Libera

Libera BPM and Closed Orbit feedback systems

Aleš Bardorfer, ARIES workshop, November 2018

Libera

Outline

- Libera BPM family
- COFB examples
- COFB algorithms & GDX module
- Current limitations (BW, latency)
- Discussion: Future outlook (BPMs, FPGA technology, magnets)

Libera BPM family

- Circular electron: Libera Brilliance/+, Libera Electron
- Circular hadron: Libera Hadron
- Linear electron: Libera Single-Pass
- Linear hadron: Libera Single-Pass-H

- Very different analogue RF front-ends, as well as different DSP processing

LB+: High-performance BPM system

Libera Brilliance+

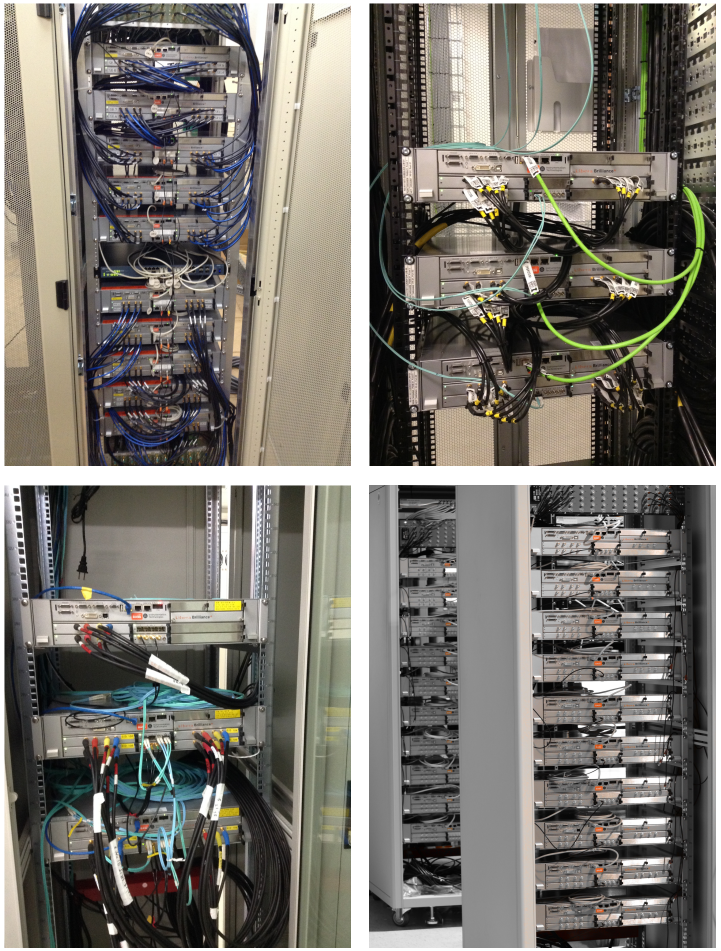
- Wide and narrow bandwidth BPM
- Parallel processing & data access
- Sub-micron long-term stability
- EPICS/TANGO/LABVIEW/MATLAB

- Embedded COFB application
- Fibre-link daisy chain connections
- Full Event-receiver & generator support
- Direct RS-485 & optical interfaces to magnet power supply controllers

LB+: Installations

<u>Larger installations (>20)</u>

- Taiwan Photon Source (~250)
- MAX-IV (~250)
- Australian Synchrotron (~110)
- KEK PF AR (~90)
- SESAME (~50)
- SOLARIS (~35)
- IHEP (~30)
- Hefei Light Source (~20)
- THOM-X (~20)

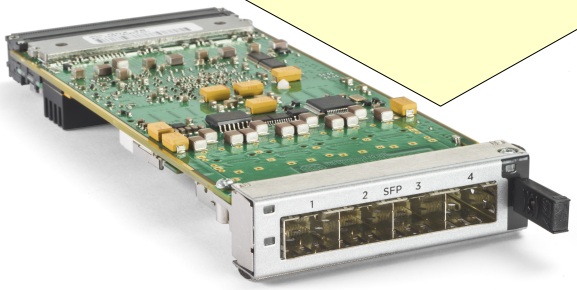


LB+: Performance and extensions

Measurement resolution*: < (50-100) nm
Longterm stability**: < 100 nm over several days
Current dependence*: < 5 µm over 80 dBm

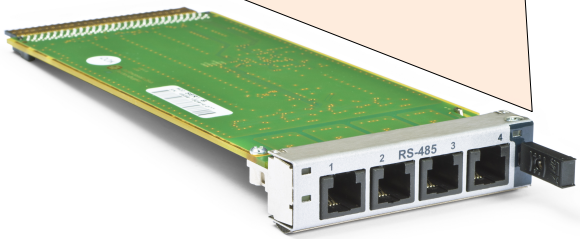
* At various fill patterns and beam currents, 1 kHz bandwidth, K=10 mm
** Measured with 10 S/s data, 4 Hz bandwidth, RF generator source

Gigabit Data Exchange module (GDX)

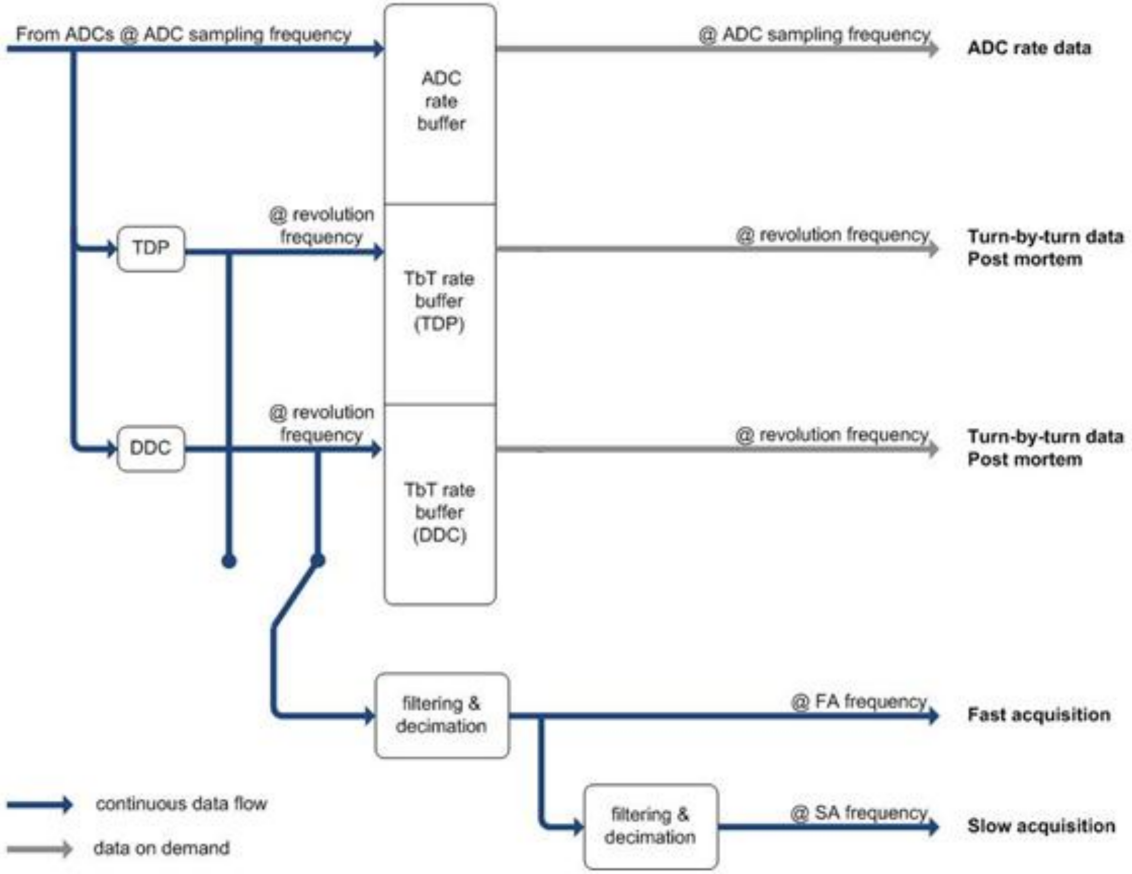


Event-receiver (EvRx)

