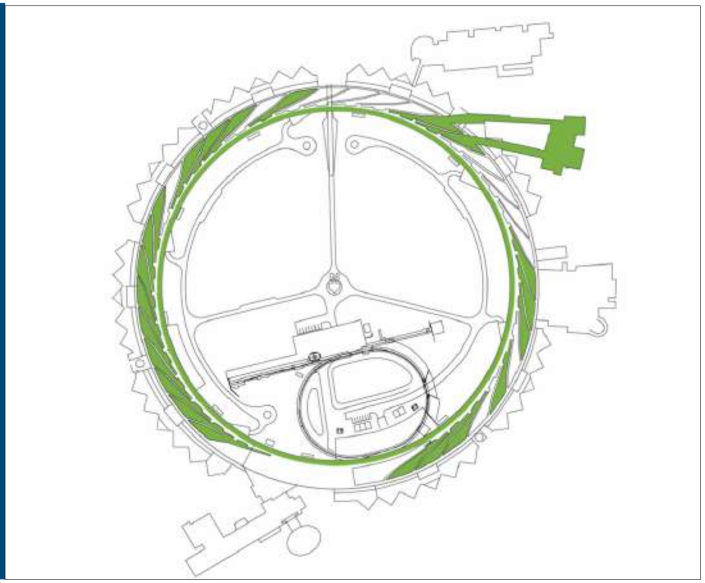
Libera Brilliance+ Synthetic Data Generator Usage for the Advanced Photon Source Upgrade



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Outline

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- Description of synthetic data implementation
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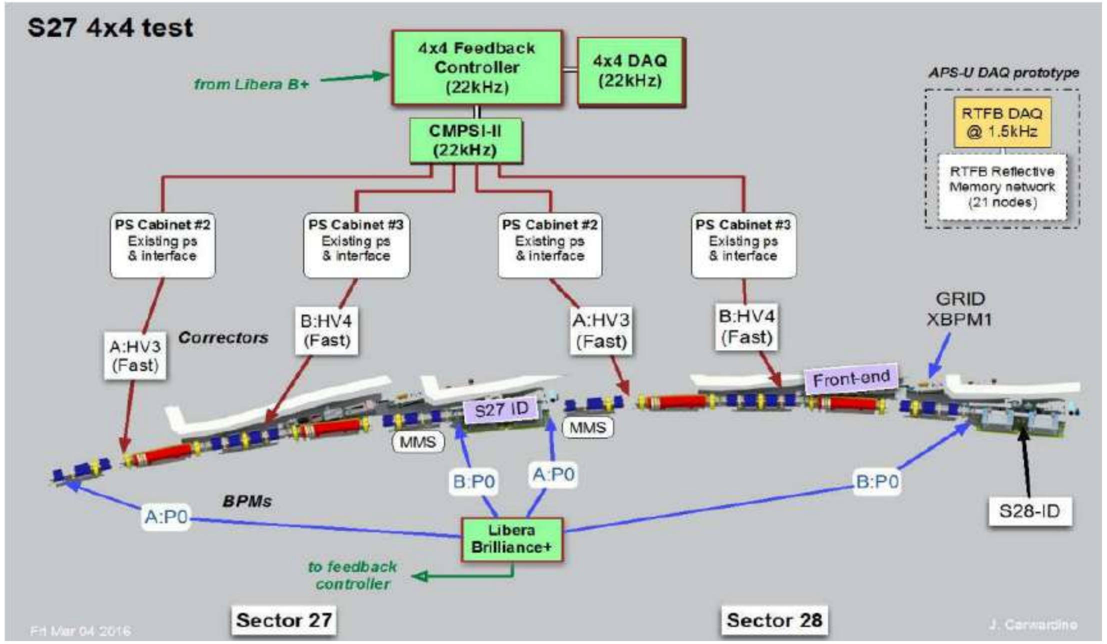
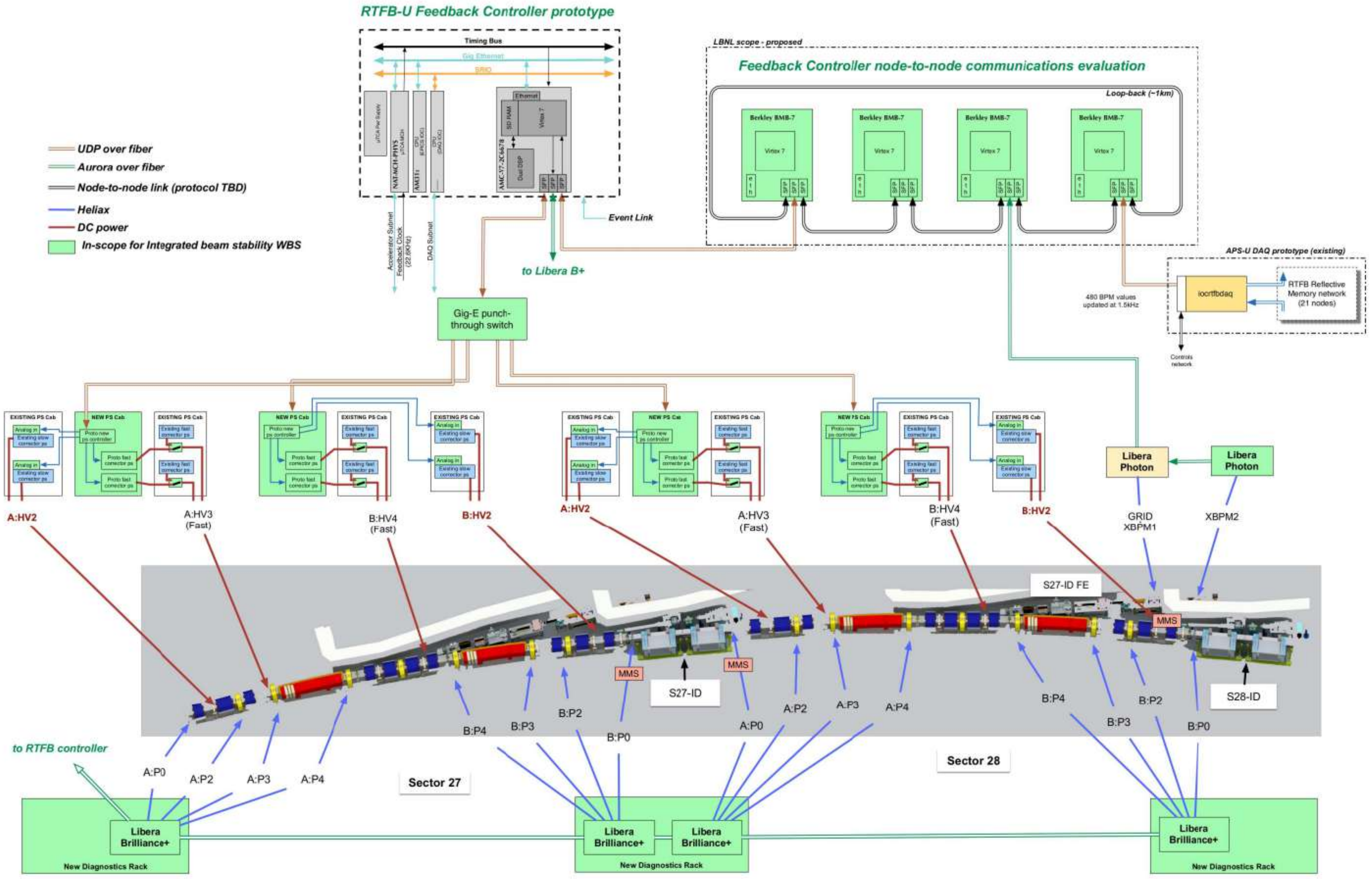
Introduction: Libera Brilliance+ at APS

