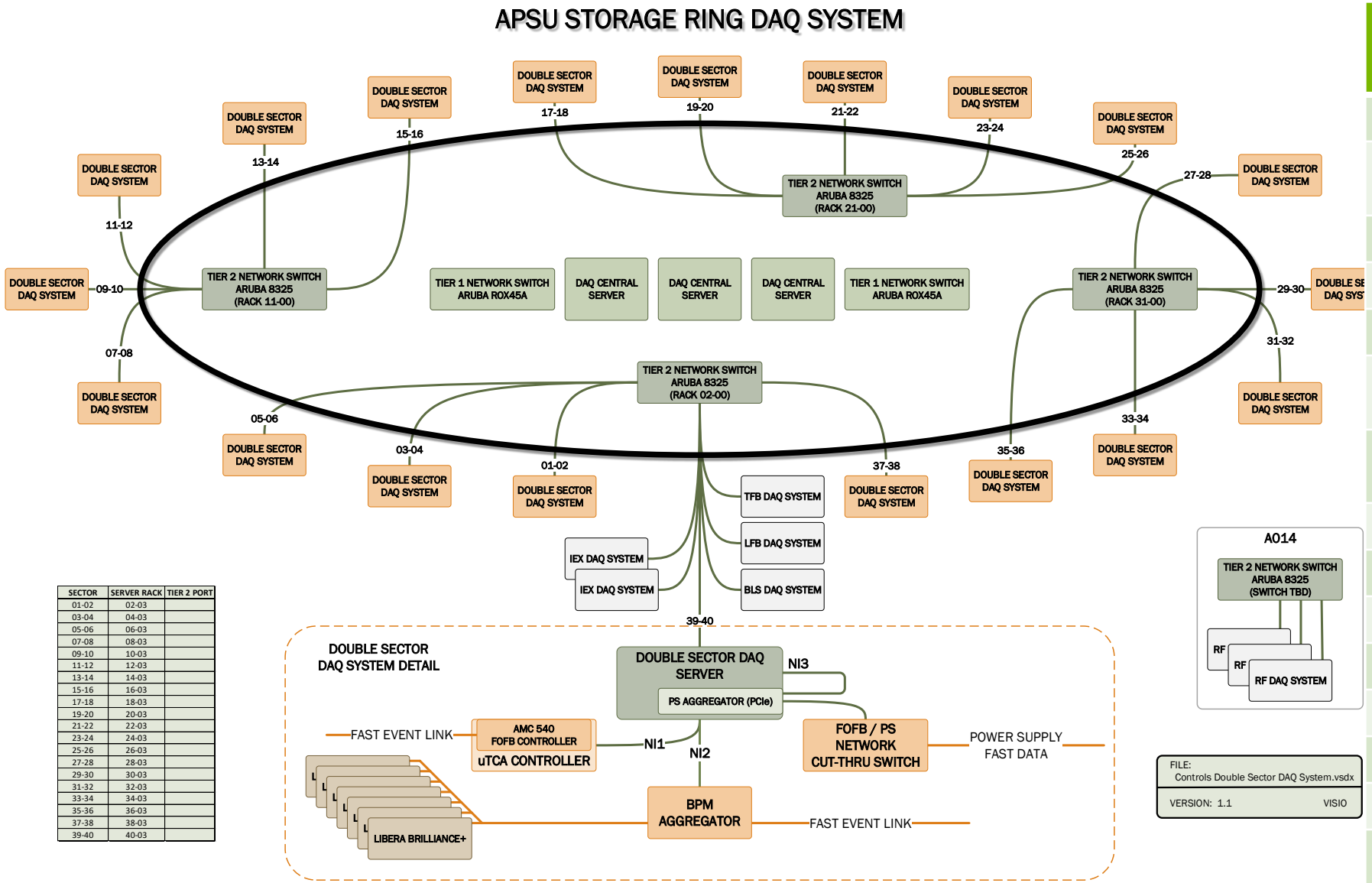
- Suppression of 147Hz vibration source in the ring using the DAQ system + post-processing with FFT
- Vacuum chamber was vibrating and introduced a Bx field
- Identification of the nearest quadrupoles required 400 channels, 20 seconds of continuous DAQ data to get 0.5Hz precision





- This allowed separating line frequencies of 20 pumps
- Shims were inserted between poles and vacuum chamber (S37AQ3, S37AQ2)

