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# CERN Lab talk

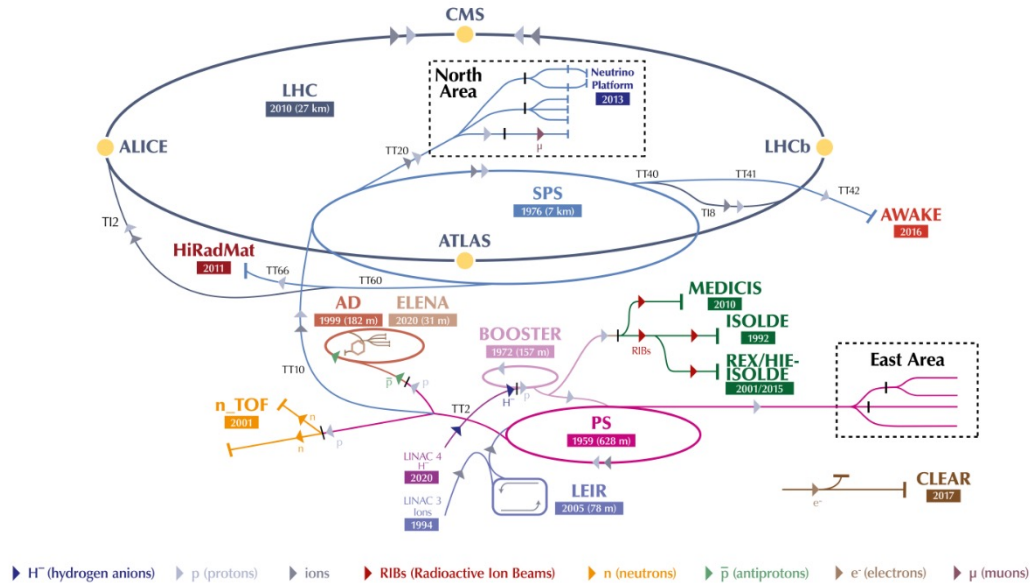
W. Höfle

CERN, Geneva, Switzerland

on behalf of teams in SY-RF-FB, SY-RF-BR, SY-RF-CS

# Overview of CERN Accelerators

The CERN accelerator complex  
*Complexe des accélérateurs du CERN*



LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear  
 Electron Accelerator for Research // AWAKE - Advanced WAKEfield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE-ISOLDE - Radioactive  
 Experiment/High Intensity and Energy ISOLDE // MEDICIS // LEIR - Low Energy Ion Ring // LINAC - LInear ACcelerator //  
 n\_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials // Neutrino Platform

# Variety of LLRF from analog to MicroTCA

- VXS and VME digital systems deployed in a wide range of machines since 2006, have to support these platforms for many years to come
  - VXS: AD, ELENA, PSB, PS, LEIR → small synchrotrons varying revolution frequency
  - VME: LHC, SPS partially, PS, LINAC3 (ions), LINAC4 (H<sup>-</sup>), HIE-Isolde, AWAKE, small frequency swing or fixed RF frequency
- MicroTCA technology rolled out in SPS for 200 MHz RF system, commissioned during the last two years (restart after a long shutdown)
- Legacy, mostly analog systems for e-beam acceleration used in CLEAR and AWAKE (3 GHz RF system)
- Future evolution towards more use of MicroTCA.4 based on experience with this technology in SPS
  - New LLRF for PS 200 MHz RF system under commissioning
  - AWAKE + with new LLRF for 3 GHz under planning
- Large number of accelerators, continuously running make it difficult to roll-out common technology; adaptation of technology to different requirements takes time and technology changes fast ...



