
# LLRF at CERN
# Status and Progress

Presented by W. Hofle

LLRF workshop 2019, Chicago, 30th September 2019

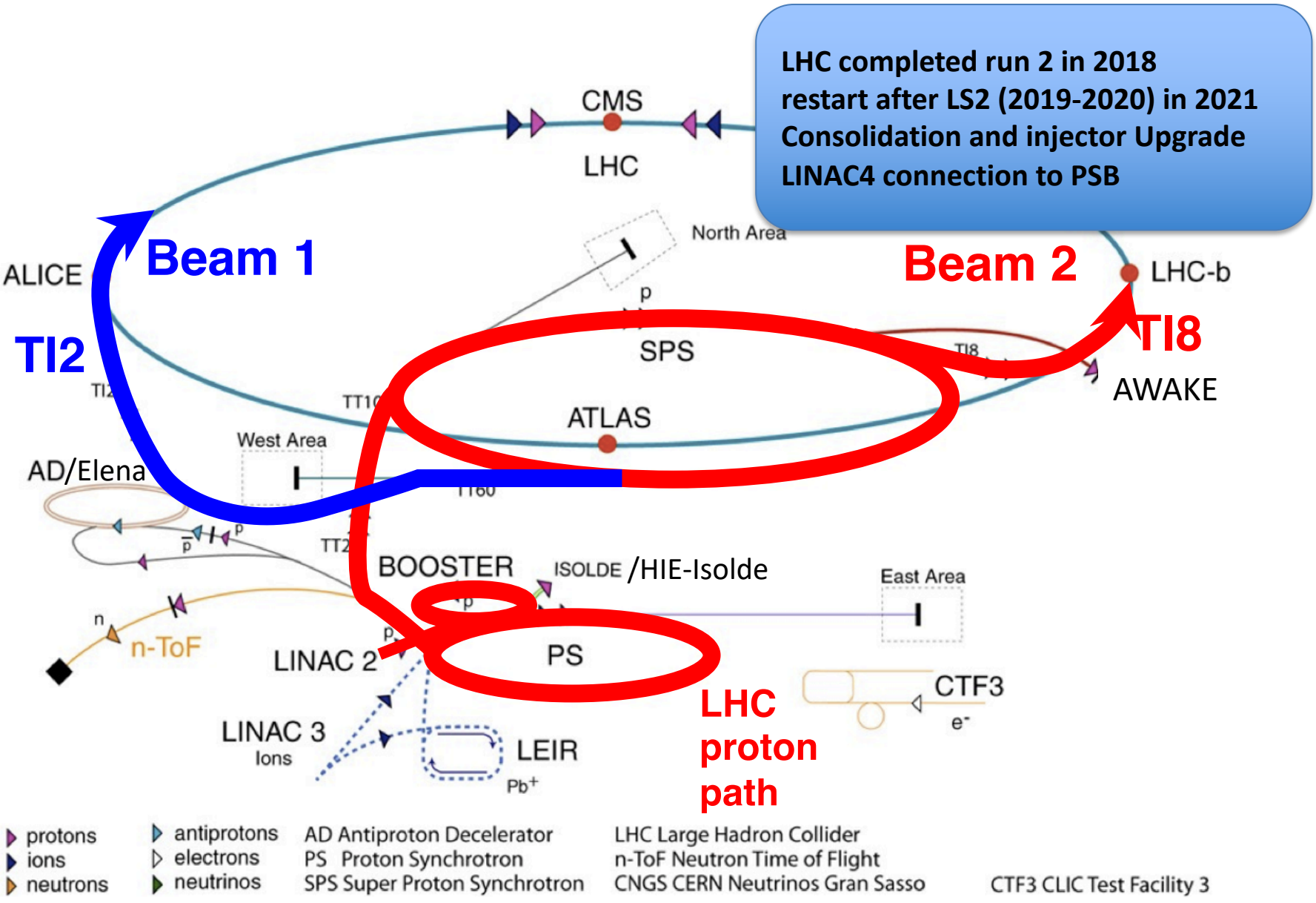
# Overview

**Contributions from CERN for**

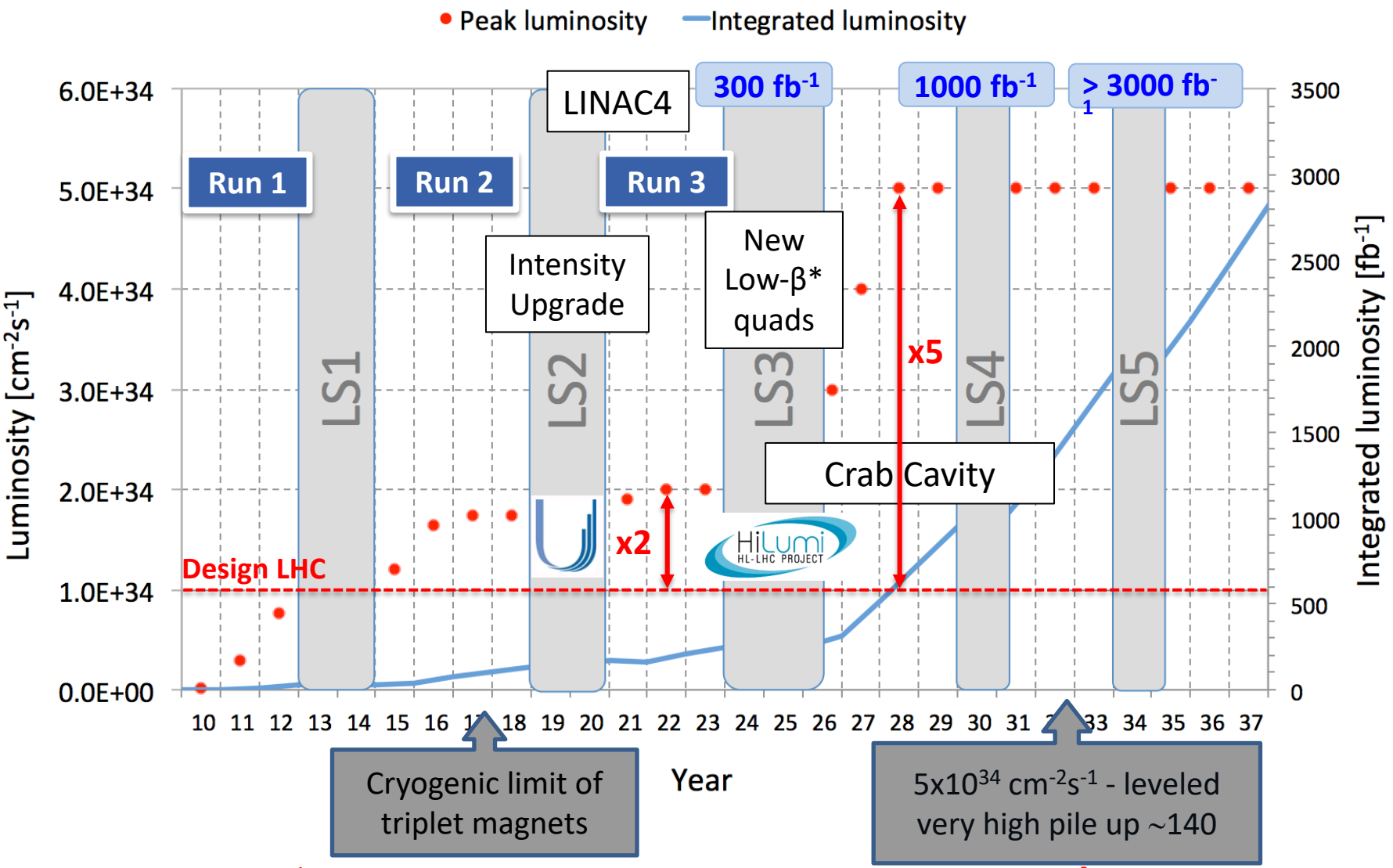
- **LINAC4**
- **LHC Injector Upgrade Project (LIU)**
- **Limiting and interlocking (LINAC3, HIE-Isolde)**
- **AWAKE**
- **LEIR, ELENA, AD (anti-proton deceleration)**
- **PSB, PS, SPS**

