MicroTCA for the new Beam Control of the CERN SPS

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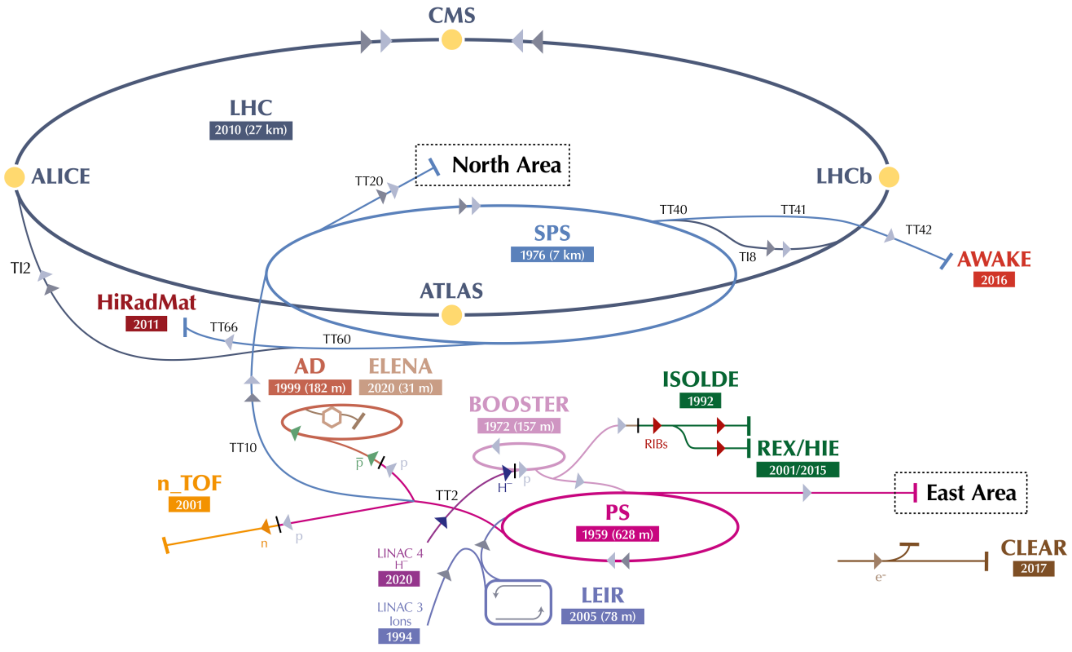
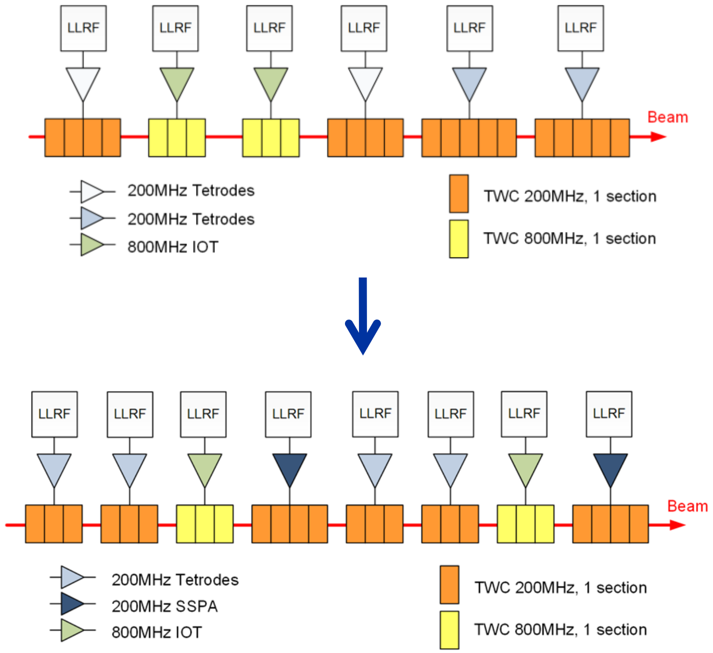
Overview of the CERN SPS LLRF upgrade