Hardware Architecture

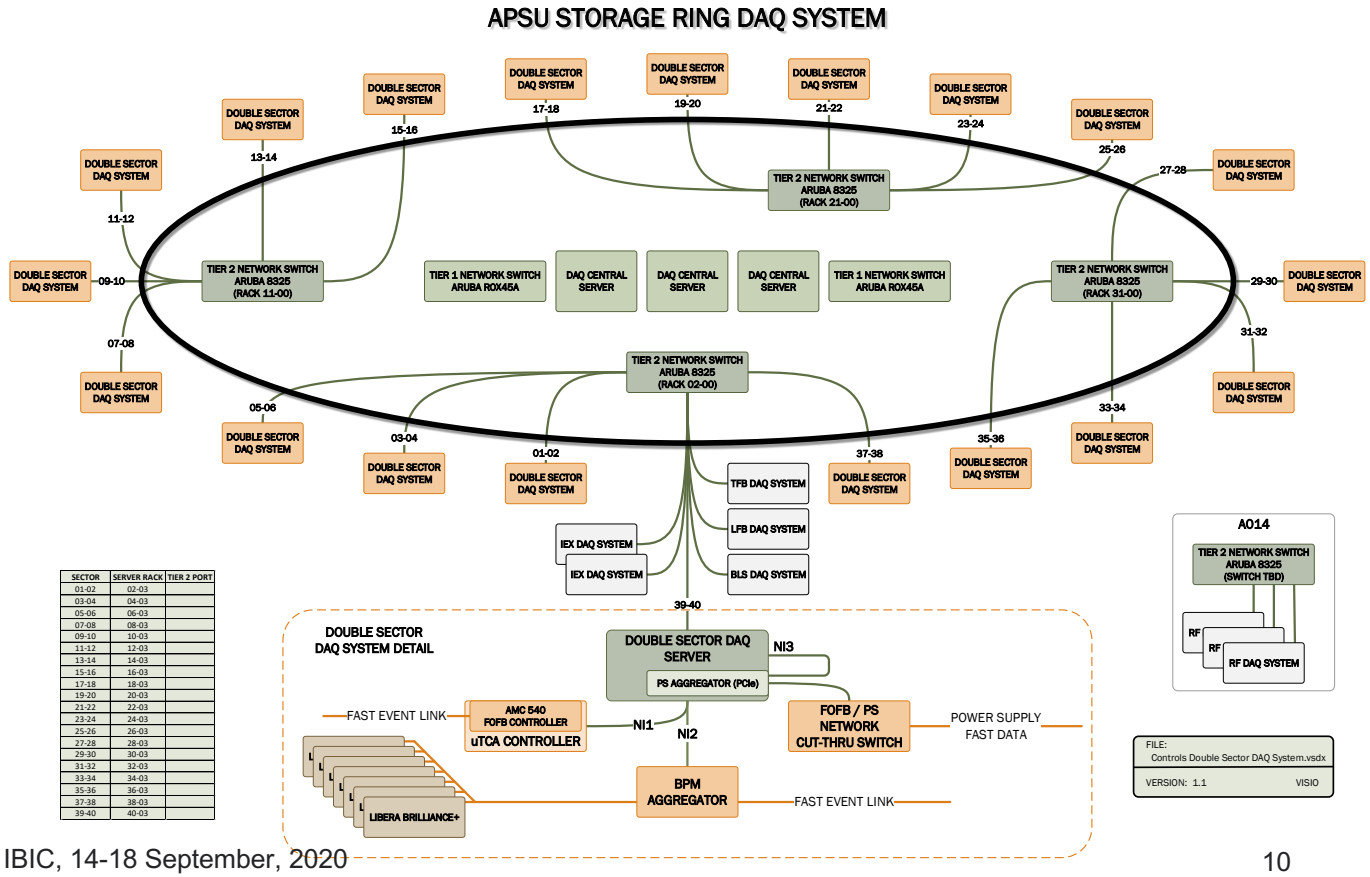


SECTOR	SERVER RACK	TIER 2 PORT
01-02	02-03	
03-04	04-03	
05-06	06-03	
07-08	08-03	
09-10	10-03	
11-12	12-03	
13-14	14-03	
15-16	16-03	
17-18	18-03	
19-20	20-03	
21-22	22-03	
23-24	24-03	
25-26	26-03	
27-28	28-03	
29-30	30-03	
31-32	32-03	
33-34	34-03	
35-36	36-03	
37-38	38-03	
39-40	40-03	