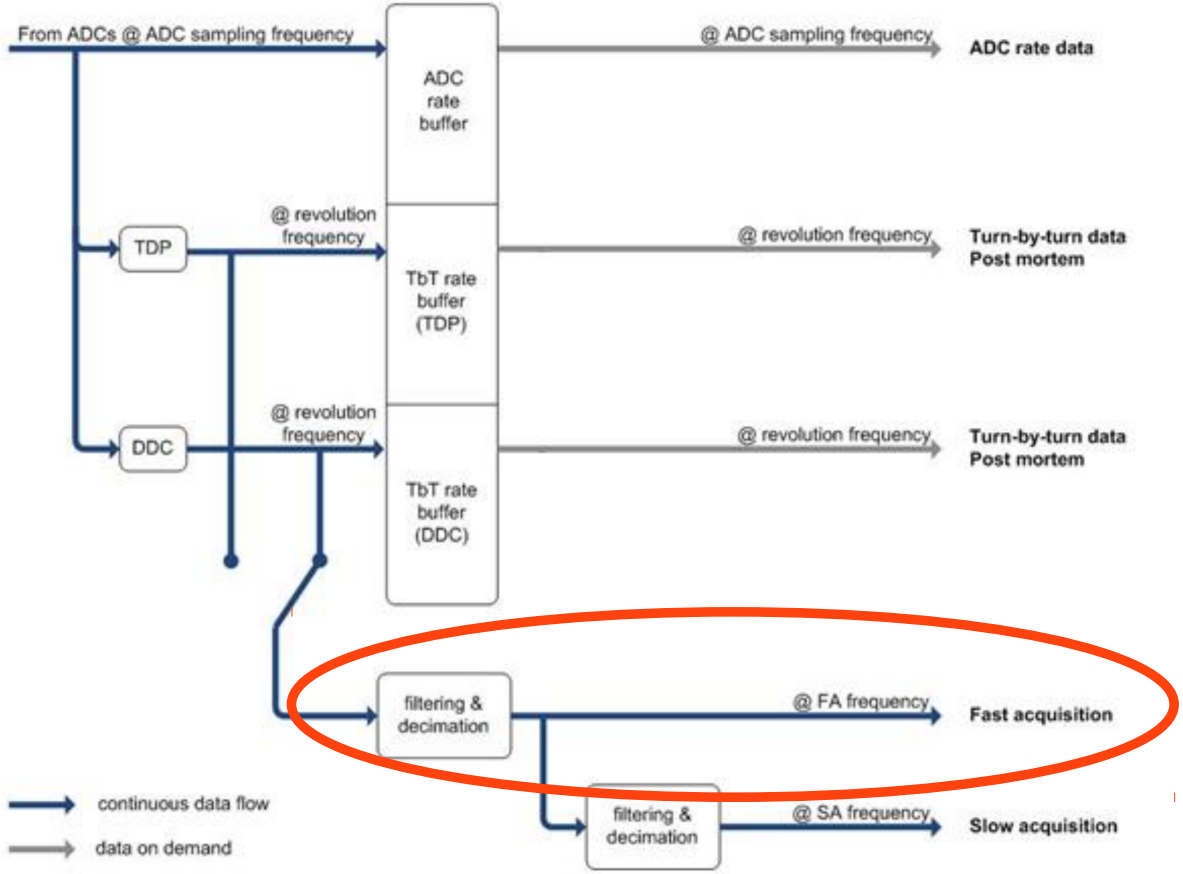
Serial module (SER)



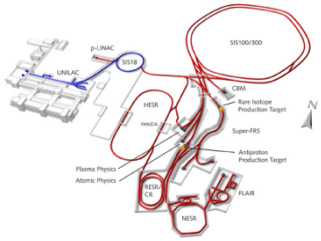
LB+: Data streams



LB+: Data streams



COFB



FAIR Facility for Antiproton and Ion Research in Europe GmbH

Libera

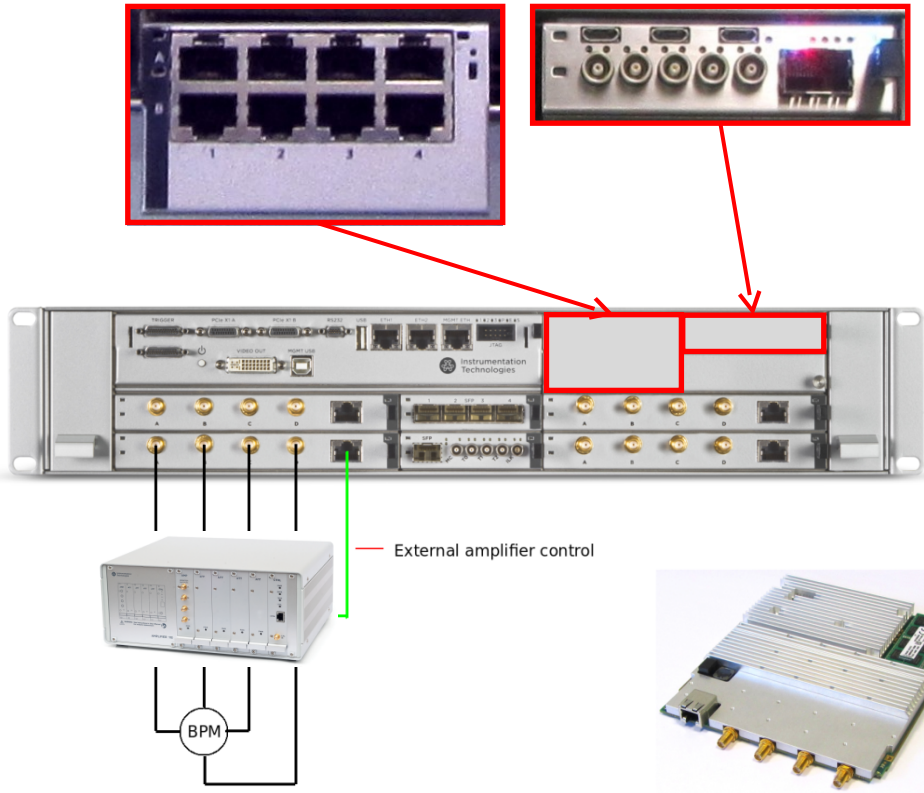
Libera Hadron

- GSI/FAIR contributions
- Libera Hadron system components:
- Software controlled Preamplifier
- FTRN timing module (COSYLAB)