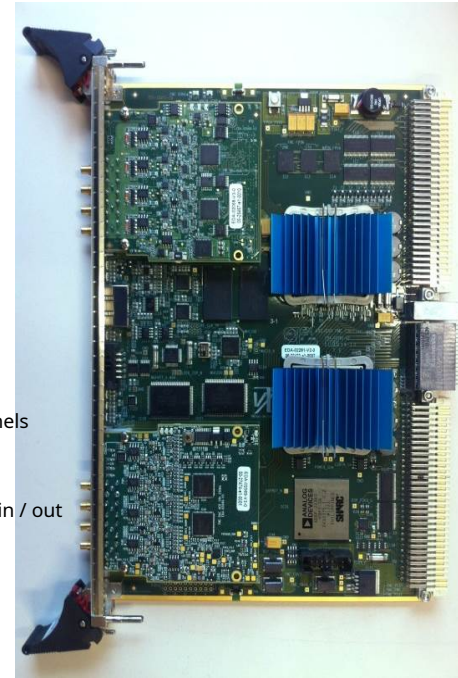
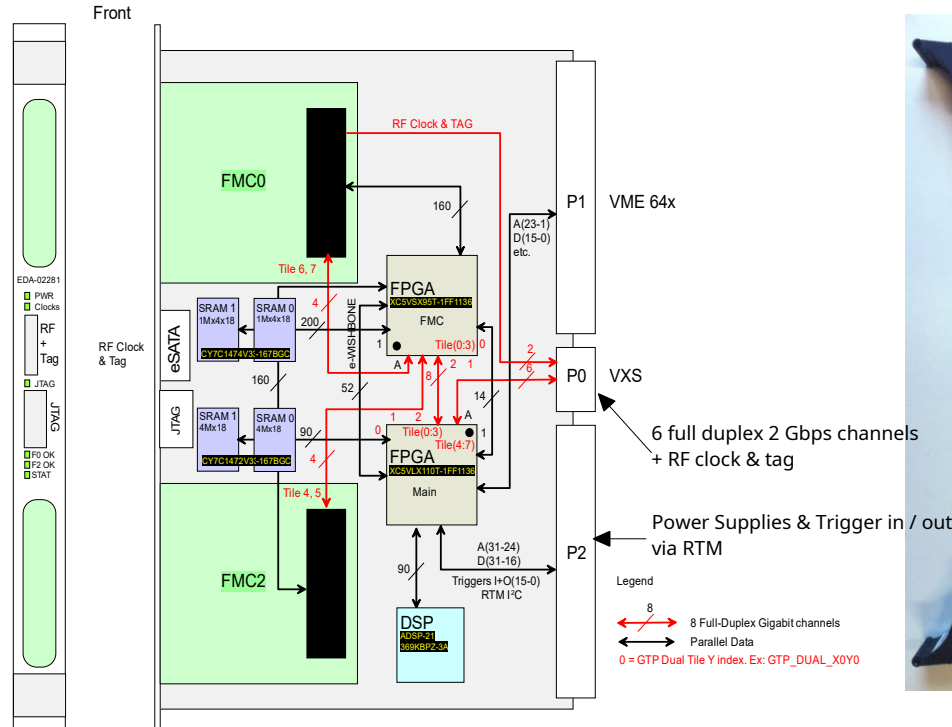
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# Progress VXS systems in small synchrotrons

- PSB
  - Moving from Ferrite to Finemet cavities (wideband, no tuner) and various servo-loops at beam harmonics
  - WR Btrain distribution
  - New injection mechanism, also with long. Painting from LINAC4
- AD
  - Designed, implemented and deployed the new LLRF + in-frequency longitudinal diagnostics. Implemented a new manner of controlling the LLRF parameters via makerules. Initial deployment of the Obsbox diagnostics
- ELENA
  - Implemented a new manner of controlling the LLRF parameters via makerules. Initial deployment of the Obsbox diagnostics
- LEIR
  - Implemented a new manner of controlling the LLRF parameters via makerules (automated setting-up)
- Obsbox system deployed for collecting data for beam measurements
- Support for medical accelerators outside CERN