- In 2014, APS acquired our first Libera Brilliance+ unit for evaluation in the APS storage ring.
- Through 2015, we evaluated the performance of the electronics, familiarizing ourselves with the different features and measuring performance under a variety of conditions. Results were promising.
- Around the beginning of 2016, we began using the GDX module to stream position data via fiber optic link to a receiver that evolved into the prototype for our Fast Orbit Feedback controller system for the APS Upgrade. Initially, this consisted of a 4x4 system, using a single Brilliance+ to measure position at 4 BPMs and control 4 correctors.
- After successful testing of the 4x4 controller, we expanded the system to include 4 Brilliance+ units (16 bpms) and 8 correctors. This system used a daisy chain configuration to transmit turn-by-turn data at 271 kHz, and was used extensively for testing from late 2016 through the end of 2022.



4x4 Feedback Controller test configuration in APS sector 27

Introduction: Libera Brilliance+ at APS



Integrated beam stability double sector test configuration using Libera Brilliance+ at APS.

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Introduction: Libera Brilliance+ for APS-U

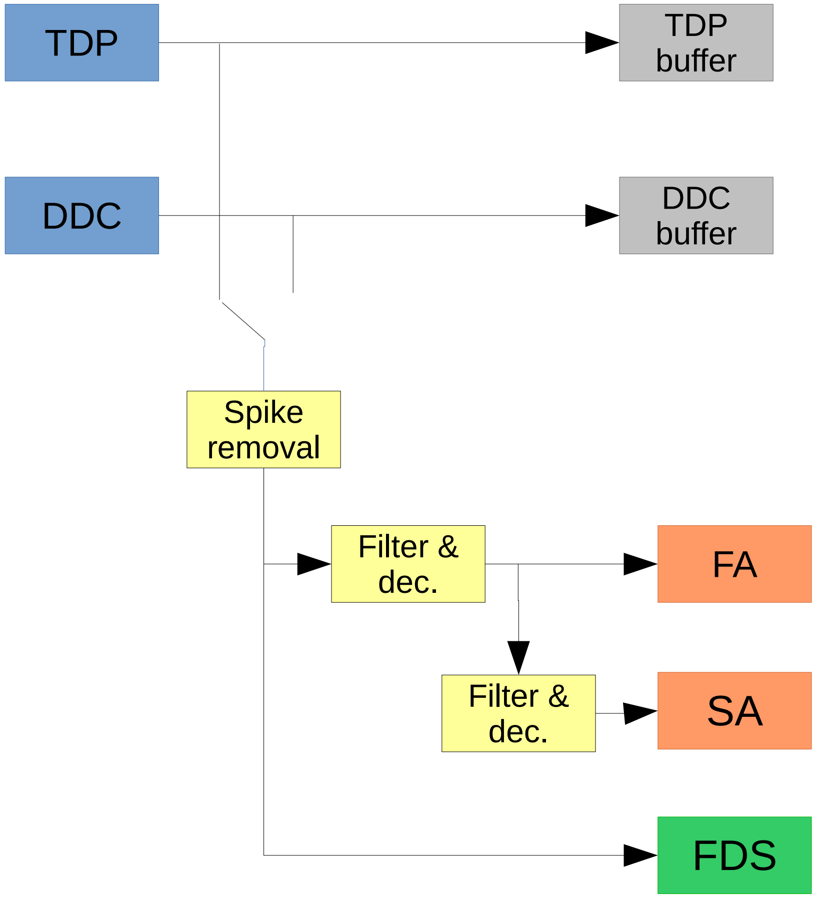
- Our success with the feedback controller testing led to choosing the Libera Brilliance+ as the primary BPM processor for the APS Upgrade project. This includes 140 Brilliance+ units covering 560 BPMs in the storage ring.
- There are 40 (nearly) identical sectors in the APS-U, with 14 BPMs in each sector. Each sector contains 12 arc BPMs and 2 insertion device BPMs.
- Each double sector of the ring includes 7 Brilliance+ units (28 BPMs) which provide turn-by-turn position data to local receivers for the Machine Protection System, turn-by-turn data acquisition system, and Fast Orbit Feedback controller.
- The Advance Photon Source Upgrade is currently in progress. This includes replacing essentially all of the existing storage ring hardware and electronics with updated components. Removal began on April 24th, 2023, with first beam scheduled for early 2024.

Introduction: Purpose of synthetic data

- There were several reasons to request the ability to generate user-defined GDX position data:
  - Testing and troubleshooting of systems receiving BPM position information
  - Verification of the Beam Position Limit Detector (BPLD) of the Machine Protection System
  - Verification of timing between multiple units and systems
- During the development and troubleshooting of our Fast Orbit Feedback controller, we realized the value of the ability to send known values to external systems receiving BPM position data.
- For validation of the BPLD system, we need to minimize the number of times that beam is actually dumped. By using synthetic data, the system can be easily verified when no beam is present by setting the position to specific values to cause a limit error that trips the MPS.
- Using synthetic triggered waveform data, synchronization between systems can be verified. With a programmable waveform that is triggered by an external event, the received waveform data can be used to ensure synchronization.