  WR protocol support
- SER module

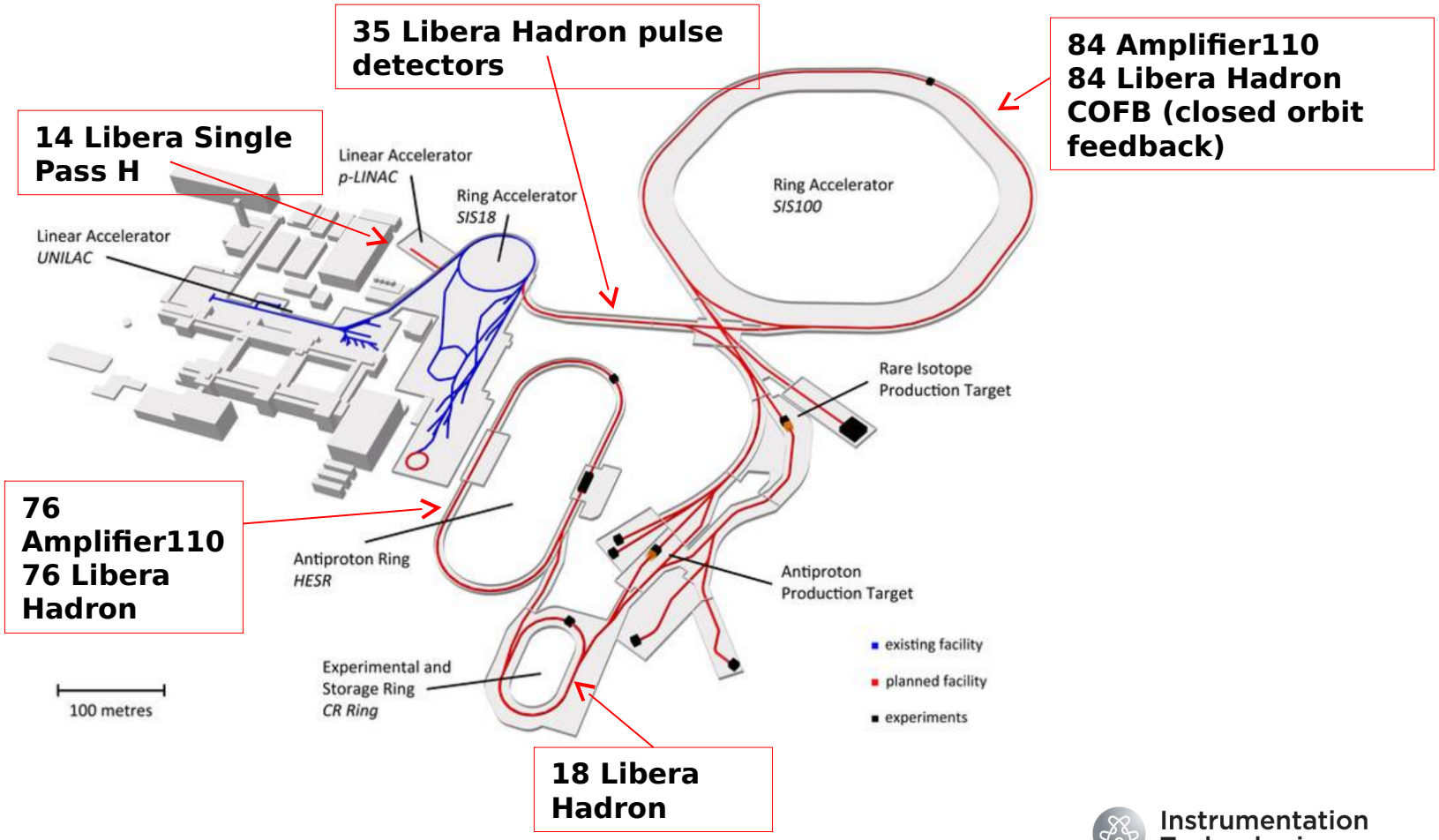
  Provides data to the magnet
- Fast data exchange GDX module

  global position processing (COFB)