- **Summary and outlook**

# The accelerator complex



# HL-LHC luminosity reach

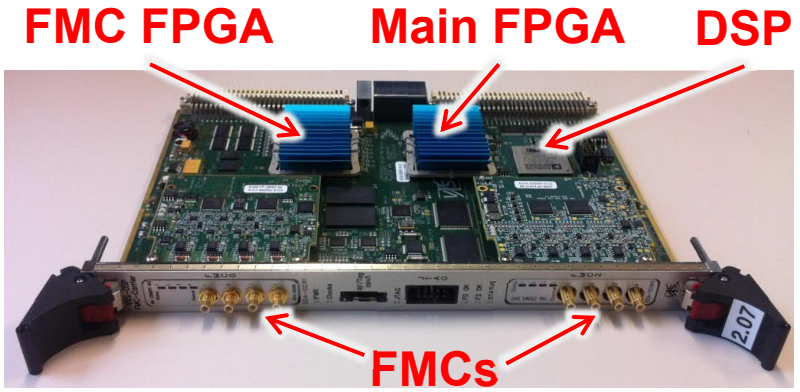



160 $fb^{-1}$ reached in in Run 2 with 25 ns spacing at 6.5 TeV → LLRF ok

# LLRF Hardware Families

- VXS carrier board with DSP and FPGA
  - LEIR, PSB, ELENA, AD, MedAustron
  - some application in PS
  - Paradigm change implemented:
    - shift to fixed frequency clock