Synthetic data implementation in the Libera Brilliance+

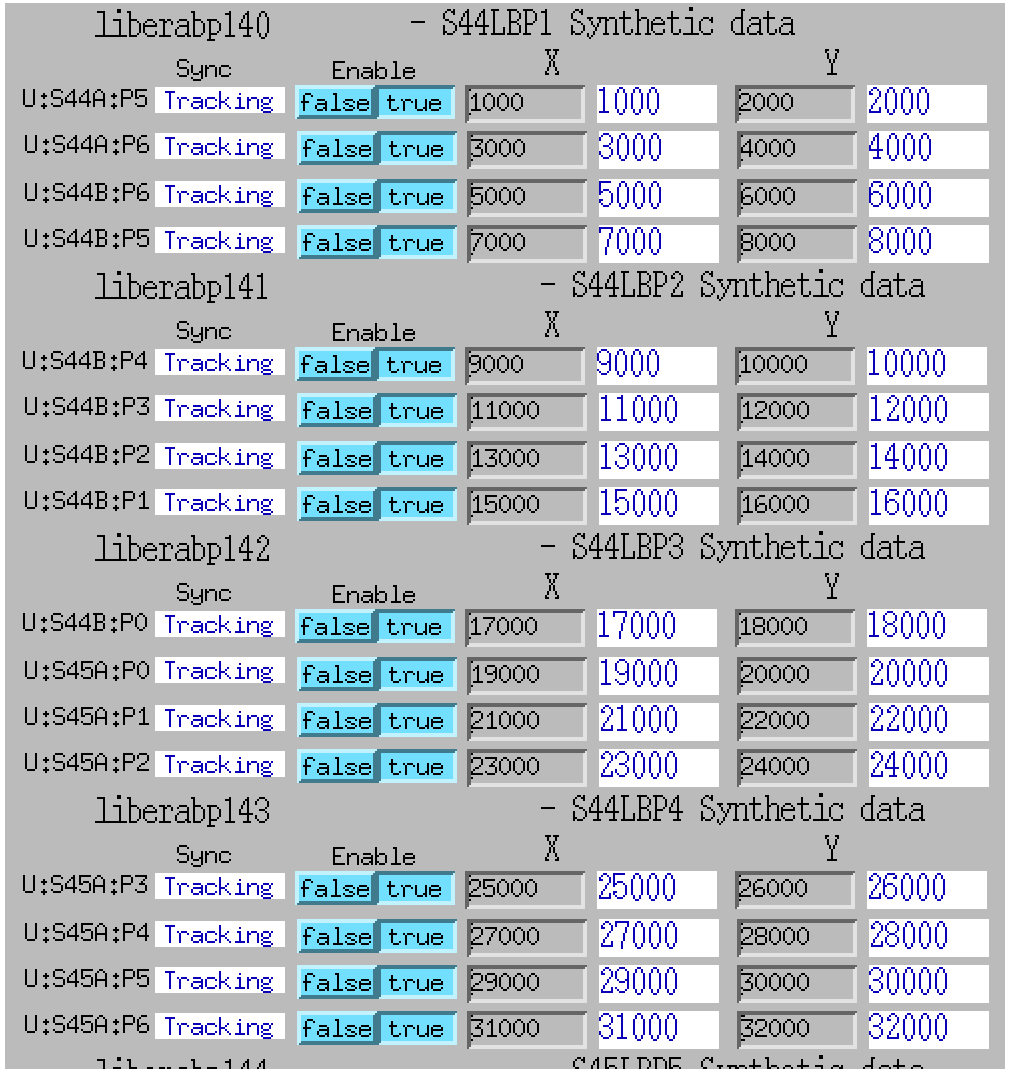
- The fast data stream for each BPM module sent to the GDX can be replaced with user-defined synthetic values. Only the data streamed out from the GDX SFPs is affected, not the local buffers or EPICS process variables for the various position readback types (TBT, FA, SA).
- There are two types of synthetic data: static values and triggered waveform
- Static values can be set to an integer in the range $\pm 2^{31}$ for each of the 8 standard fields of the fast data stream (Va, Vb, Vc, Vd, Sum, Q, X, Y). When synthetic data is enabled, all fields for the selected BPM contain the static synthetic values.



Simplified data path diagram. The synthetic data is applied to the FDS data that is routed to the GDX module, leaving other data streams unaffected.

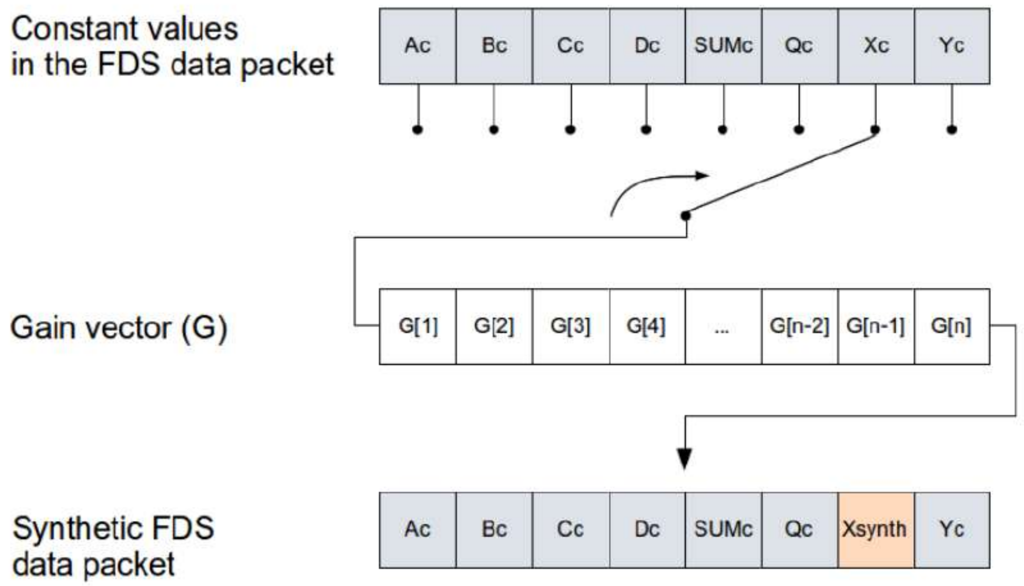
Implementation: Static data example

- By setting a unique static value for X and Y position of each BPM, it is simple to verify that the receiver is handling the data correctly.
- Prior to the availability of synthetic data, it was a tedious process to confirm that data for each BPM is routed to the expected destination after firmware updates or other work was done on external systems.