Technical System DAQ	# of Channels
Fast Orbit Feedback	256 x 20
Power Supply Fast Monitoring	354 x 20
BPM Turn-by-turn	84 (typical) x 20
Single Bunch BPMs	TBD
IX/EX Waveforms	8 x 2
Bunch Lengthening System	9 (typical)
Longitudinal Feedback	1
Transverse Feedback	2
SR X-Ray BPMs	TBD
SR RF (current)	6
SR RF (near term)	10 (typ) x 4
SR RF (future)	5 (typ) x 12
Booster RF (5)	14, 10, 10, 8, 8 (typ)
PAR RF (3)	9, 12, 10 (typ)
Total # of Channels	**> 13,000**

Significant Architecture Change During Final Design

- Previous Plan
  - TBT DAQ IOC hosted on a µTCA FPGA card
  - PS DAQ IOC hosted on a µTCA CPU
  - FOFB DAQ IOC hosted on a linux server
- Revised Plan
  - TBT DAQ IOC hosted on a linux “DAQ double-sector server” (requires an FPGA-based BPM Aggregator)
  - PS DAQ IOC hosted on a linux “DAQ double-sector server” (requires an FPGA-based PS Aggregator)
  - FOFB DAQ IOC hosted on a linux server “DAQ double-sector server”
- Advantages
  - Common platform for three major DAQ IOCs
  - Local network, local processing, local storage
  - Cost effectiveness of commodity servers



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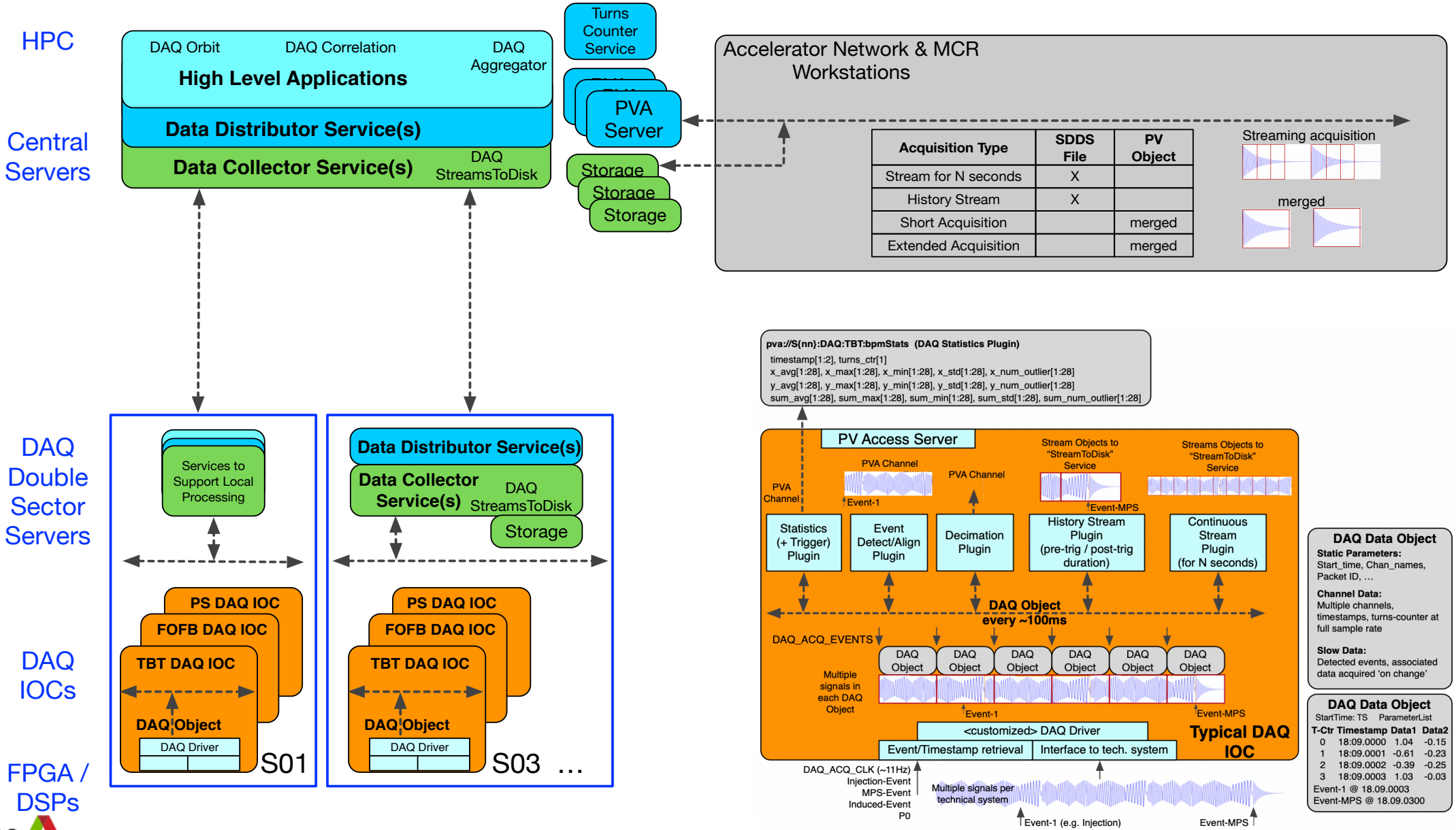
15-16	16-03	
17-18	18-03	
19-20	20-03	
21-22	22-03	
23-24	24-03	
25-26	26-03	
27-28	28-03	
29-30	30-03	
31-32	32-03	
33-34	34-03	
35-36	36-03	
37-38	38-03	
39-40	40-03	