Talk by M. E. Angoletta

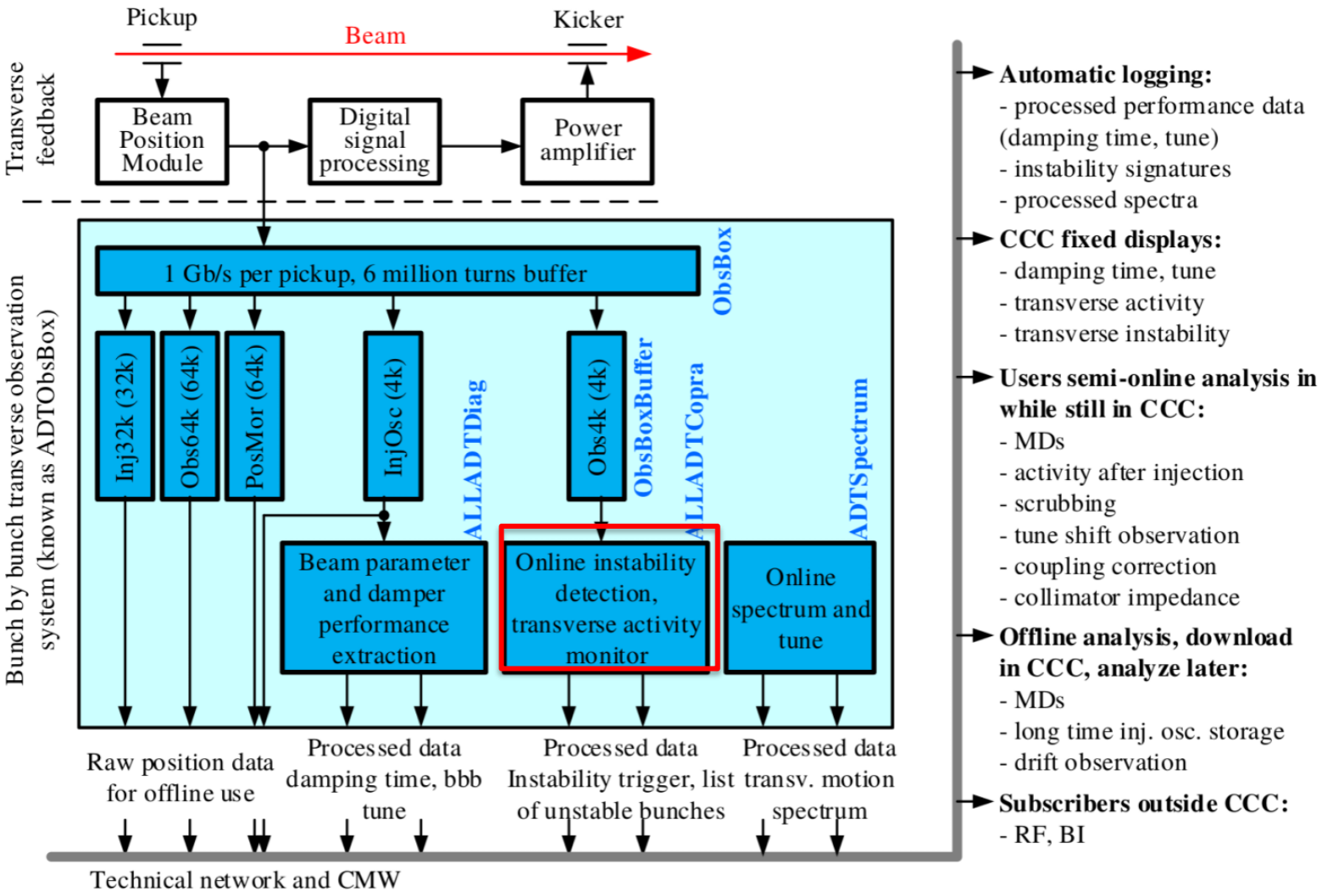



FMC-DSP carrier board

- Custom VME system:
  - LHC LLRF, all transverse dampers, crab cavity SPS tests, SPS 800 MHz, LINAC4, HIE-Isolde, LINAC3 consolidation
  - add-on to record data in a separate server ("ObsBox") helps extending lifetime
    - also to be deployed for the VXS system of AD and on other VME systems when required

- SPS 200 MHz LLRF:
  - Complete new LLRF being developed for restart in 2021
  - based on μTCA
  - use of commercially available hardware and collaboration