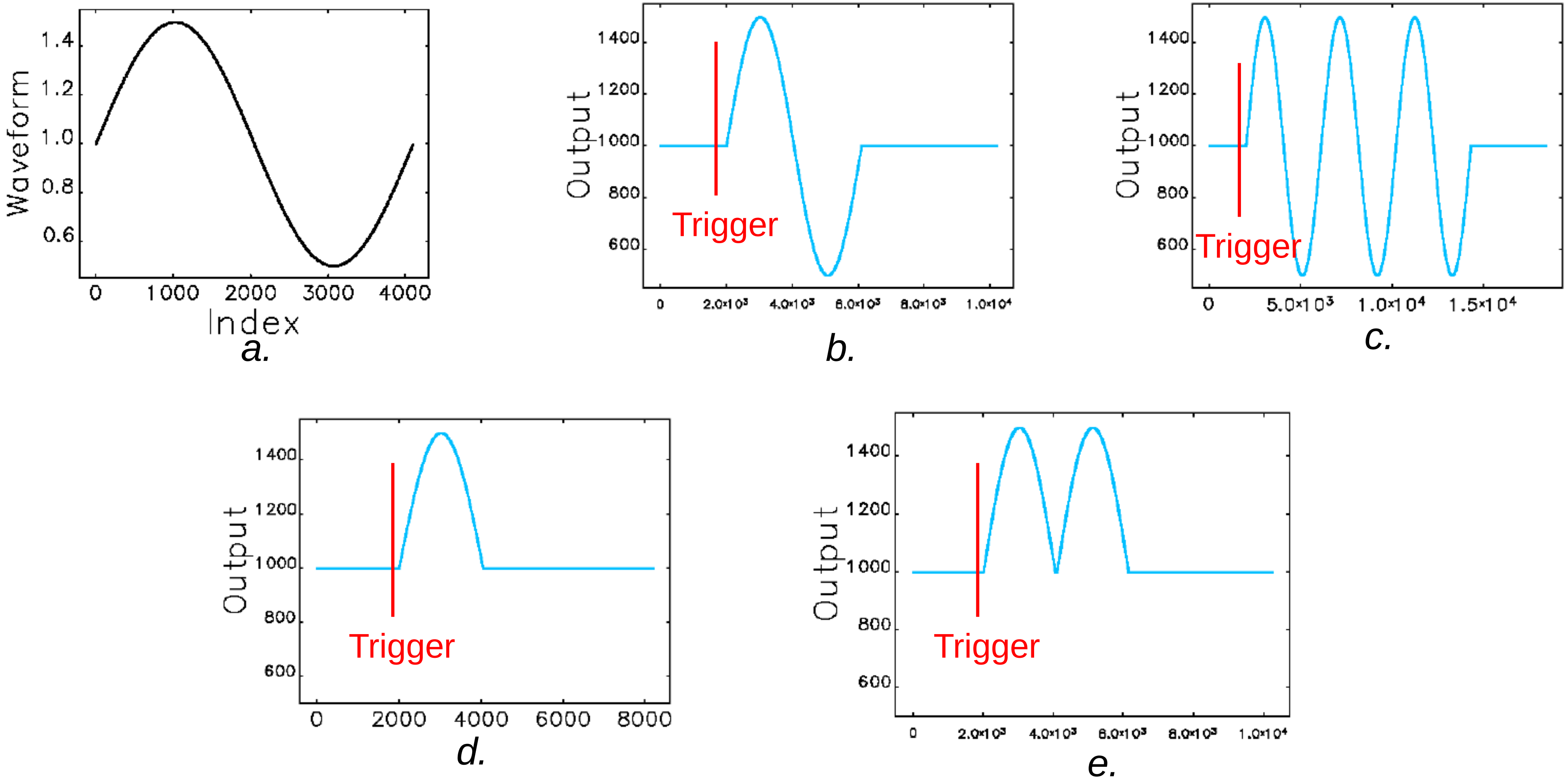
Implementation: Synthetic data waveform

- To create a triggered waveform burst, a gain vector is applied to the static value of a single field. The gain vector has 4096 elements, with each element in the range -2048 to 2047.9375 in increments of 0.0625.
- For a single trigger event, the output waveform can be repeated up to 4096 times, using a selectable number of gain element samples, allowing for a variety of use cases.
- With a triggered waveform, multiple units can be configured to enable the waveform on a common trigger. This is useful to verify that received data for a given turn number across multiple units arrives simultaneously.



Application of gain vector to a selected fast data stream field. The selected field (X in this example) is multiplied by the gain vector on a trigger, while the remaining fields contain the static values.