# VXS system with custom built carrier board

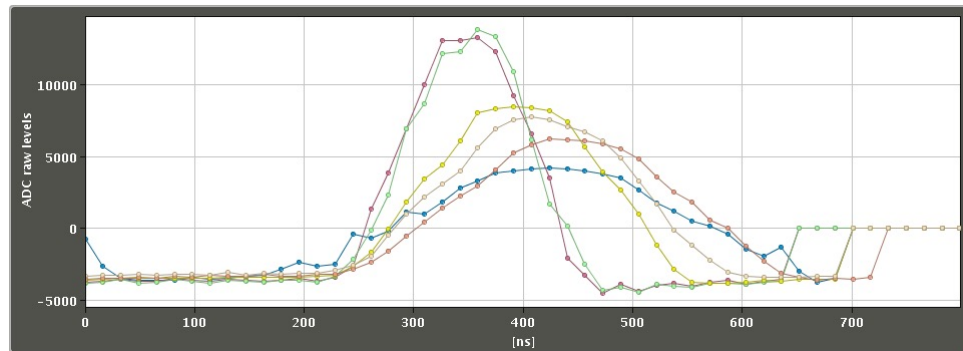
## VXS-DSP-FMC carrier



Fixed frequency sampling clock (ADCs, DACs on FMC mezanines)

# Obs Box system for data extraction from VME and VXS systems (streaming of data to server)

- originally conceived for observing bunch-by bunch position data in LHC on the VME system
- allows processing of data from beam on a separate server with low latency
- Transfer of data via custom fiber links



Bunch length AD complex from Obs Box

M. E. Angoletta,  
M. Soderen et al., Poster #69

# Hardware in LHC transverse plane for ObsBox

- Hitech Global HTG-FMC-X10SFP+ FMC mezzanine
- Trenz Electronics TEC0330-4 FMC carrier
- Xilinx Virtex7 FPGA
- PCIe 3.0 x8 resulting in transfer rate to the host of 7.88GB/s
- Own firmware and driver
- Up to 10 channels @ 5 Gbps



- GIGABYTE G481-HA0
- 2 x Intel Xeon 'Skylake' 8260 24 Core 48 Threads 2.4GHz
- 768 GB DDR4 RAM
- 10 x 3.0 16x PCIe FH FL DW
- 2 x 10Gb/s BASE-T LAN ports

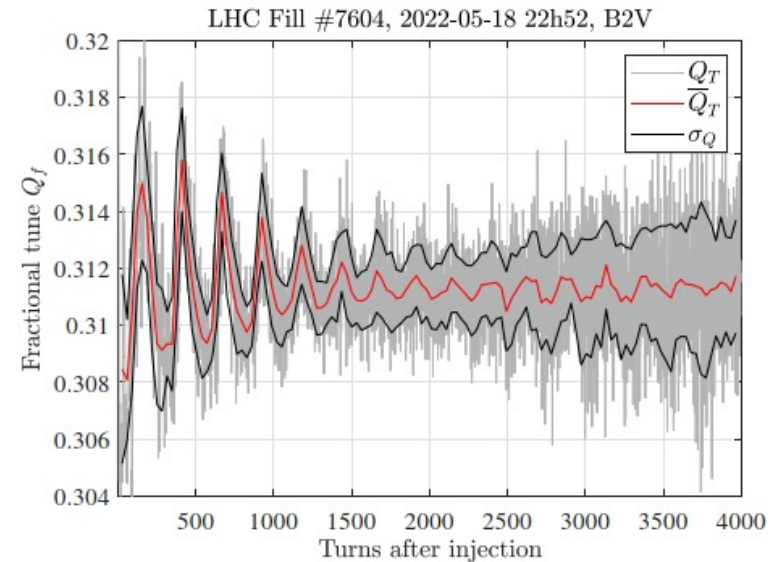
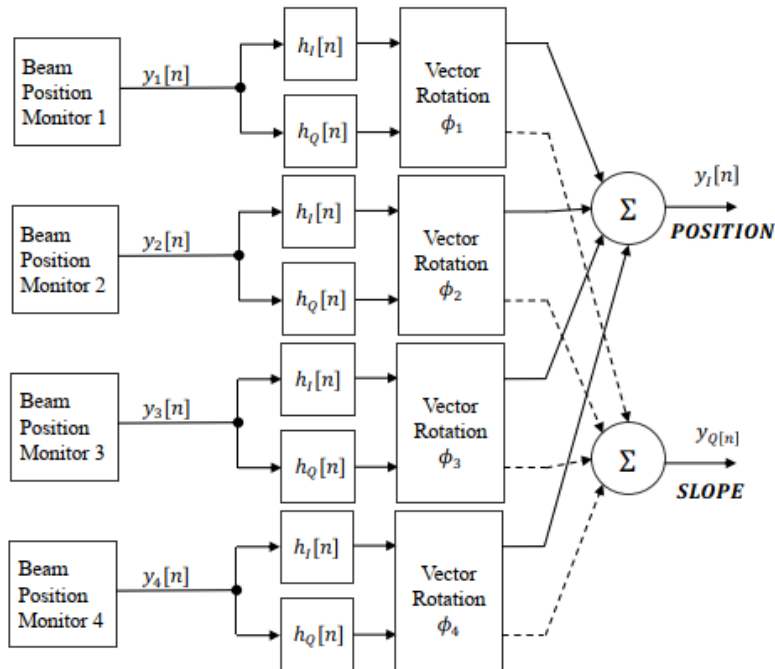