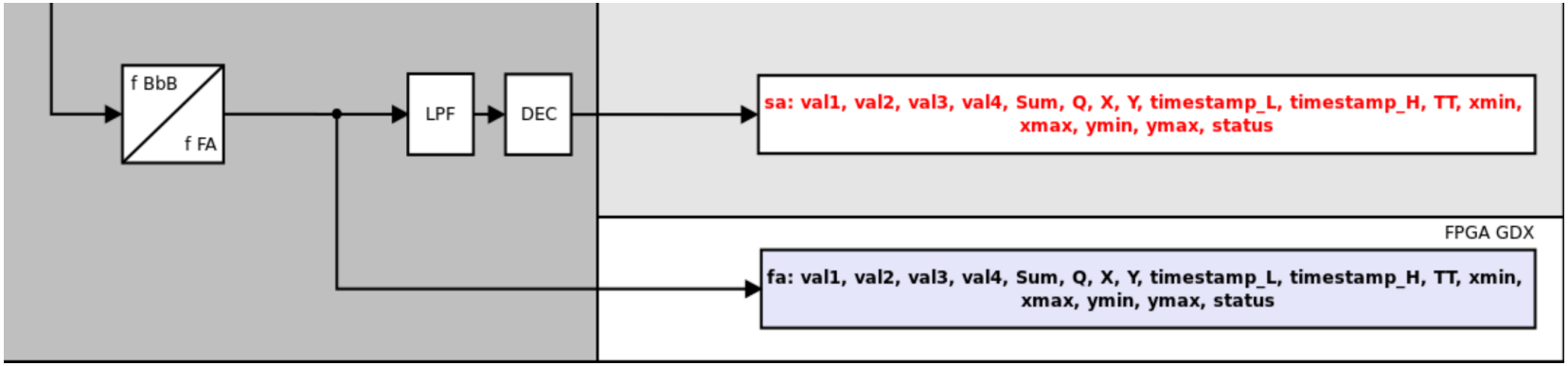


Instrumentation Technologies

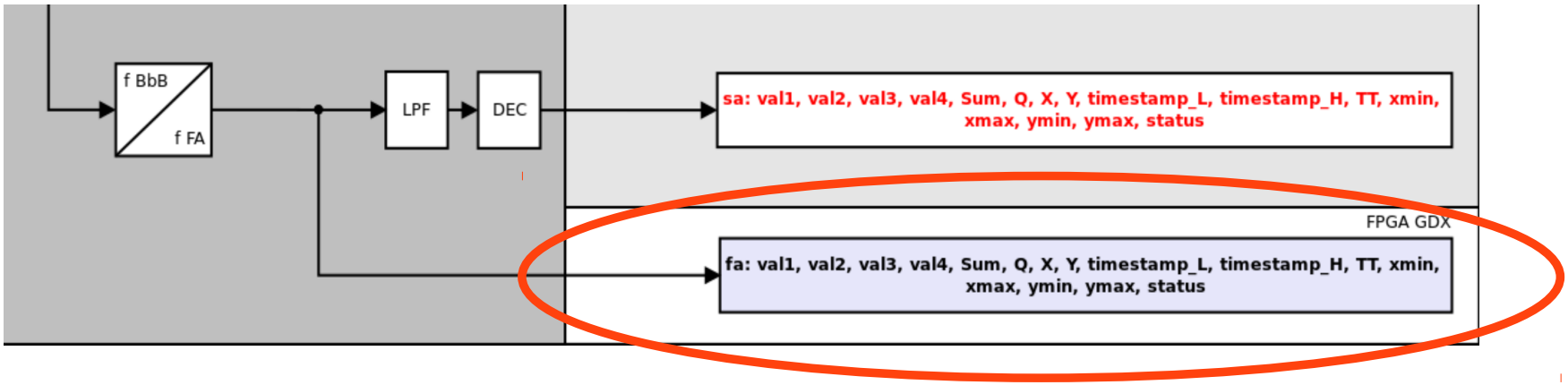
FAIR complex



Libera Hadron: Data streams



Libera Hadron: Data streams

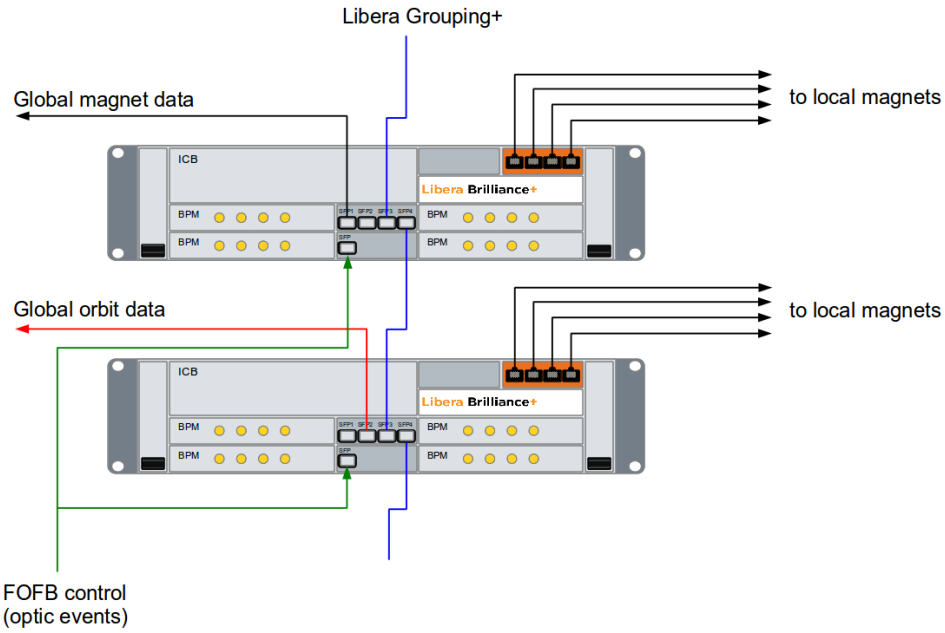


COFB

Closed Orbit feedback

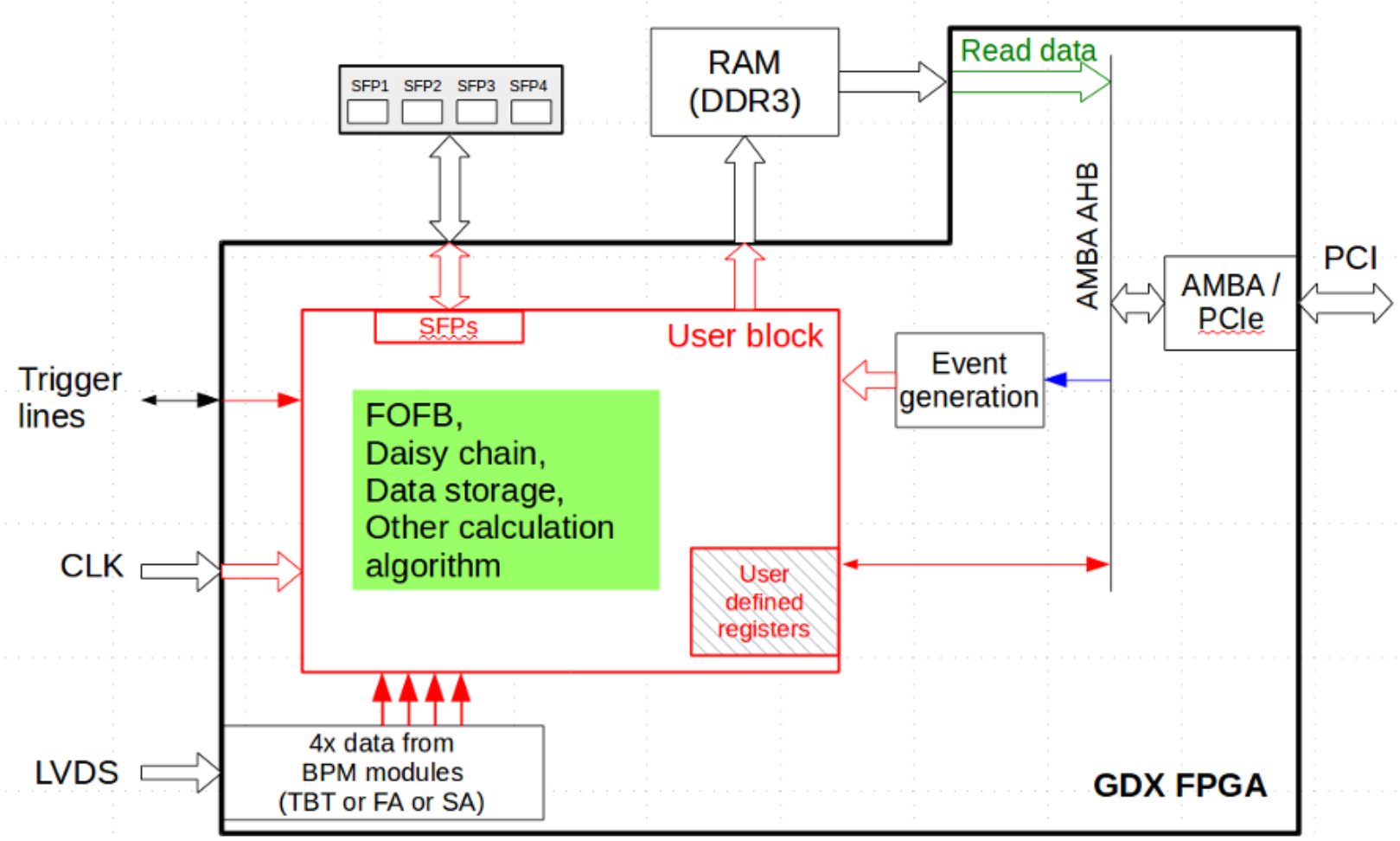
Current capabilities

- 256 BPM IDs
- 128 magnets
- 6.5 Gbps fibre links
- < 2 µs FOFB calculation latency
- ~ 50 ns latency / BPM
- Eigenmode space (128 modes)
- Fully event-controlled
- 2 kHz closed loop (theoretical limit)



Instrumentation Technologies

GDX module


SFP1
SFP2
SFP3
SFP4
RAM
(DDR3)
Read data
AMBA AHB
AMBA /
PCIe
PCI
SFPs
User block
Event
generation
Trigger
lines
FOFB,
Daisy chain,
Data storage,
Other calculation
algorithm
CLK
User
defined
registers
LVDS
4x data from
BPM modules
(TBT or FA or SA)
GDX FPGA

Libera

COFB as a generic MIMO system

$$M_{cx1} = V_{cxe} \cdot PI_{ex1}\left(S^{-1}_{mxn} \cdot U^{T}_{nxn} \cdot dP_{nx1}\right)$$

$$\begin{bmatrix} c_{43} \\ c_{44} \\ c_{45} \\ c_{46} \end{bmatrix} = \begin{bmatrix} v_{431} & v_{4396} \\ v_{441} \ldots & v_{4496} \\ v_{451} & v_{4596} \\ y_{461} & y_{4696} \end{bmatrix} \cdot PI\left(\begin{bmatrix} s_{11} & s_{12} & s_{1168} \\ s_{21} & s_{22} \ldots & s_{2168} \\ \vdots & \vdots & \vdots \\ s_{961} & s_{962} & s_{96168} \end{bmatrix} \cdot \begin{bmatrix} u_{11} & u_{12} & u_{1168} \\ u_{21} & u_{22} \ldots & u_{2168} \\ \vdots & \vdots & \vdots \\ u_{1681} & u_{1682} & u_{168168} \end{bmatrix} \cdot \begin{bmatrix} dx_1 \\ dx_2 \\ \vdots \\ dx_{168} \end{bmatrix} \right)$$

Instrumentation Technologies

Libera

COFB as a generic MIMO system

Compitationally intensive

Communication

$$\begin{bmatrix} c_{43} \\ c_{44} \\ c_{45} \\ c_{46} \end{bmatrix} = \begin{bmatrix} v_{431} & \dots & v_{4396} \\ v_{441} & & v_{4496} \\ v_{451} & & v_{4596} \\ y_{461} & & y_{4696} \end{bmatrix} \cdot PI\left(\begin{bmatrix} s_{11} & & s_{1168} \\ s_{21} & s_{22} \dots & s_{2168} \\ \vdots & \vdots & \vdots \\ s_{961} & s_{962} & s_{96168} \end{bmatrix}^{-1}_{mxn} \cdot \begin{bmatrix} u_{11} & u_{12} & & u_{1168} \\ u_{21} & u_{22} & \dots & u_{2168} \\ \vdots & \vdots & & \vdots \\ u_{1681} & u_{1682} & & u_{168168} \end{bmatrix} \cdot \begin{bmatrix} dx_1 \\ dx_2 \\ \vdots \\ dx_{168} \end{bmatrix} \right)$$