- High Luminosity LHC requirements: Doubling proton beam intensity
  - To increase accelerating voltage vs. beam induced voltage the longest cavities are split into shorter ones
  - The LLRF beam-loading compensation is improved
- New beam requirements for ions beams and other physics targets
  - Ions slip stacking [2]: Individual control of two groups of cavities (frequency, phase and amplitude)



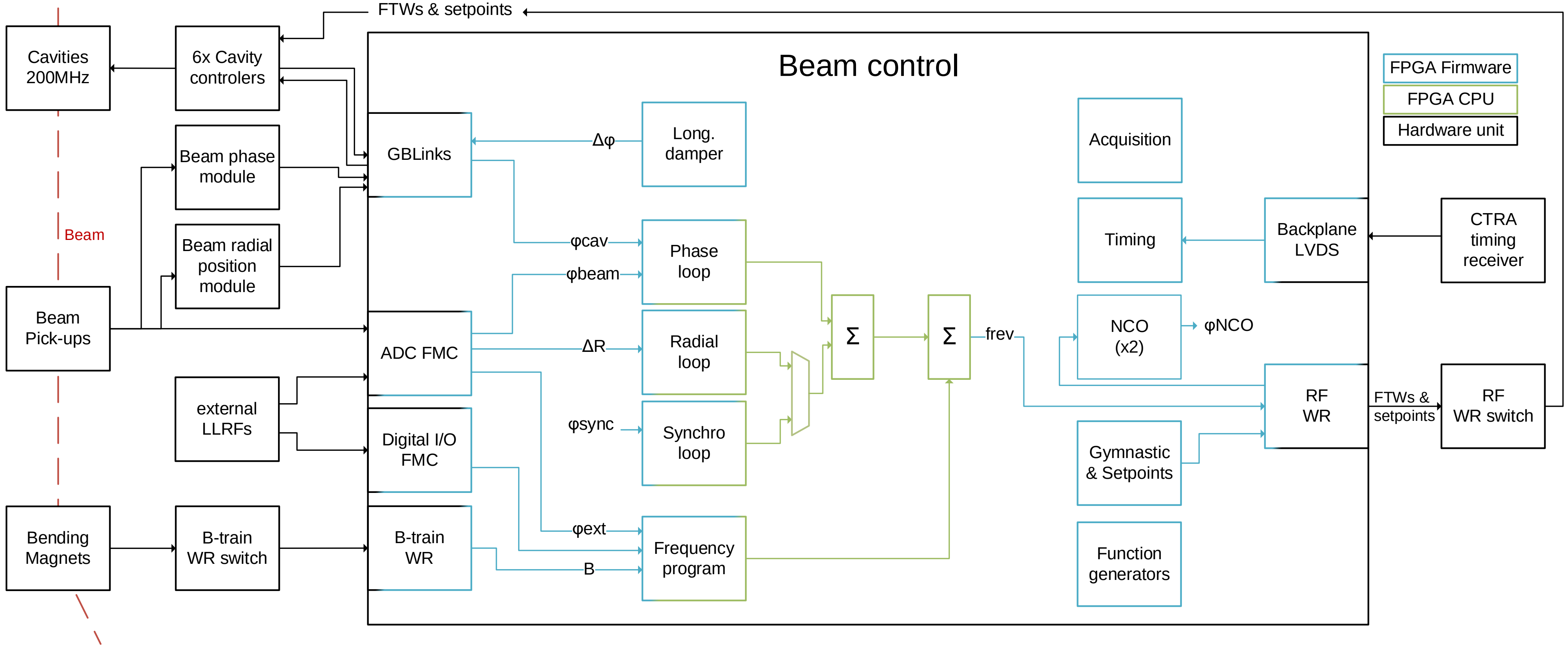


Overview of the CERN SPS LLRF upgrade

- New requirements + components obsolescence of the cavity controllers and beam control:
  - Move from VME / NIM platform to MicroTCA
  - Use fixed clocking frequency for all digital electronics (used to be locked to the RF)
  - Use the White Rabbit network for synchronisation and clocking [1]