- Runs Centos 7 real-time kernel
- Configured as a front-end computer
- Runs FESA classes
- GPGPU ready

M. Soderen et al.

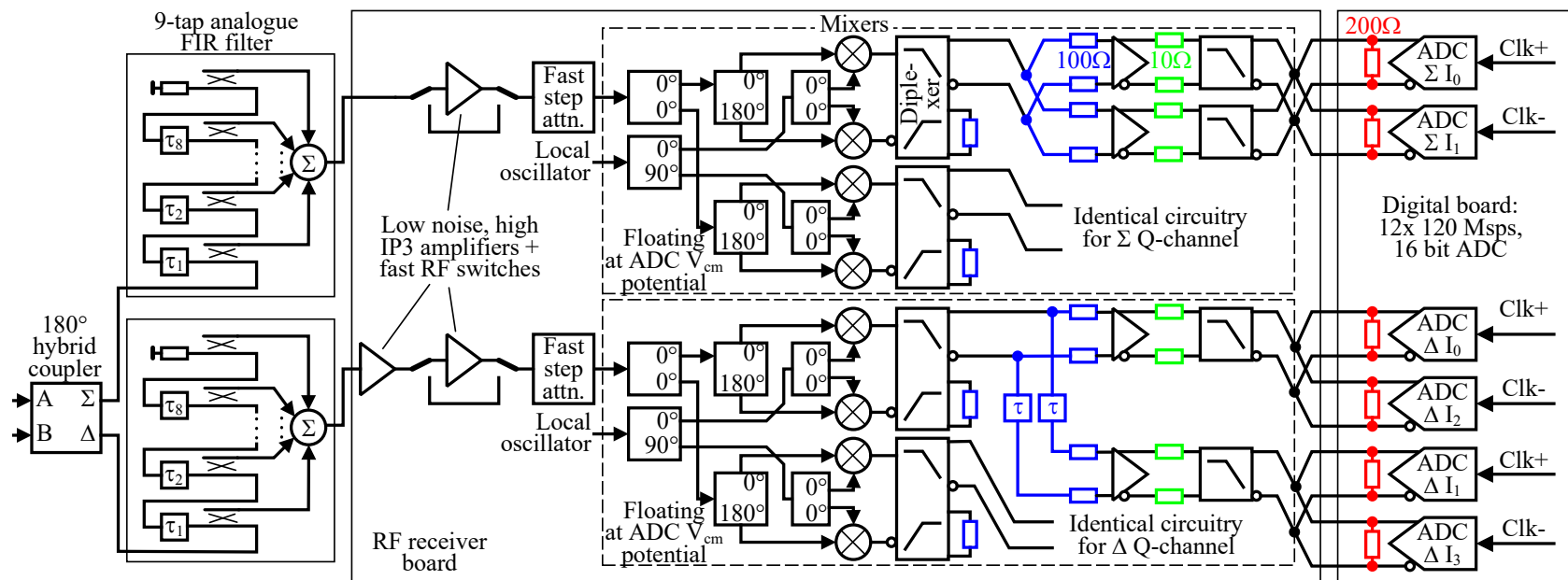
# Data from LHC transverse feedback in LHC