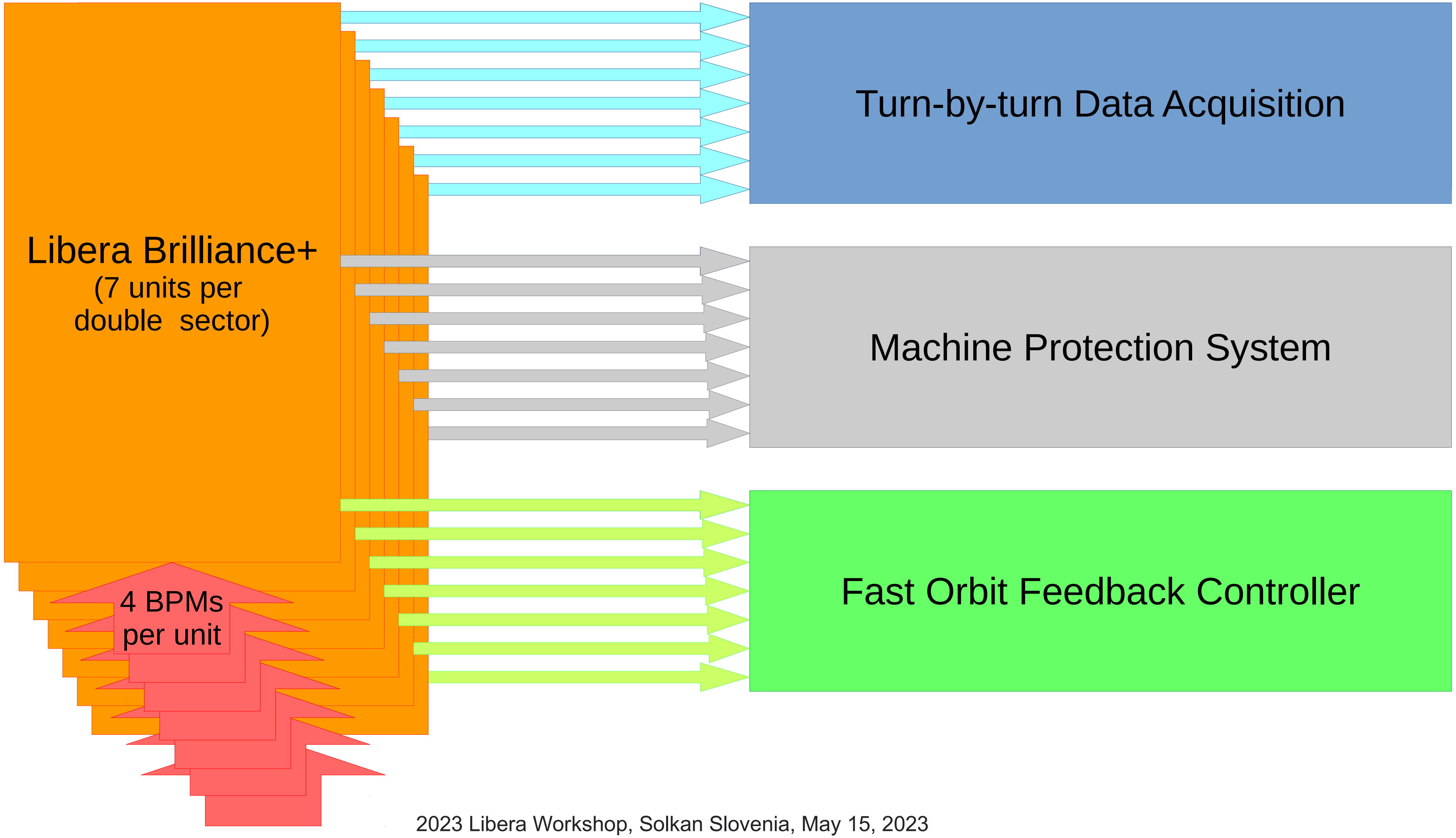
Synthetic data waveform examples



Examples of waveform manipulation: (a) original 4096 sample gain waveform. (b) single triggered repetition. (c) three repetitions on one trigger. (d) one repetition limited to 2048 samples. (e) two repetitions of 2048 samples on a single trigger.

APS-U systems using GDX data

In a double sector, each of 7 Brilliance+ units has a dedicated fiber optic link to three systems.



APS-U systems using GDX data

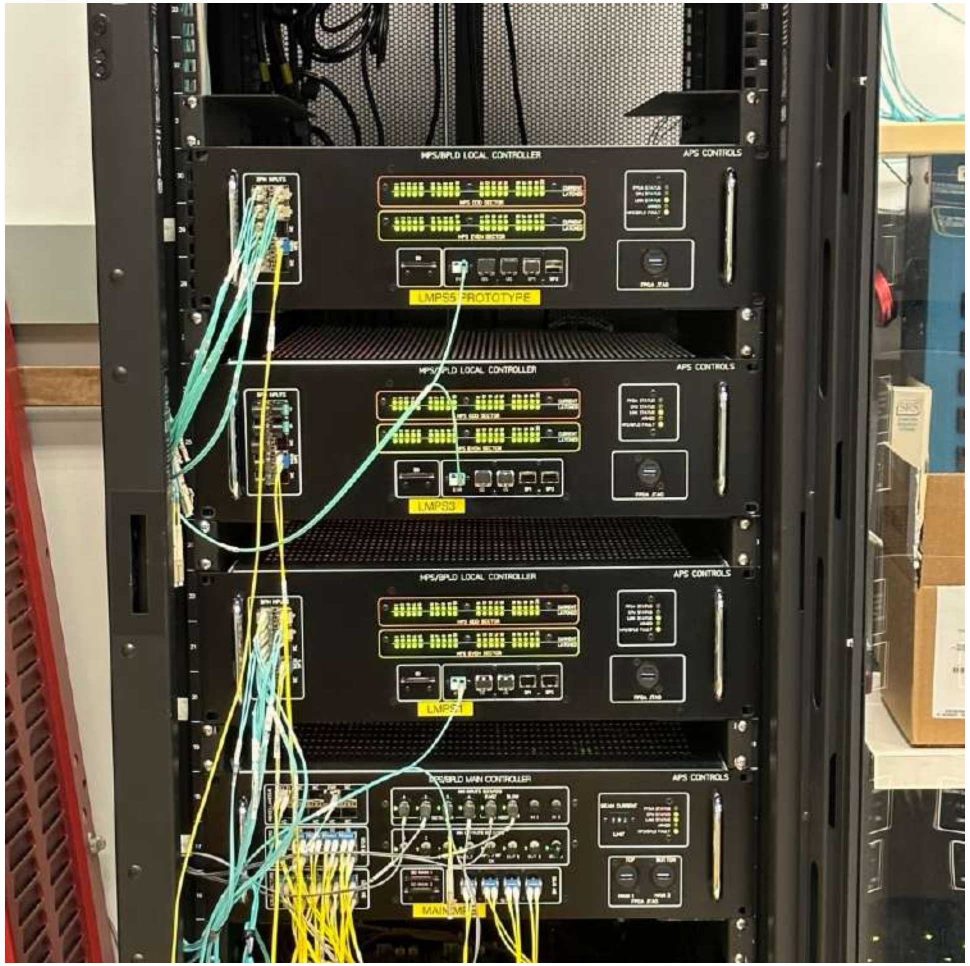
- There are three systems receiving turn-by-turn data from the GDX module SFPs: the turn-by-turn data acquisition system (TBT DAQ), the Fast Orbit Feedback Controller, and the Beam Position Limit Detector (BPLD) of the Machine Protection System.
- The turn-by-turn data acquisition system receives position data for every BPM in the storage ring, and can be triggered to save to a file on demand (i.e. for post-mortem after a beam dump, or to view injection transients).
- The Fast Orbit Feedback Controller improves beam stability by measuring and suppressing unwanted beam motion up to 1 kHz.
- The BPLD compares position at the insertion devices to defined limits to prevent damage to components due to mis-steered beam. If beam position is outside of these limits, the BPLD trips the MPS to immediately dump the beam.