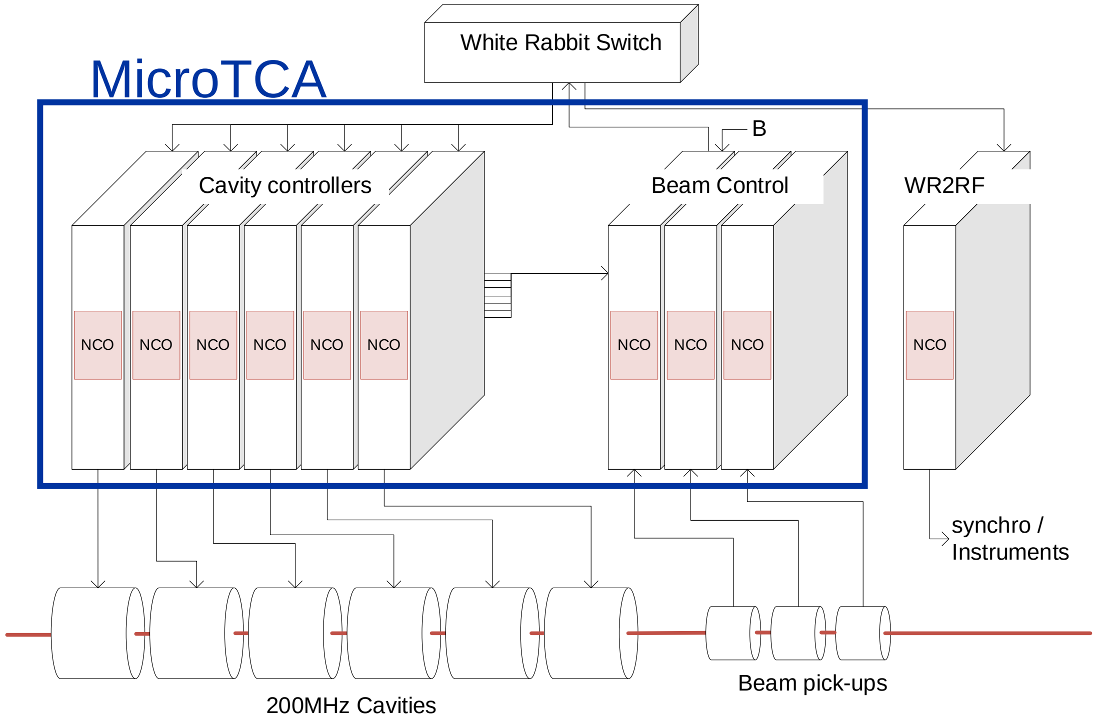
Functionality of the beam control

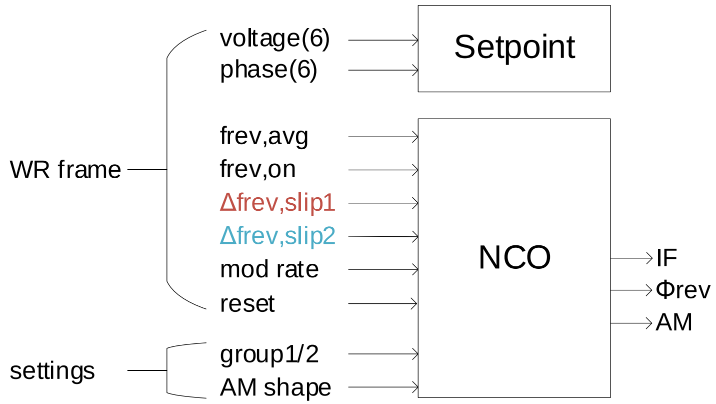
- The accelerating RF frequency is computed in the beam control from the bending magnetic field and the contribution of the control loops.
- It also transmits the phase and amplitude setpoints to the cavities.