- Analysis  $\rightarrow$  tune determination from phase advance



G. Kotzian et al.  
IPAC'22, TUPOST037

# Receiver technology with very small resolution



ADC: LTC2185

Deployed for transverse damper in LHC

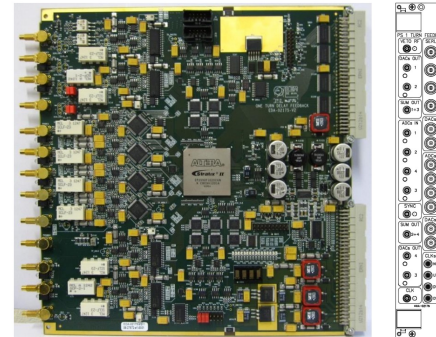
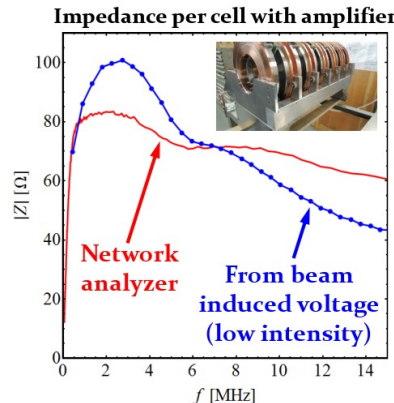
Transverse feedback noise performance will be critical for LHC High Lumi area crab cavities

D. Valuch, #80 (talk)

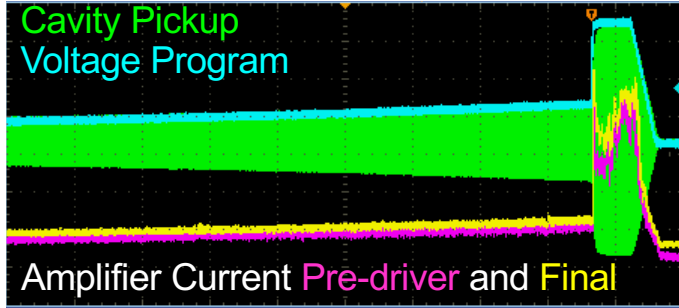
IPAC'22, TUPOST007

# Progress PS, Proton Synchrotron

- Multi-harmonic Feedbacks for High frequency Cavities
- Advanced technics using wide band finemet cavity initial installed for a longitudinal damper, VME custom digital feedback
  - barrier bucket scheme to create a beam free gap for reducing extraction losses → **M. Vadai et al. #33 (talk)**
    - prototype electronics for machine development studies added to LLRF
  - Quadrupole mode damping for high intensity proton beams → **J. Paszkiewicz et al. #40 (talk)**