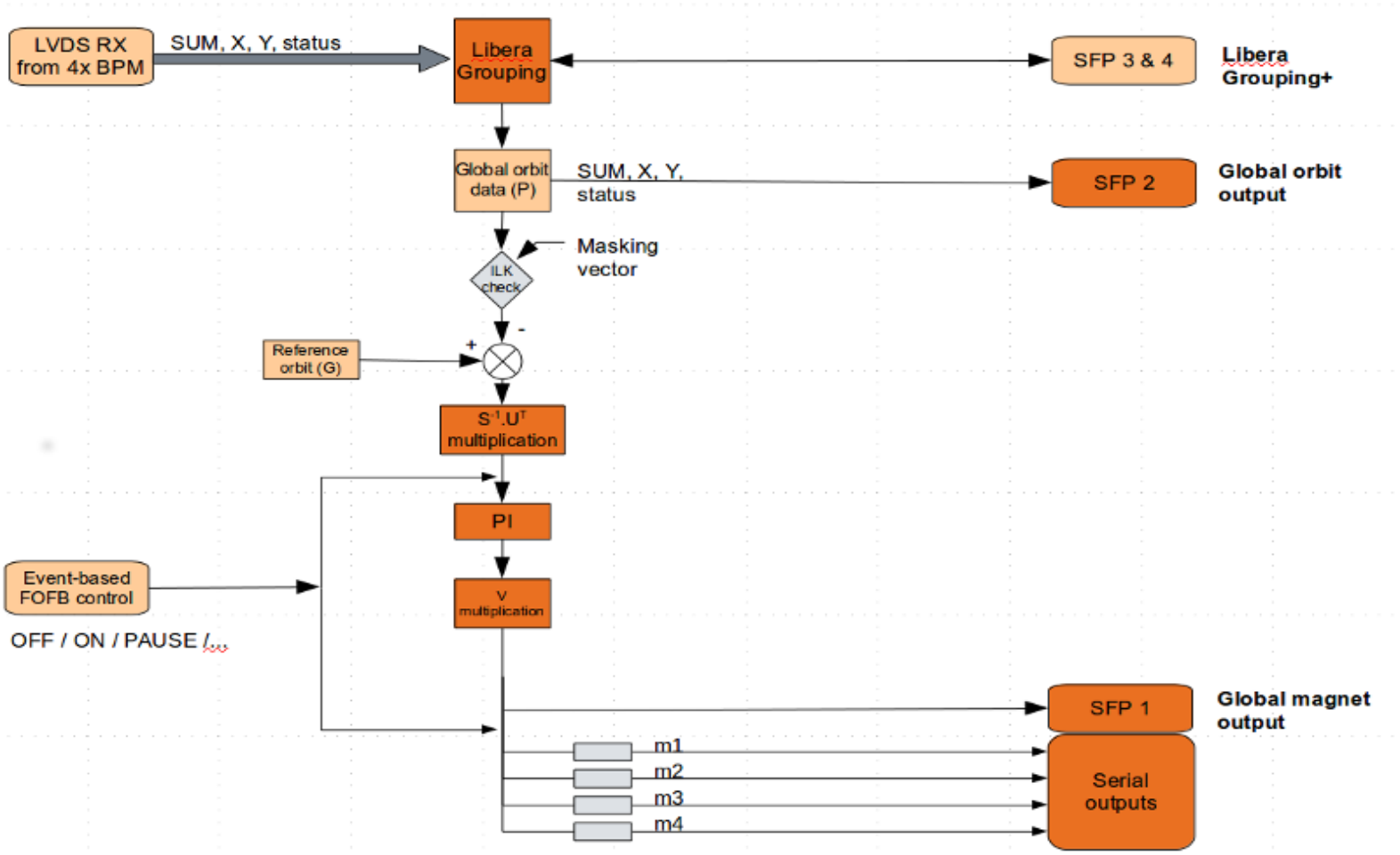
Instrumentation Technologies

Technologies for building COFB systems

- **Communication:**
  - **Libera Grouping (6.5 Gbit/s)**
  - **Diamond Communication Controller 2.12 Gbit/s**
  - **Gigabit Ethernet (1 Gbit/s)**
  - **Reflected memory**

- **COFB algorithm calculation:**
  - **Hard real-time?**
  - **Centralized vs. distributed (matrix, magnet distribution)**
  - **Based on: CPU, FPGA, GPU?**

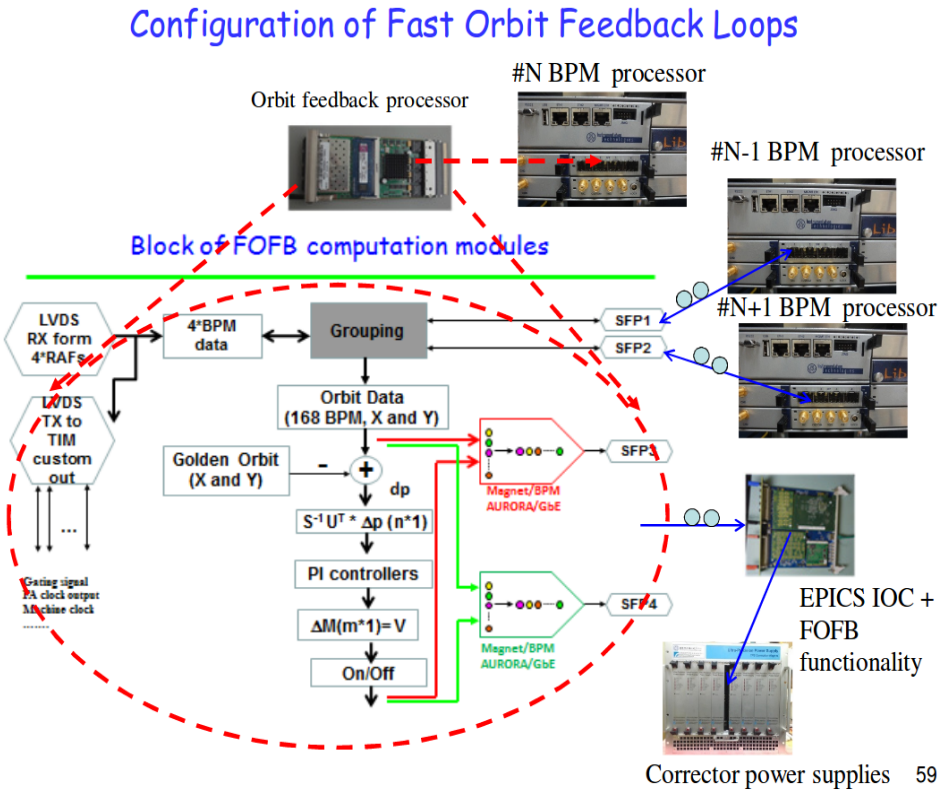
COFB control algorithm



Orbit feedback examples

NSRRC TPS

- 173 BPM IDs
- 80 magnets
- 10 kS/s data
- ~1.5 μs FOFB calculation
- ~17 μs data concentration (including fibre links)



Courtesy of K.Hsu

Orbit feedback examples

Advanced Photon Source

- Turn-by-turn data in a daisy chain
- Up to ~20 BPMs in a single loop
- User-configurable IIR filtering
- Fast data output links
- ~ 4 μs step response (TBT data)
- FOFB algorithm runs externally