RF distribution over White Rabbit

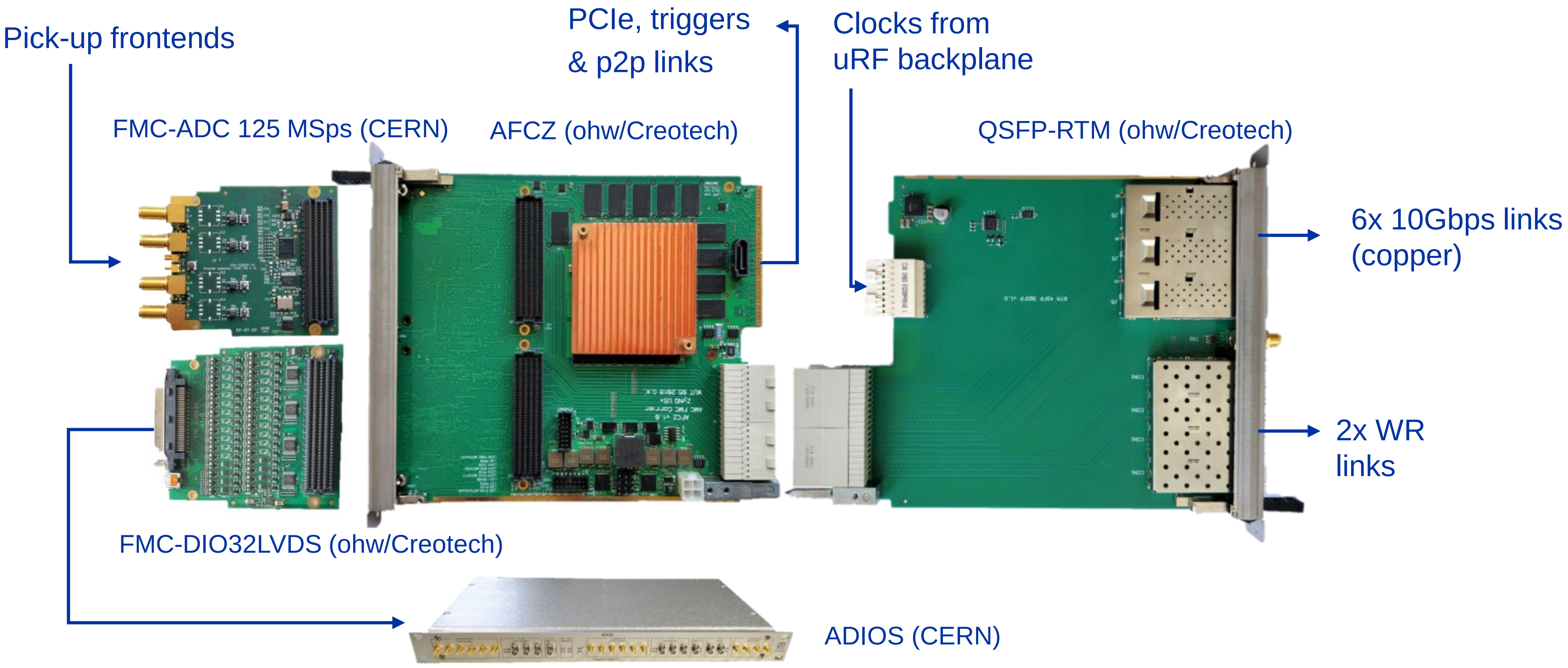
- The WR-RF frame is sent by the beam control at every beam revolution (23us).
- Thanks to the White Rabbit fixed latency, the frame is delivered simultaneously to all the node's NCOs (Numerically Controlled oscillators).





Hardware: AMC FMC Carrier with Zynq (AFCZ)

- The signal processing is implemented in the Zynq Ultrascale+ of the AFCZ
- It receives the 6 cavities voltages through 10Gbps links (Aurora-based)



Hardware: Wideband beam pick-up modules

- These modules with up to 6.4 GSps ADCs will provide additional wideband beam pick-up inputs for the loops and beam observation
- The pre-processed data stream is sent over the backplane or cabled links