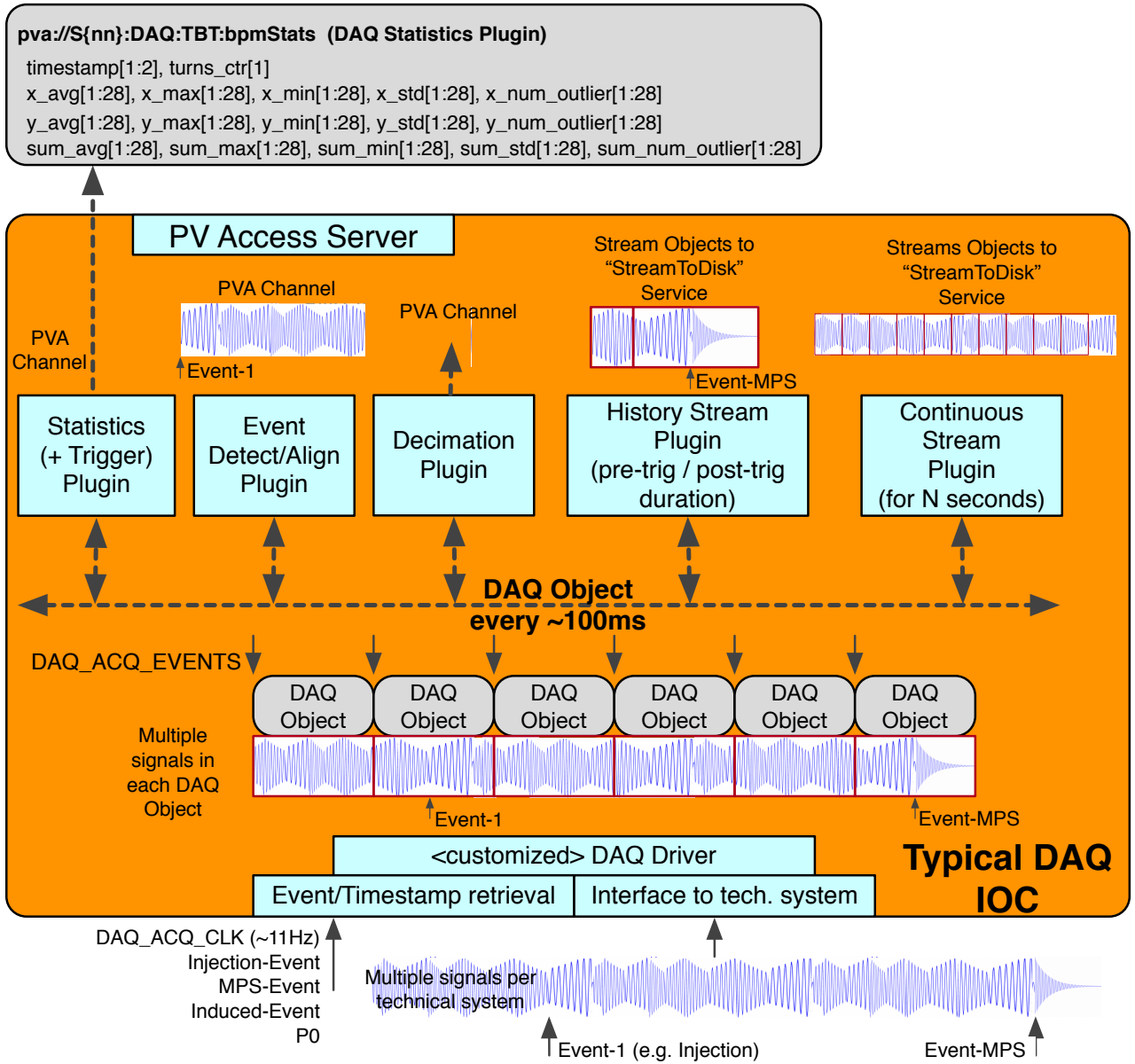
Software Architecture



Acquisition Modes

- Start of DAQ Objects is synchronized across IOCs (using fast event system)
- Can attach ‘slow data’ to the DAQ Object