Turn-by-turn DAQ and FOFB Controller

- At each double sector of the APS-U, the TBT DAQ and FOFB controller receive turn-by-turn data from 28 BPMs of 7 Brilliance+ units.
- These systems have been been developed at APS for the APS-U, with prototypes in use for several years during dedicated feedback machine studies.
- In the lab, we have created a double sector test setup to duplicate the APS-U installation, consisting of 7 Brilliance+ units, a TBT DAQ receiver, a FOFB controller receiver, and an MPS receiver.
- Synthetic data has been used to verify signal routing of individual position values, as well as timing synchronization between different BPMs.

Machine Protection System (BPLD)

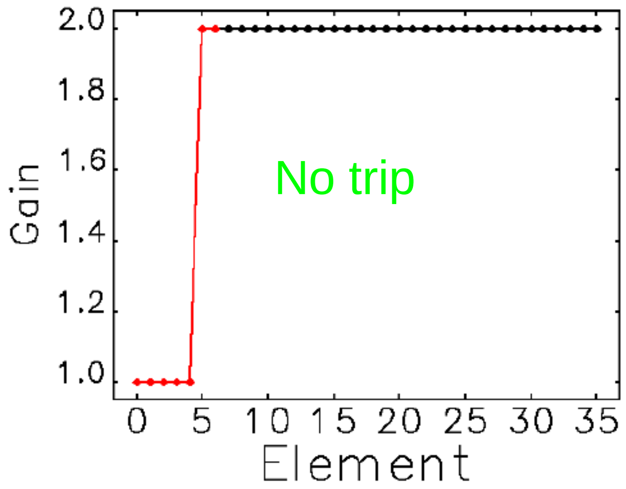
- The BPLD has defined limits at selected BPMs for beam position and angle (calculated between two BPMs) to determine the threshold to trip the beam.
- To reduce spurious trips from random noise, the BPLD system requires the position to exceed the defined limits for several consecutive turns before a trip is generated.
- Synthetic data (both static and waveform) have been invaluable for testing and validation of the system.

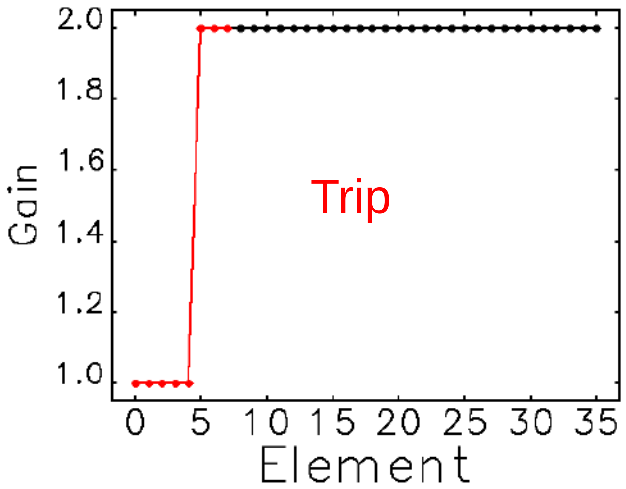


MPS double sector test rack in the lab with several local controllers connected to the main controller

Machine Protection System (BPLD)

- The MPS system was developed in partnership with Brookhaven National Laboratory, so the waveform data was particularly useful for APS engineers as we familiarized ourselves with its operation and started testing the system with input from multiple connected Brilliance+ devices.
- By choosing appropriate static values and gain waveforms, initial setup, testing, and validation can be automated to simulate a variety of different conditions. For example, using a single loaded step waveform, we can evaluate the behavior of the BPLD by varying the number of samples used in the waveform, and choosing which BPM has the waveform applied.