Pick-up frontends

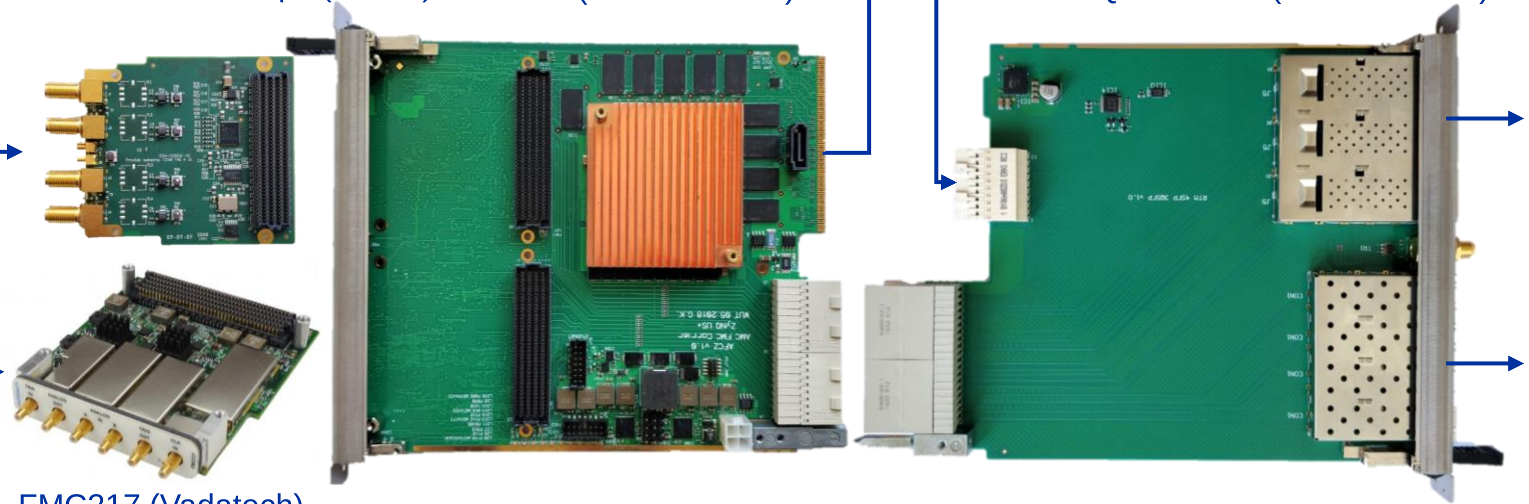
PCIe, triggers
& p2p links

Clocks from
uRF backplane

FMC-ADC 125 MSps (CERN)

AFCZ (ohw/Creotech)

QSFP-RTM (ohw/Creotech)



6x 10Gbps links
(copper)

2x WR
links

FMC217 (Vadatech)

Wide band Pick-up
frontends

Hardware: MTCA Crate and clock distribution

- The uRF backplane is used for the clock distribution (details in T. W. presentation)

Front (AMCs)

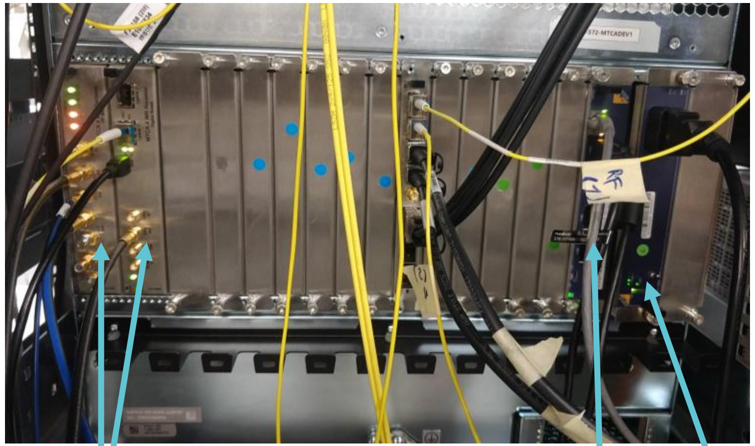
MCH

CTRA (Timing receiver)

AFCZ

Aux Power modules

Back (RTMs)