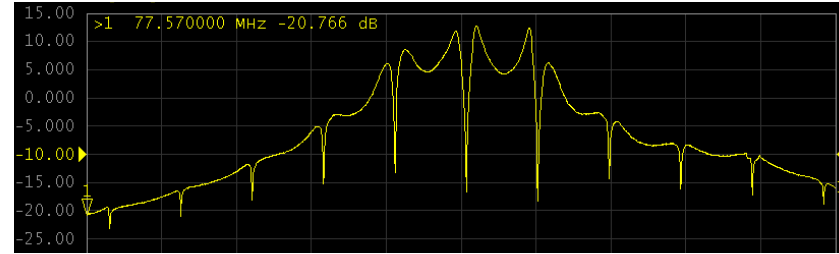


# Digital cavity controller for the PS 40/80 MHz cavities

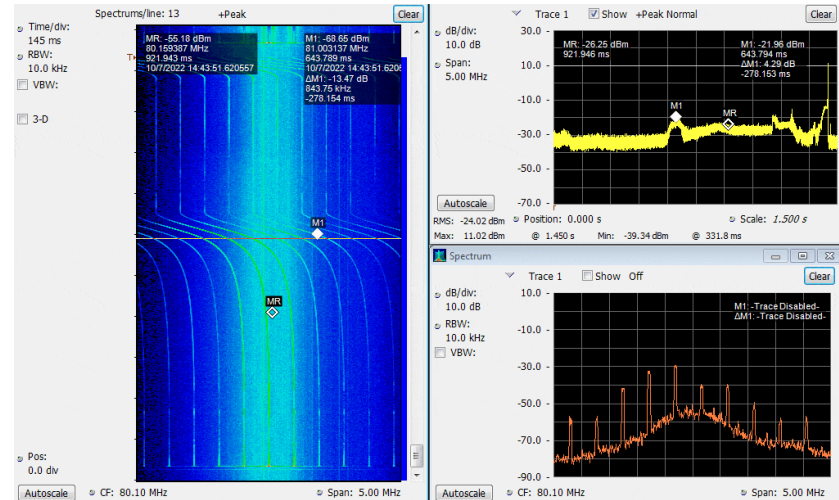


40 MHz Cavity Pulse, voltage program and amplifier currents.

- Multi-harmonic feedback covering central harmonic  $\pm 5$  harmonics.
  - 15-20 dB reduction in beam induced voltage.
- Automated voltage and phase control loop.
- Cavity phase measurement and tuning feed-forward.



80 MHz Cavity Transfer function with MHFB enabled



80 MHz Cavity Transfer function with MHFB enabled/disabled

# Progress SPS

- New uTCA based system using white rabbit frequency distribution,
  - Feedback for 200 MHz TWC (6x)
  - Feedback for 800 MHz TWC (2x)
  - Beam Control LLRF with Beam feedback loops with LLRF for acceleration
  - Longitudinal damper feedback loop
  - Blow-up generation
  - Synchronization to LHC, AWAKE and crab cavities
  - Beam commissioning 2021/2021
  - Innovative fixed frequency sampling
  - Setting-up tools in Python (SPS, LHC)

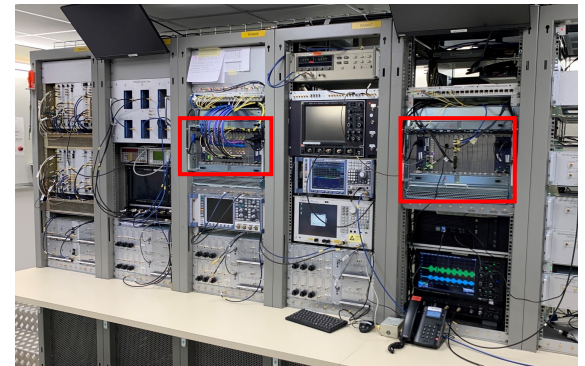
G. Hagmann et al. #67 (talk)

T. Wlostowski et al. #107 (talk, white rabbit)

D. Dlugosz et al. #36 (poster)



Thales 200 MHz solid state RF plant  
2x 1 MW



New LLRF with MicroTCA

# Multi Gsps for SPS using MicroTCA hardware

- The Beam Phase module has been designed on the uTCA platform. The beam phase module is based on a AFCZ mezzanine carrier with a Xilinx Zynq Ultrasacle+ FPGA and the Vadatech FMC217 mezzanine card. The FMC217 ADC FMC has sample rates of up to 6.2 Gsps. For this application we are using a sampling rate of 5Gsps for easier synchronisation with the 250 MHz FPGA processing clock
- In view of bunch-by-bunch beam phase measurements in SPS (5 ns bunch spacing)
- Potential application also for transverse systems



R. Borner et al., #37 (poster)

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# Progress LHC and SRF support

- Setting-up tools for LLRF in Python
- Data collection with obs box
- R&D towards crab cavity LLRF using MicroTCA technology
- Crab cavity testing in SPS
- SRF development support
  - LLRF for production testing for crab cavities
  - study for a fast Reactive tuner for beam loading compensation
    - N. Shipman et al. presented at ERL'22 workshop
  - occasion to visit SM18 test stands for SRF on Friday 14.10.22

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# Acknowledgements

M. E. Angoletta, D. Barrientos, P. Baudrenghien, A. Butterworth,  
R. Borner, D. Dlugosz, J. Egli, G. Hagmann, G. Kotzian, M. Söderén,  
A. Spierer, H. Timko, M. Vadai, D. Valuch, T. Wlostowski, B. Woolley