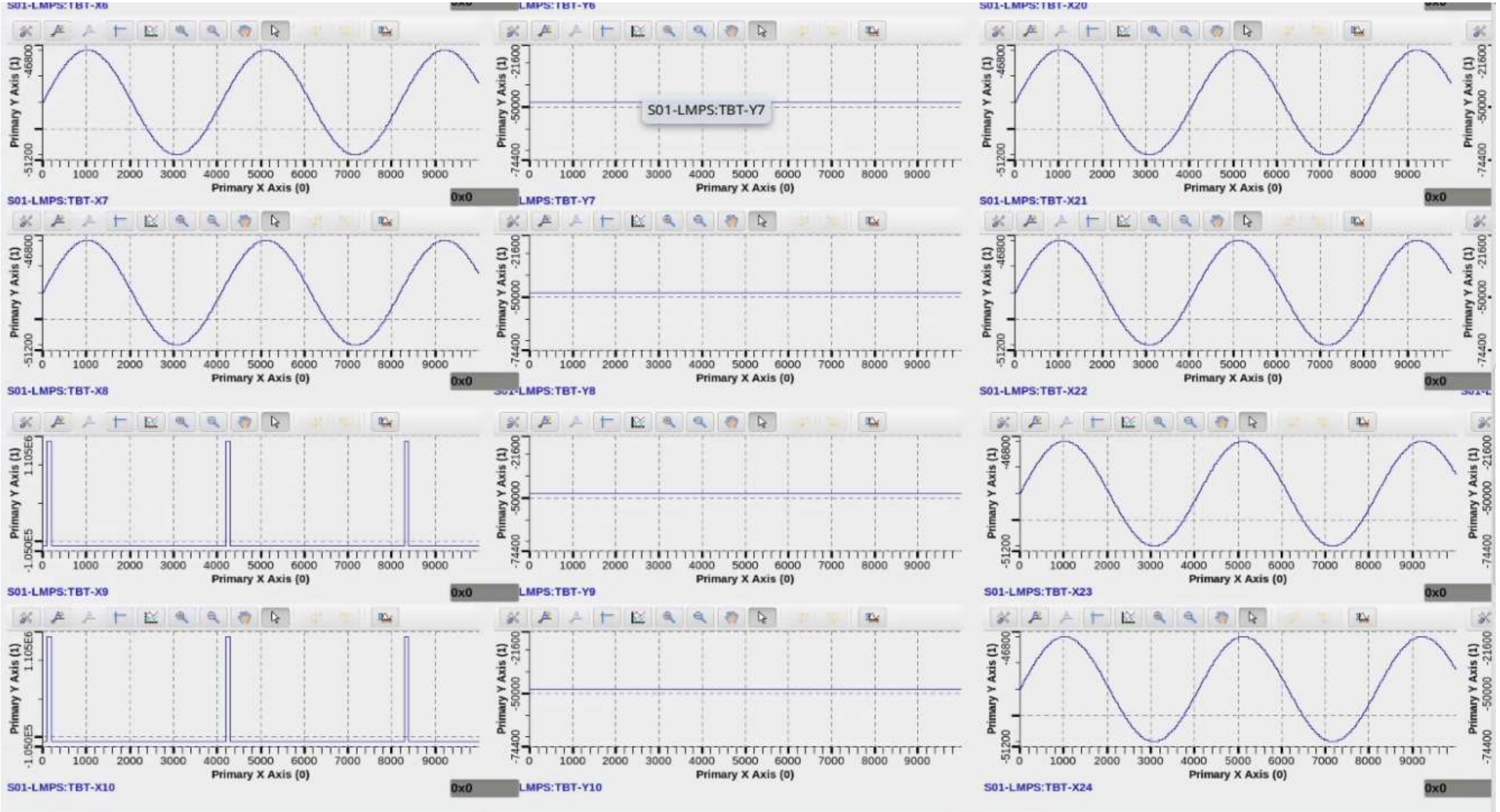


Using gain waveform size to test BPLD operation. The red samples indicate the selected size of the gain waveform. With only two consecutive samples exceeding the limit, no trip is detected (left). When three consecutive samples exceed the limit, a trip is generated. These parameters can be set using a script to quickly test the function of the system.

Machine Protection System (BPLD)

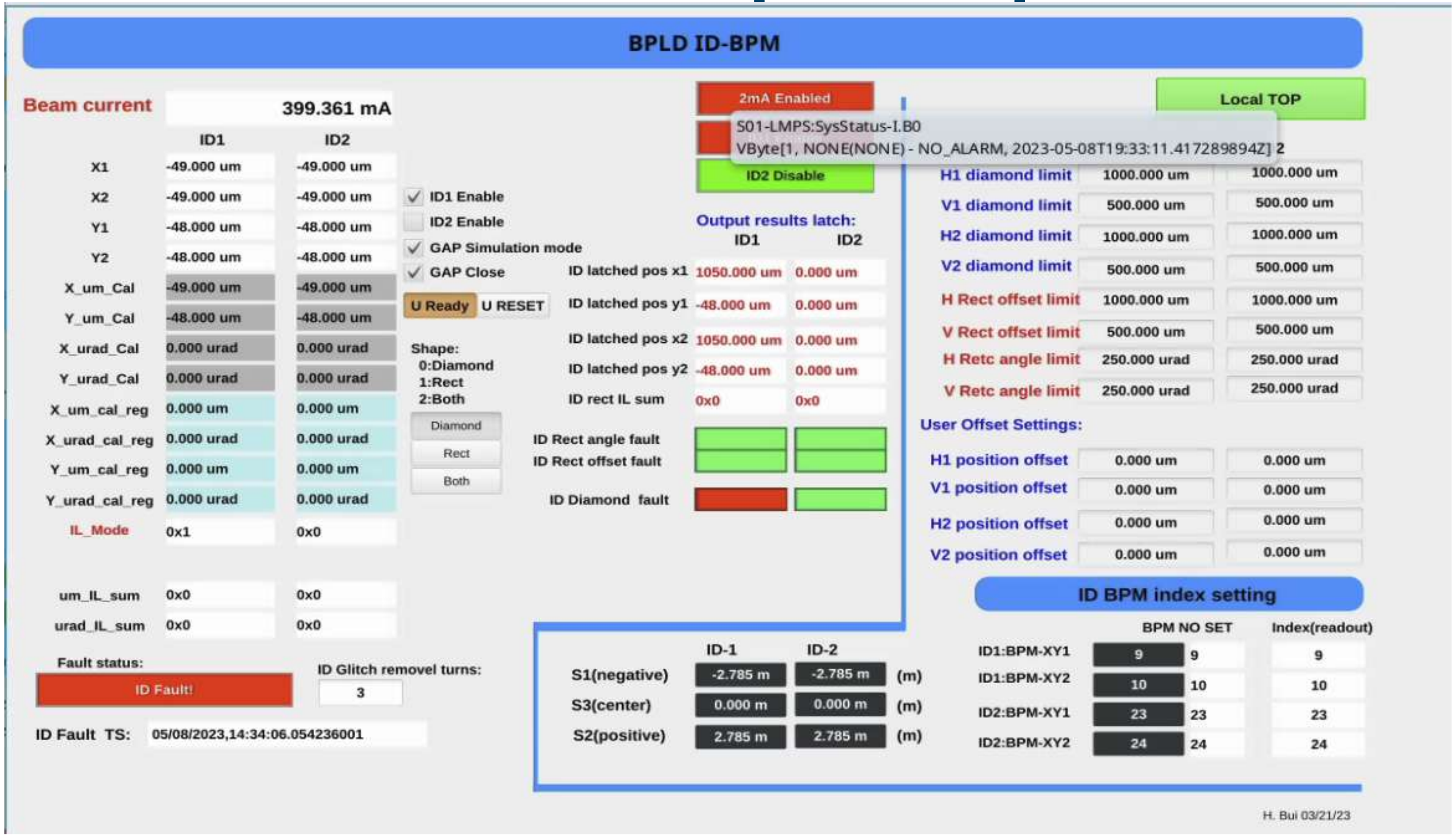
- Validation of the BPLD system at APS included two different measurements involving mis-steering the beam beyond the BPLD limits:
  - With the insertion device gaps open, a “pending” trip indicates that a limit error occurred but no trip was generated.
  - With an insertion device closed just past the “arm” threshold, a limit error triggers the MPS to dump the beam immediately.
- At APS-U, MPS trips with stored beam must be minimized to prevent unnecessary damage to components. The synthetic waveform data allows us to safely test the system, including causing an MPS trip without stored beam.
- Routine validation of the system can be performed without beam before a user run using a script to configure the BPMs and MPS as required.
- A status bit in the GDX data packet indicates the state of the synthetic data. This status bit is checked to prevent inadvertently leaving the synthetic data enabled.

BPLD received data



Received turn-by-turn data for multiple BPMs, showing sinusoidal, step, and static data in use.