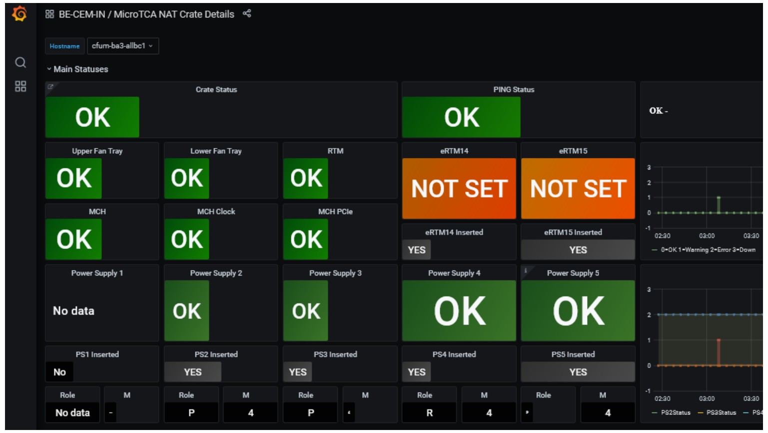
eRTM14/15
(clocks generation)

Front end CPU

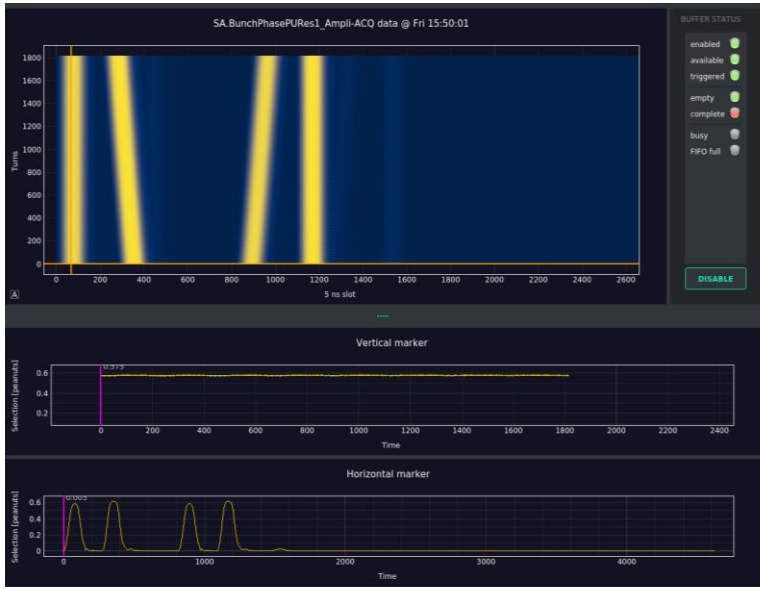
Rear Power Module

Monitoring and data Acquisition

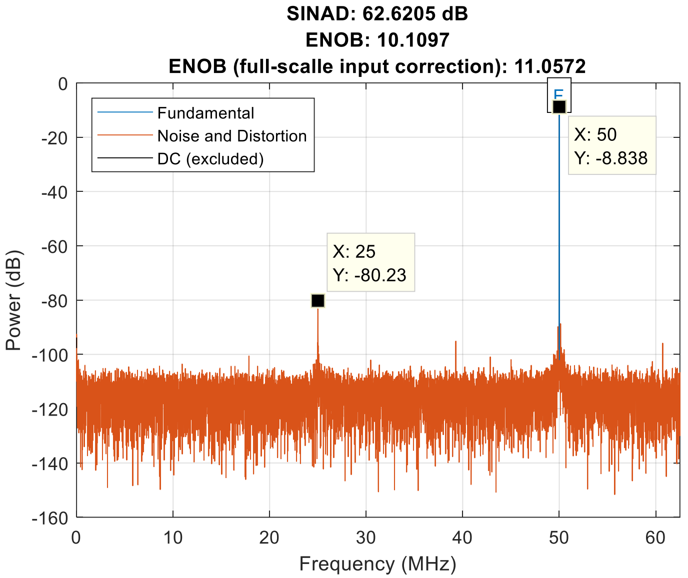
- Crate monitoring (MCH) displayed using Grafana
- Controls and data acquisitions over PCIe
  - Read/Write up to 200 MB per machine cycle (every ~10s) in a 100 ms window
  - The DMA to/from FPGA DDR allows up to 3Gbps transfers
- Allows for bunch-by-bunch acquisitions (200 MSps) and later on bunch profile (5 GSps)