Orbit feedback examples

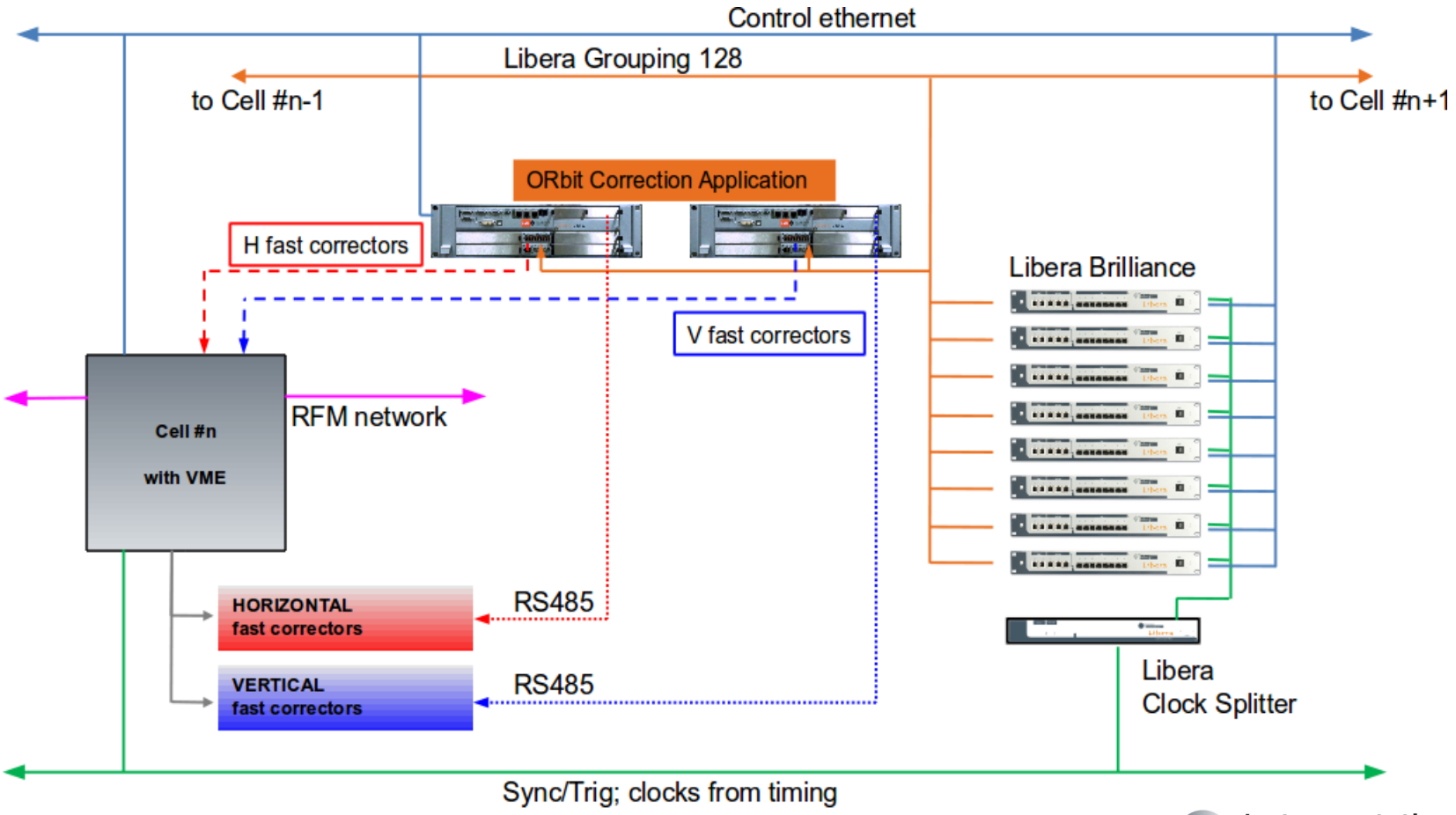
MAX-IV, SOLARIS

- Similar to TPS application
- Double buffering
- Serial output

SESAME, AUSTRALIAN SYNCHROTRON

- Daisy chain support
- Global orbit data output

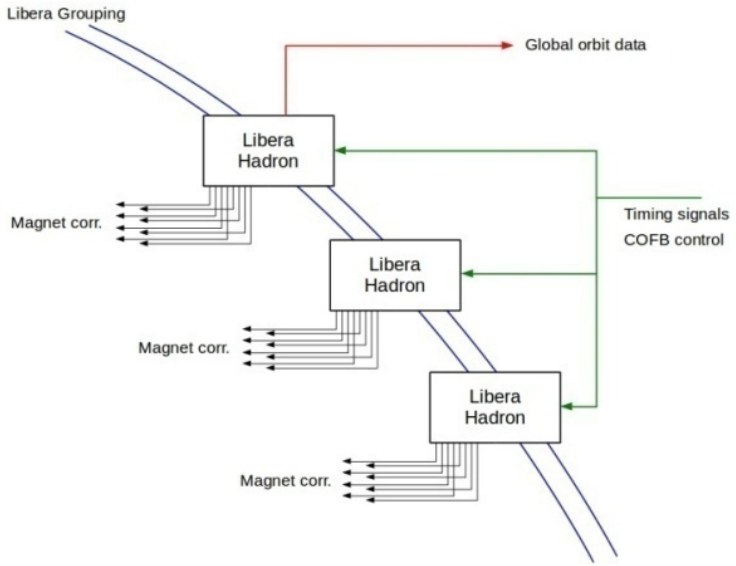
Orbit feedback examples (hybrid, TLS)



Orbit feedback examples

GSI/FAIR (SIS 100)

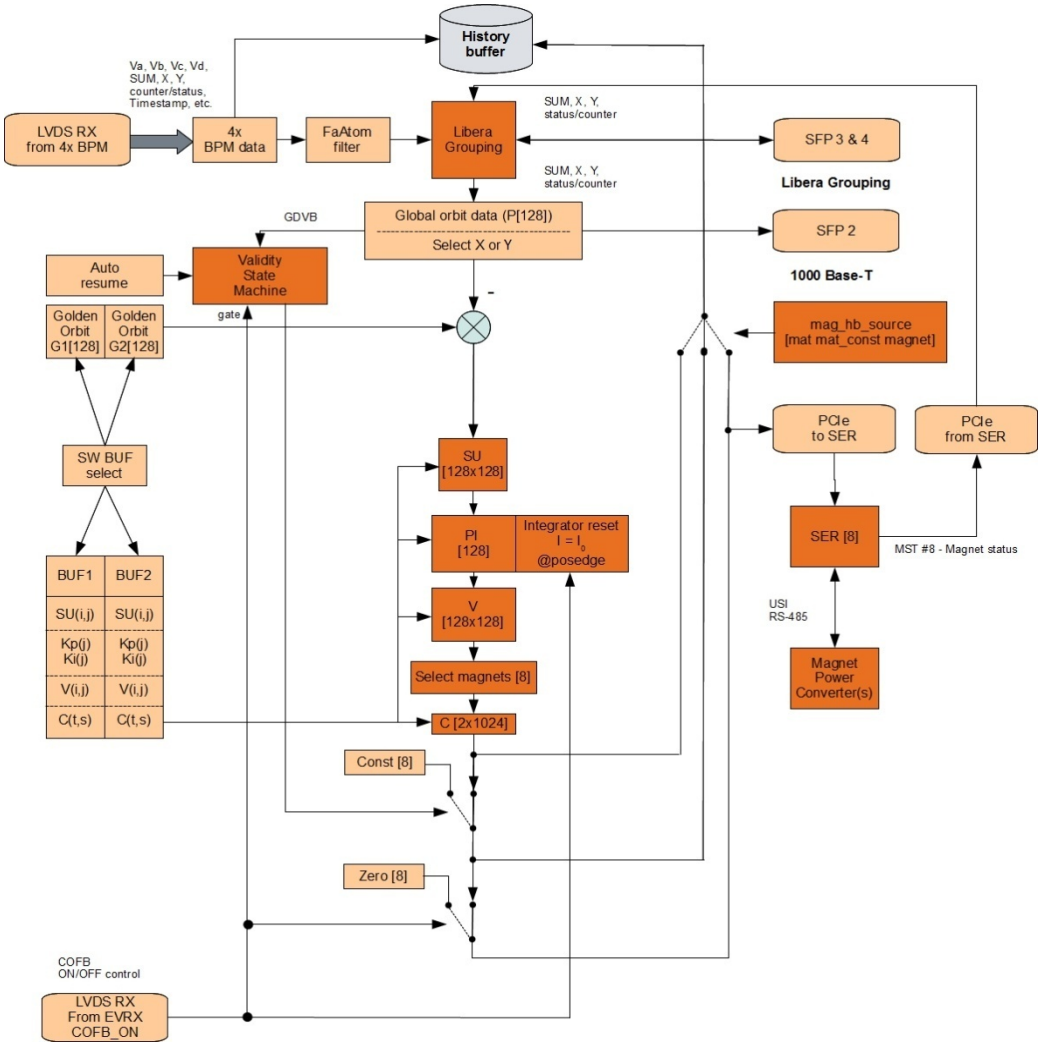
- 84 Hadron BPMs
- Similar to TPS application
- Double buffering
- Dynamic scaling
- USI serial interface to magnets



COFB: Control algorithm (Hadron)

GSI/FAIR (SIS 100)