CERN, Geneva, Switzerland



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spare



# Injector transverse feedbacks at CERN

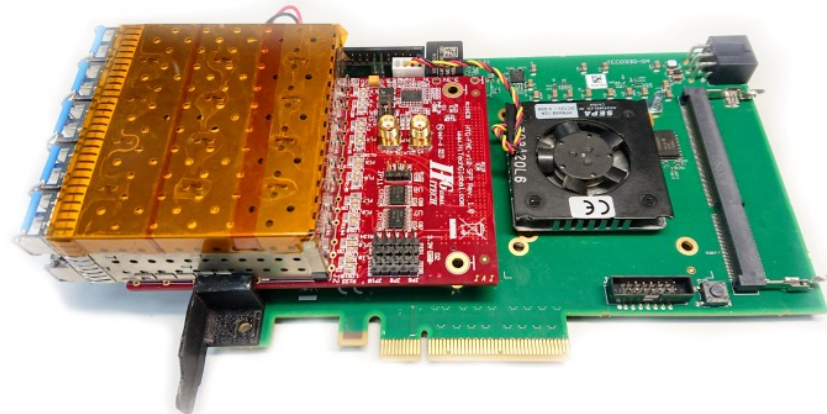
- LHC Injector transverse feedbacks at CERN and studies
  - next “upgrade to digital” opportunity for LEIR

Accelerator / energy	Kicker / power per electrode frequency band	Processing used	Last upgrade
<b>LEIR</b>	striplines up to 100 MHz	2 pick-ups	2005
4.2 MeV/u – 72 MeV/u (kin. E)	100 W, 50 $\Omega$ , up to 100 MHz	analog, vector sum	
<b>PS Booster</b>	striplines up to 100 MHz	1 pick-up	2020
160 MeV – 2 GeV	800 W, 50 $\Omega$	digital	
<b>PS</b>	striplines with impedance transformer	1 pick-up (+spare)	2020
2 GeV – 26 GeV/c	5 kW, 125 $\Omega$ , up to $\sim$ 60 MHz	digital	
<b>SPS</b>	electric field kickers, high impedance	striplines, electro-static	2014
14, 26 GeV/c – 450 GeV/c	tetrodes, 30 kW, 180 $\Omega$ , up to 20 MHz	digital, pick-up pairs	
<b>SPS for wideband feedback study</b>	2 short striplines and 1 Faltn type kicker	1 stripline exponential PU	2008
26 GeV/c	250 W, 50 $\Omega$ , 5 MHz – 1 GHz	Digital up to 4 GS/s (3.2 Gs/s)	to 2018

# ADT ObsBox for data recording from feedback

- data recording from feedback systems

	Level-1 Rate (Hz)	Event size (Bytes)	Readout Bandw. (GB/s)	HLT Out MB/s (Events/s)
ALICE (Pb-Pb)	500	$5 \times 10^7$	25	1250 ( $10^2$ )
ALICE (p-p)	$10^3$	$2 \times 10^6$	25	200 ( $10^2$ )
ATLAS	$10^5$	$1.5 \times 10^6$	50	$\approx 1000(10^2)$
CMS	$10^5$	$10^6$	100	$\approx 1000(10^2)$
LHCb	$10^6$	$5 \times 10^4$	50	700 ( $1.2 \times 10^4$ )
ADTObsBox	$10^4$	$10^5$	2	1280 ( $10^4$ )



M. Söderén, D. Valuch  
EPJ Web of Conferences 245, 01036 (2020)  
CHEP 2019,  
<https://doi.org/10.1051/epjconf/202024501036>

# SPS Beam & results

- Protons
- Intensity achieved for LHC beam:
  - 1.84e11 p/bunch, 72 bunches, 25ns spacing
  - 1.4e11 p/bunch, 4x 72 bunches, , 25ns spacing
- Intensity achieved for AWAKE:
  - 3e11 p/bunch, 1 bunch, 1ns

- Ions
- slip-stacking from 100ns to 50ns bunch spacing
- Commissioning on going