# What is ObsBox

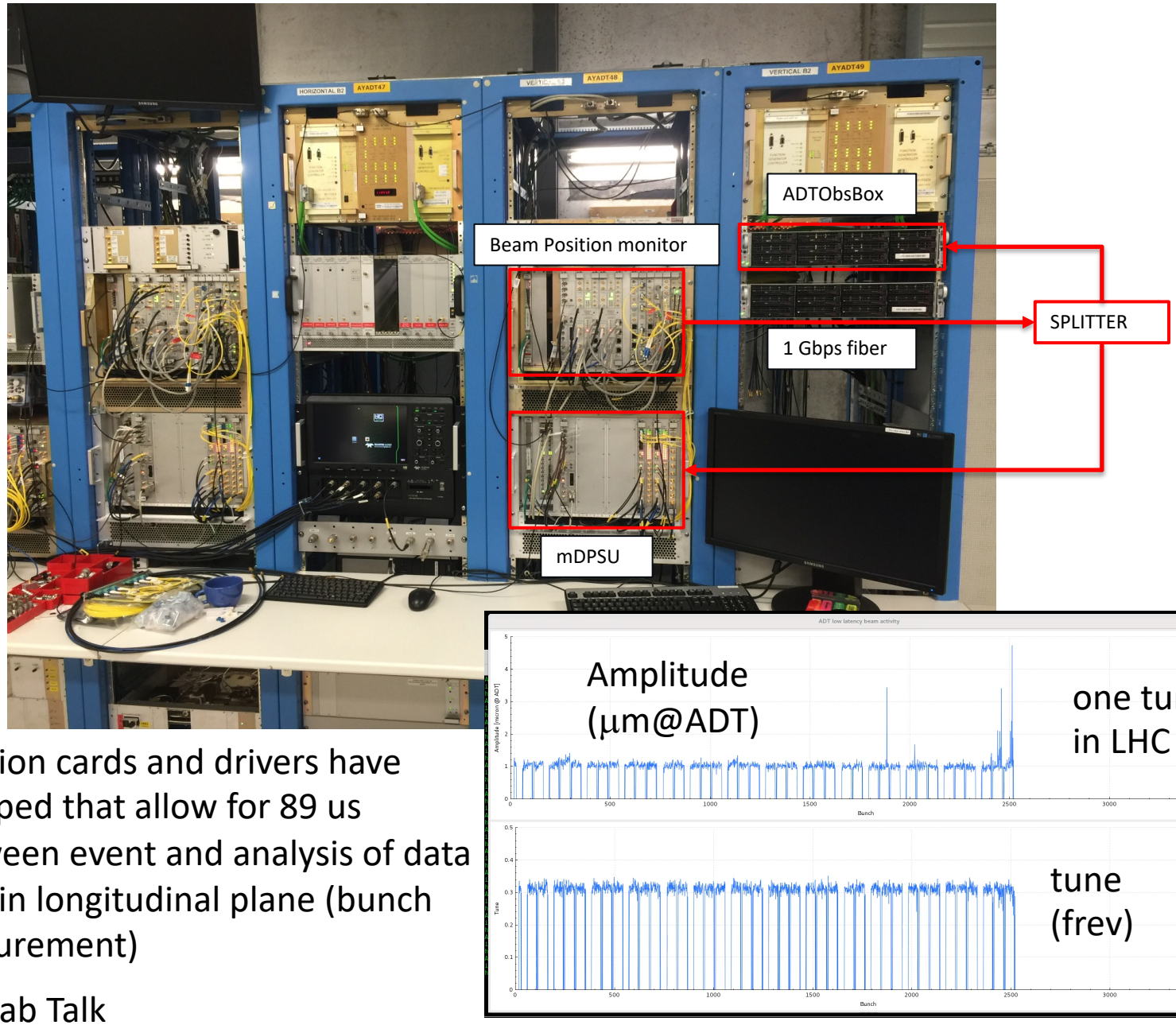



https://indico.cern.ch/event/775147/contributions/3366442/attachments/1915266/3166199/MCBI2019_ADTObsBox_to_catch_instabilities.pdf



M. Söderen, D. Valuch

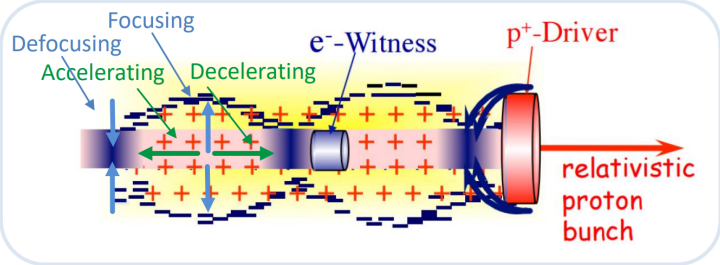
# LHC Transverse damper LLRF (VME) and ObsBox




- new acquisition cards and drivers have been developed that allow for 89 us latency between event and analysis of data
- also applied in longitudinal plane (bunch length measurement)

# AWAKE: Synchronizing 3 Beams

- Proton bunch driven, plasma wake field acceleration → synchronization and RF distribution must deliver wide range of RF signals for laser, electron and proton beams
- New: Phase measurement system to evaluate quality of lock between RF and Laser