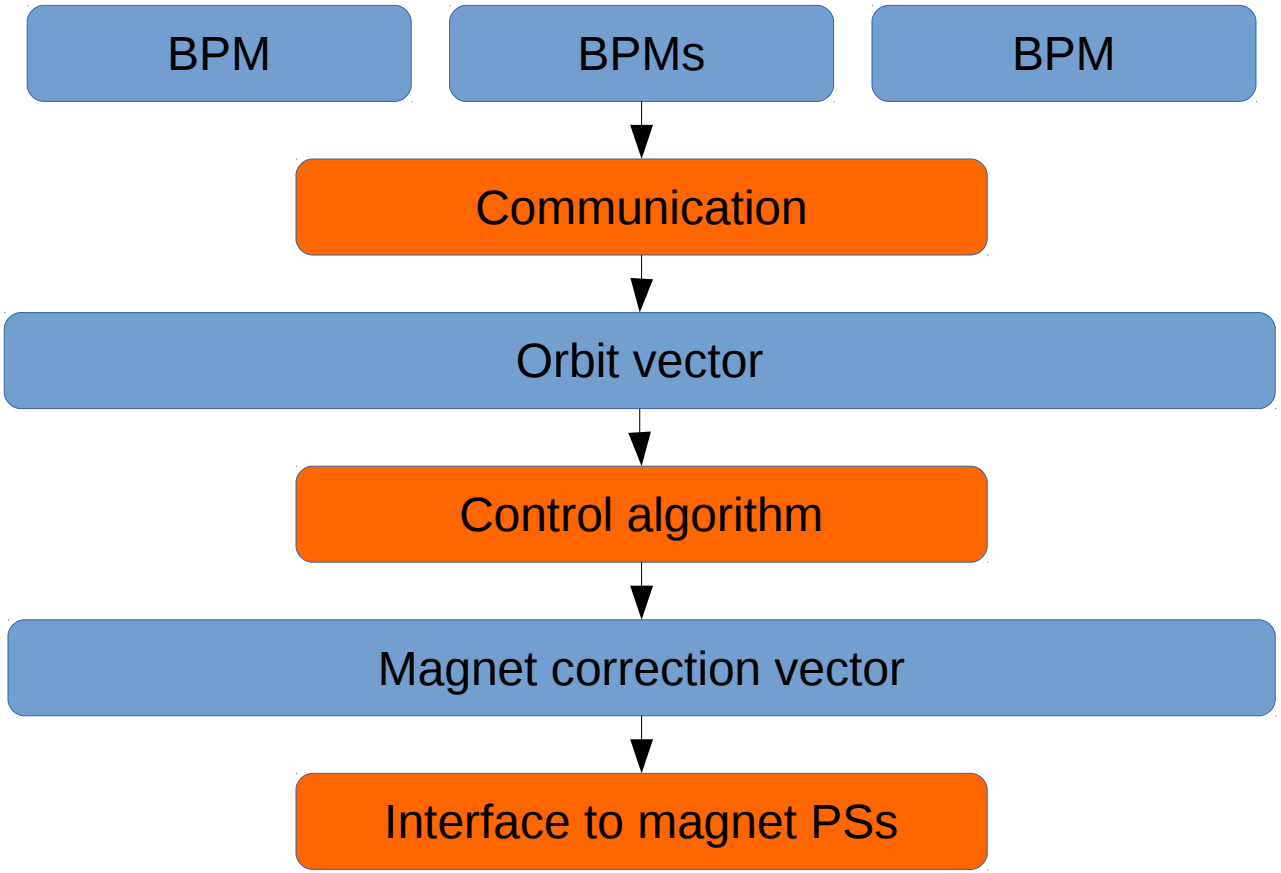
- Pulsed/cycle mode – gated operation
- Double buffering of configuration data
- Dynamic scaling in order to follow the ramp-up within the cycle



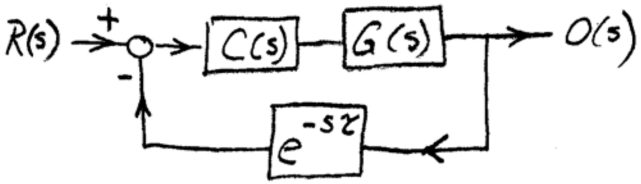
Technologies for building COFB systems

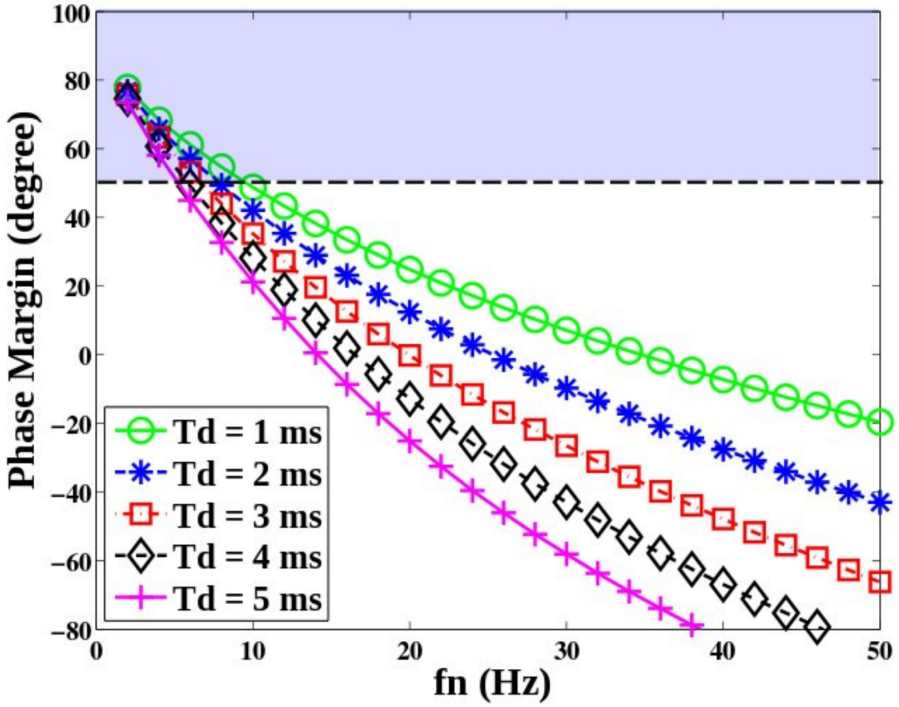
	CPU	FPGA	GPU
Hard real time (jitter)	Acceptable	Excellent	Acceptable
Massive parallelism	Poor	Excellent	Excellent
Latency	Poor	Excellent	Bad
Programming	Easy	Challenging	Medium

Closed Orbit feedback systems



COFB: Effects of latency in a feedback loop





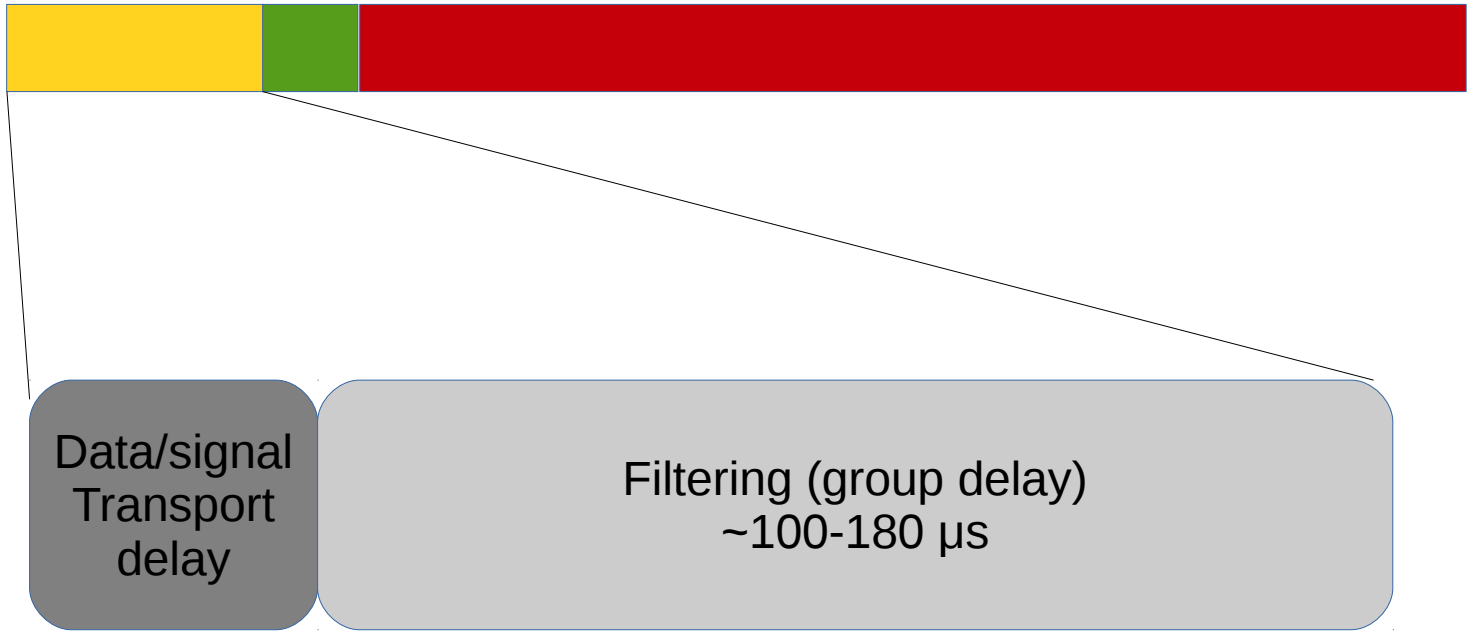
COFB latency contributions and BW limitations breakdown