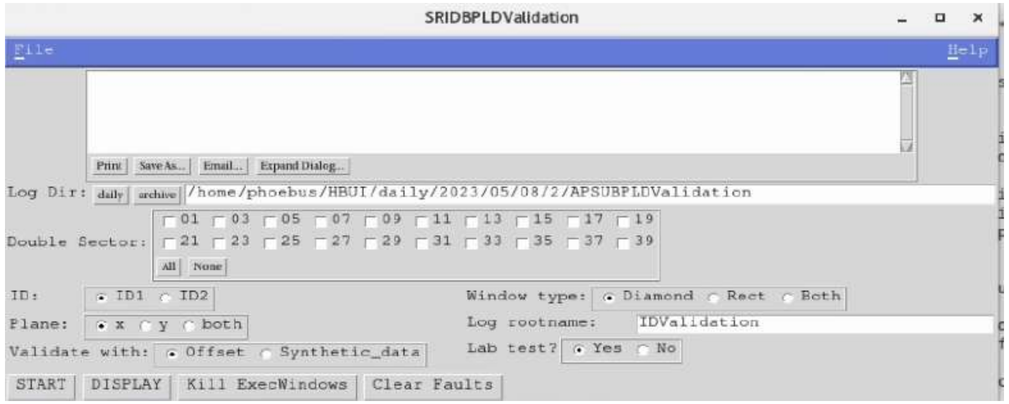
BPLD trip example

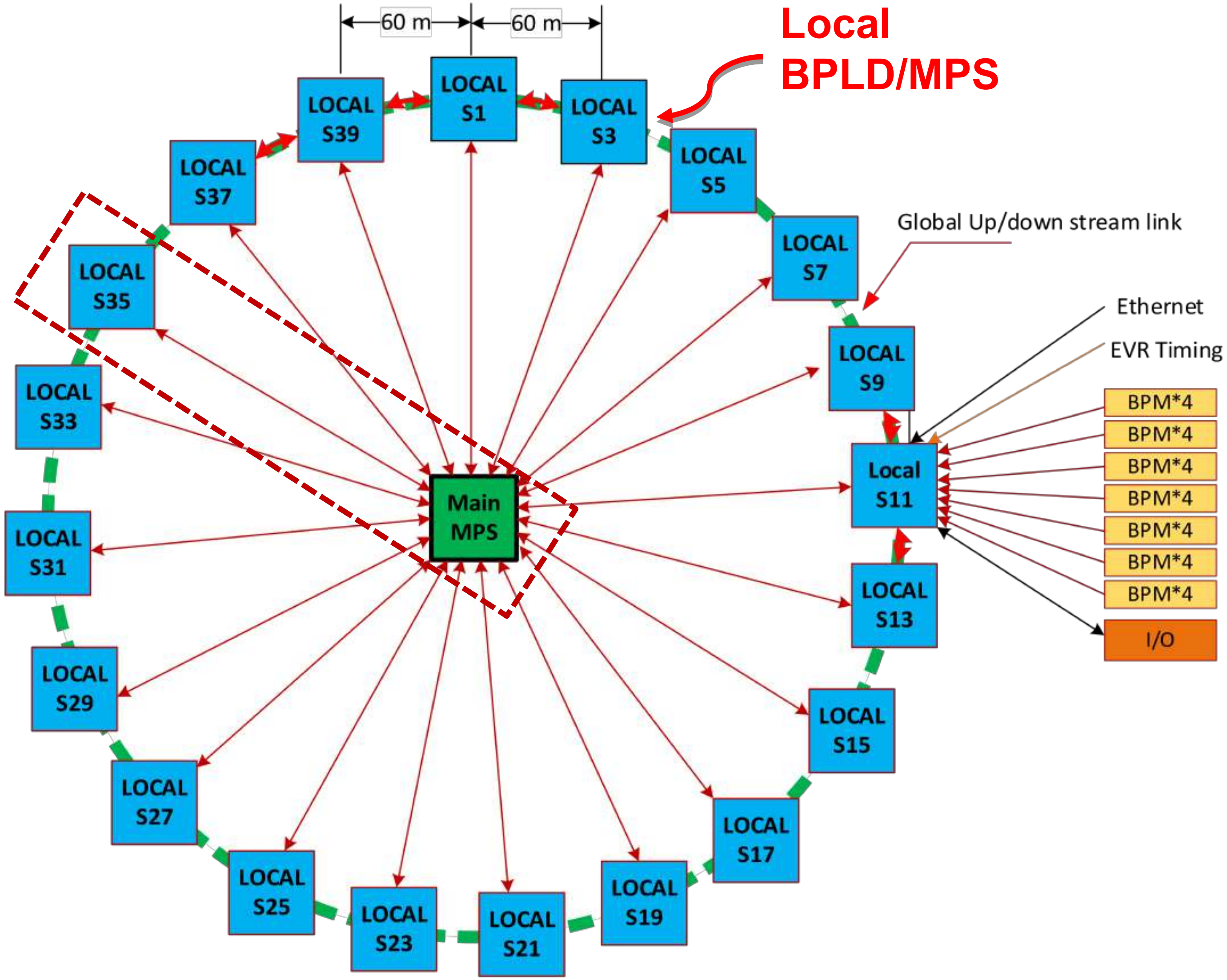


BPLD screen showing a latched fault condition for an insertion device limit error.

MPS integrated testing

- After the APS-U installation is completed, each double sector will require a check-out procedure to verify both local connections and communication with the main MPS system.
- Synthetic data will play an important role in this process.





Summary

- When specifying requirements for APS-U BPM, we requested the option of sending user-defined position values to help with troubleshooting, testing, and validation of connected systems. I-tech provided the capability to set both static values and a triggered waveform for data streamed through the GDX module.
- Synthetic data has been very useful during testing of multiple systems receiving BPM data. We are able to quickly verify that position values are assigned to the correct channels throughout multiple systems without the need to connect external signal generators.
- Triggered synthetic waveforms have been used to verify timing synchronization in the lab, and will be used extensively during the installation phase in Autumn 2023 to validate synchronization of devices around the storage ring.
- The synthetic waveform function will also be used to perform routine validations of the MPS without the requirement to dump stored beam.
- The synthetic data function of the Libera Brilliance+ has been a valuable tool that provides many important benefits for testing and operations of APS-U systems that depend on TBT streaming data.

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