Crate status in Grafana



Bunch-by-bunch beam amplitude acquisition



Direct-sampled 200 MHz RF signal @ 125 Msps

MTCA Implementation review

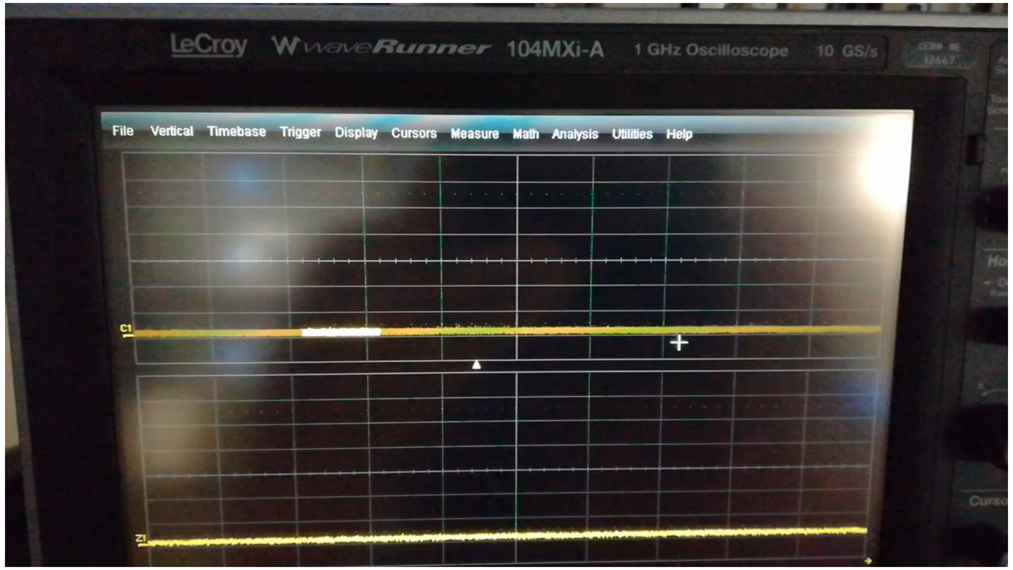
- Drawbacks
  - Complex “house keeping” firmware and software
  - Hard to debug CPU and MCH crashes
  - Fitting design in FPGA (Transceivers, DDR, PCIe, WR already take 20% of resources)
  - FMC compatibility

- Benefits
  - Gain in modularity and scalability
  - Commercial products available
  - Compact system
  - Backplane bandwidth for data acquisition and controls
  - SoC performance for floating point DSP and unloading the FPGA

Conclusion: SPS Commissioning results

- The commissioning took place from April to November 2021 with a series of successfully accelerated beams: proton LHC, proton Fixed Target, proton single bunch for AWAKE experiment, lead ions for LHC with slip stacking
- Phase and frequency manipulations made much easier (centralised control, distributed NCOs)
- Better reproducibility (once the setup is done, there is minimal drift)

Ions slip-stacking (two independent cavity groups)



Thank you, questions?

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  - Software: K. Adrianek, A. Butterworth, S. Novel Gonzalez, A. Rey, M. Suminski, …
  - Operation: T. Argyropoulos, F. Follin, V. Kain, K. Li, G. Papotti, and all SPS operation
  - Creotech

- References

  - [1] M. Lipiński, T. Włostowski, J. Serrano, P. Alvarez, White Rabbit: a PTP application for robust sub-nanosecond synchronization, Proceedings of ISPCS2011, Munich, Germany, 2011
  - [2] T. Argyropoulos et al., Momentum slip-stacking in CERN SPS for the ion beams, CERN-ACC-2019-119, IPAC 2019 http://cds.cern.ch/record/2693251/files/wepts039.pdf

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