BPM: 100-200 µs

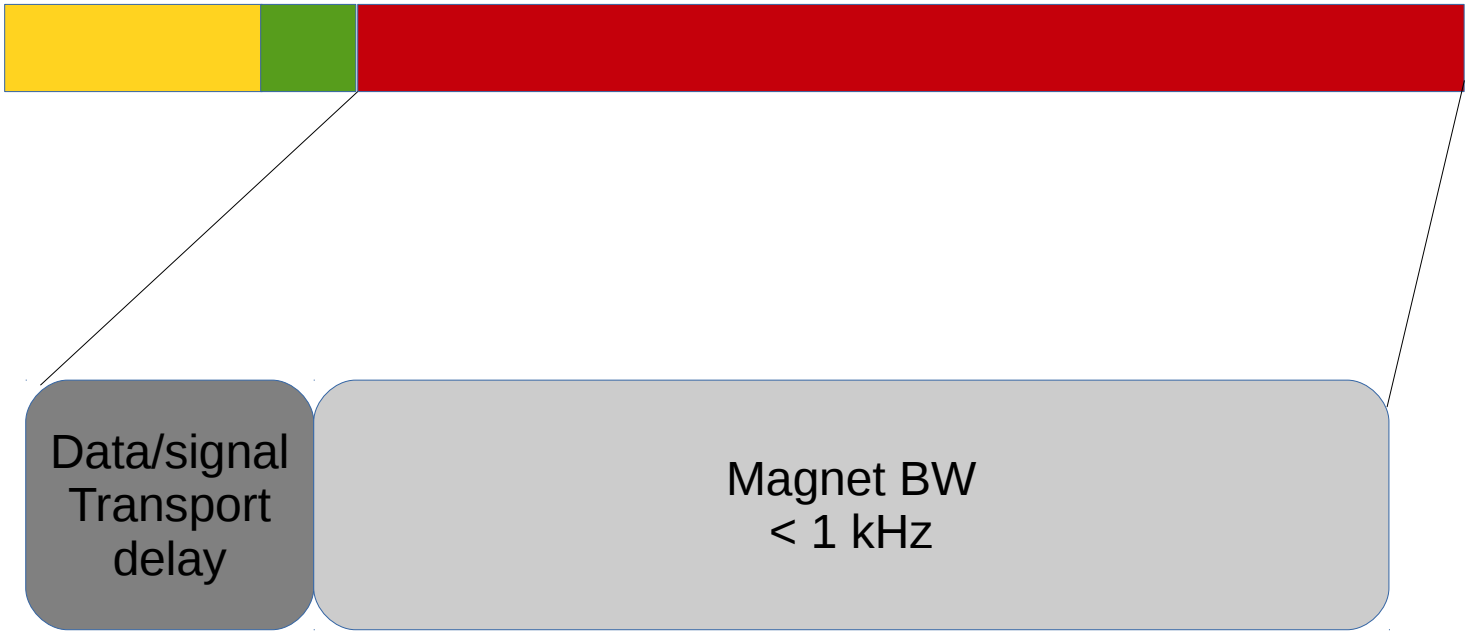
COFB: 20-30 µs

Magnets: 1-2 ms

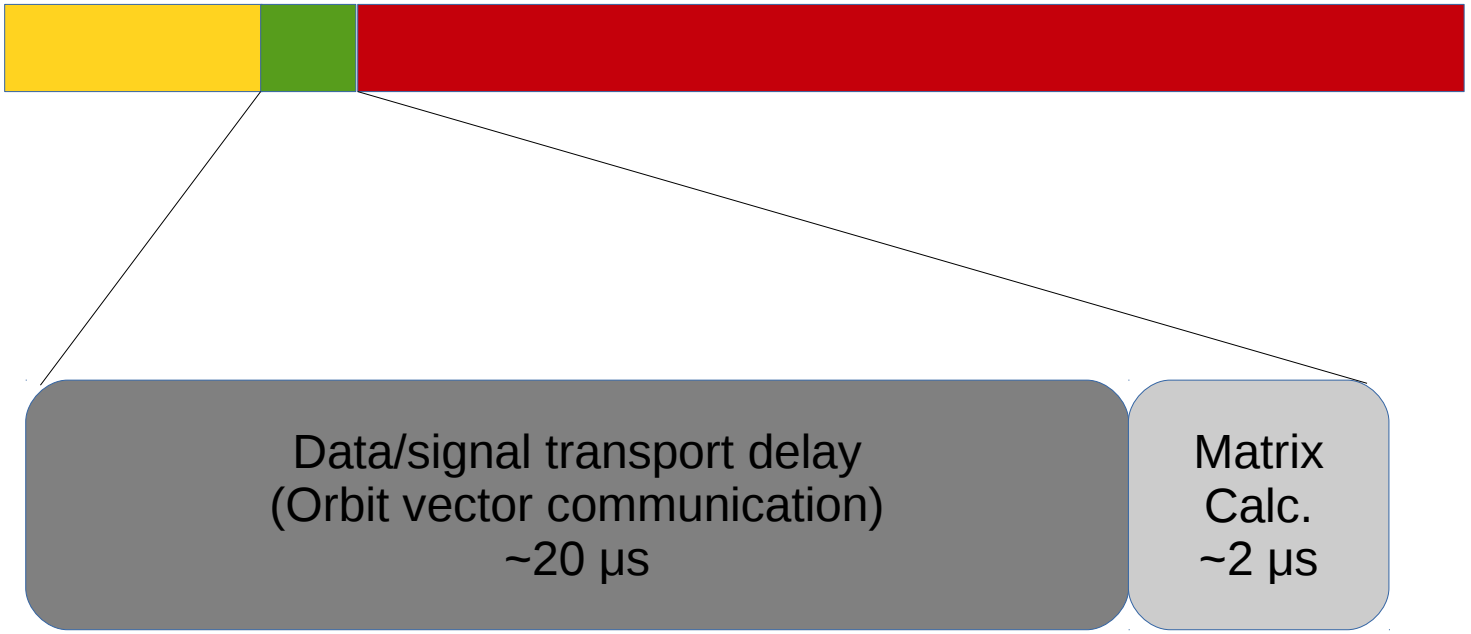
Latency/BW contributions: BPM



Latency/BW contributions: Magnets



Latency/BW contributions: COFB



What today's & future technology may bring

- **Today's & future FPGA devices offer:**
  - **Communication speed (GTH/GTY transcievers): 12-25 Mbit/s**
  - **COFB Latency: ½ to ¼ of current values → down to 5 us.**
  - **Higher COFB rates: ~100 kHz range**
  - **More DSP resources (less relevant)**
- **Other components in COFB:**
  - **Higher BW BPMs?**
  - **Higher BW magnets (in-vacuum)?**

Discussion

- **What are the expected orbit disturbance characteristics & spectra of next generation accelerators?**
- **Is there a need for increasing the COFB BW any further?**
- **Expected magnet BW of next generation accelerators?**
- **Would any standardized digital interface to the magnets be beneficial and is it realistic to achieve?**

Summary

- Libera BPM family available, mature & ready for operation
- Various COFB implementations in operation
- Libera = Openness (FPGA deevlopment kit, full sources)
- We value colaboration with you and look forward continue
- We look forward to see 1st large Libera Hadron deployment in action (COFB @ SIS18)