- Continuous stream
- Acquisition with history: pre-event/post-event times can be specified
- Event Detect/Align: Aligns data wrt a specified event and presents as a single update (appends DAQ objects)



DAQ Data Object

Static Parameters:
Start_time, Chan_names, Packet ID, …

Channel Data:
Multiple channels, timestamps, turns-counter at full sample rate

Slow Data:
Detected events, associated data acquired ‘on change’

DAQ Data Object

StartTime: TS ParameterList

T-Ctr	Timestamp	Data1	Data2
0	18:09.0000	1.04	-0.15
1	18:09.0001	-0.61	-0.23
2	18:09.0002	-0.39	-0.25
3	18:09.0003	1.03	-0.03

Event-1 @ 18.09.0003
Event-MPS @ 18.09.0300

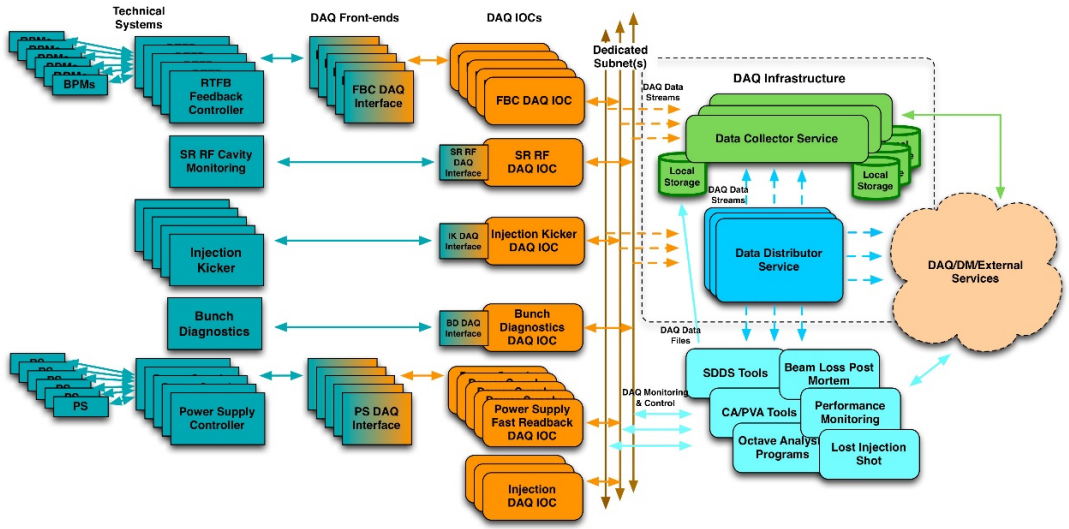
Performance Considerations

Technical System DAQ	# of Channels	Sample Rate	Anticipated Data Rate (Per IOC)
Fast Orbit Feedback	256 (x 20)	22.6 kSPS	24MB/s
Power Supply Fast Monitoring	354 (x 20)	22.6 kSPS	32.3MB/s
BPM Turn-by-turn	84 (x 20)	271 kSPS	94MB/s
IX/EX Waveforms	8 (x 2)	4GSPS for 50ns	2.7MB/s (aperiodic)
Bunch Lengthening System	9	2.44MSPS	112.2MB/s
Longitudinal Feedback	1	352 MSPS	48MB/s per acquisition (2 acquisitions/s max)
Transverse Feedback	2	352 MSPS	48MB/s per acquisition x 2 (2 acquisitions/s max)
SR X-Ray BPMs	TBD	TBD	
SR RF	6	271 kSPS	9.2MB/s

Summary

DAQ: Time-correlated Data Acquisition System

- Acquires data from multiple systems at different sample rates
- Supports continuous data acquisition
- Multiple signals (waveforms) can be acquired within a single DAQ IOC
- Deployed services and IOCs for several technical subsystems during R&D phase
- System has been used extensively for machine studies, diagnostics and troubleshooting



Plans

- Adding missing features
  - Support for event-driven acquisition
- New IOC Development
  - Injection Kicker IOC
  - Bunch Lengthening System IOCs
  - Longitudinal and Transverse Feedback IOCs
- Existing IOC Enhancements: FOFB, TBT, PS
  - New data protocol between hardware and IOCs
- Develop new tools, processing services and applications
  - Data Correlation and Alignment Service
  - Orbit Service
- Production deployment (CONDA, SUMO)