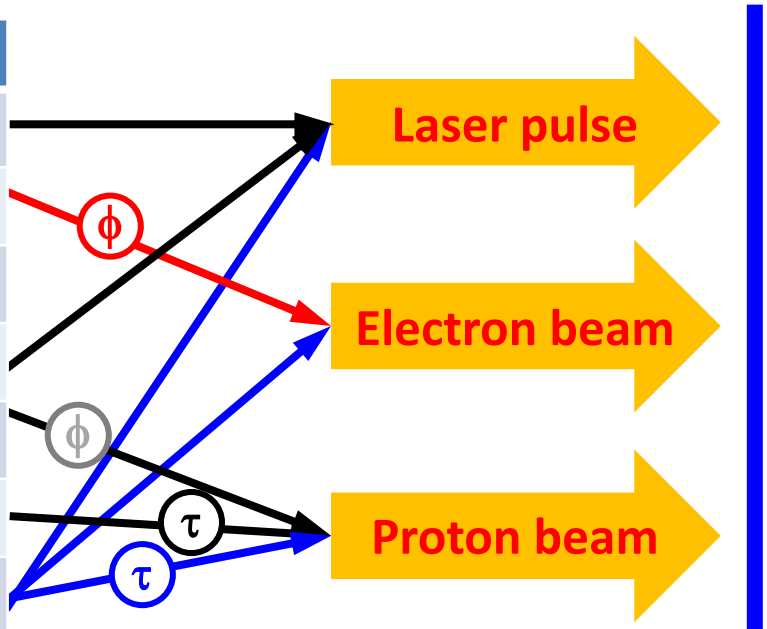



*Plasma frequency:* $\omega_{pe} = \sqrt{\frac{n_e e^2}{\varepsilon_0 m_e}}$

¼ of the period is accelerating and focusing

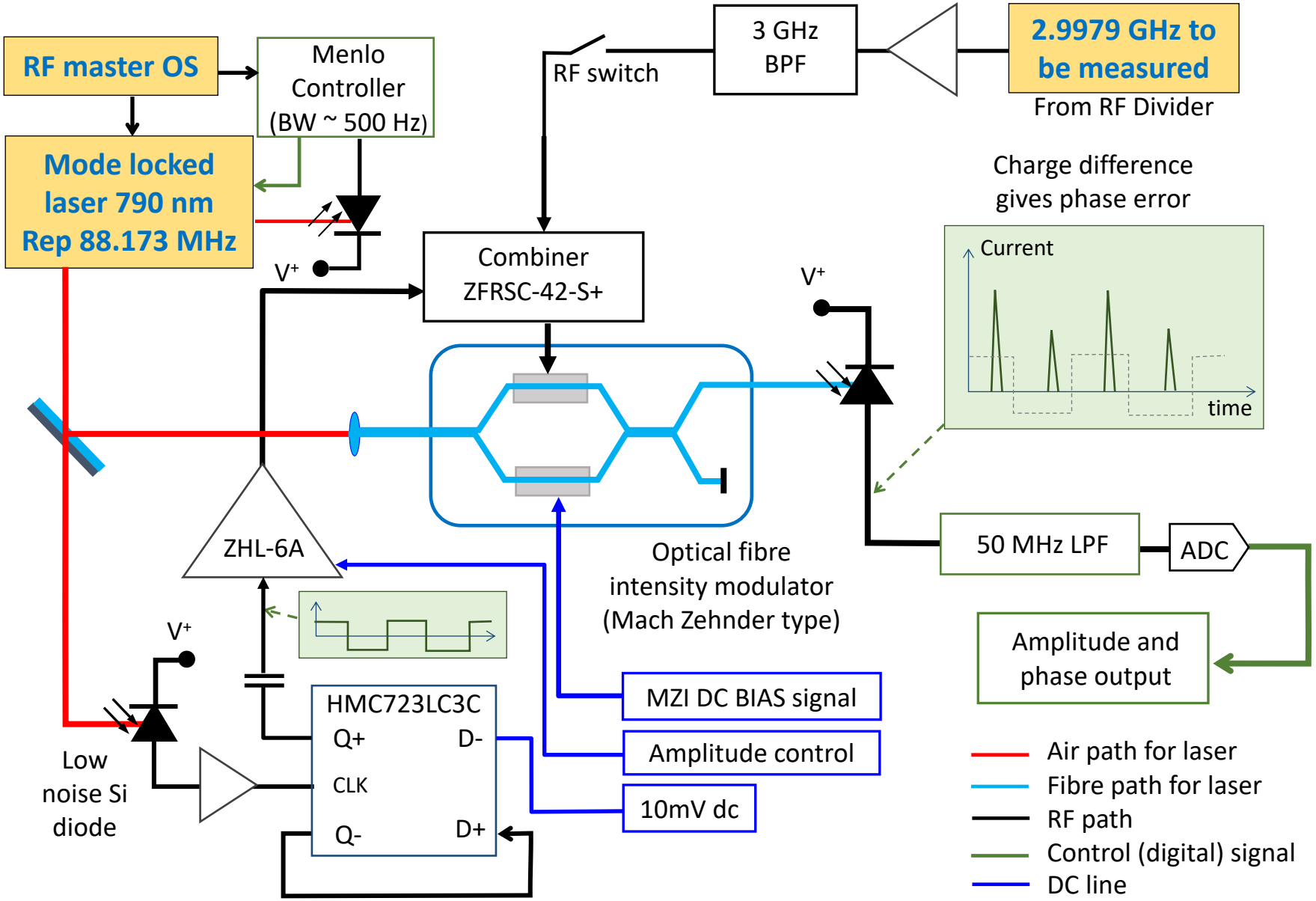
*P. Muggli*

| Signal | Frequency | Ratio |
|---|---|---|
| Laser phase locked loop, $f_{LPLL}$ | 5.9958 GHz | 1 |
| Electron acceleration, $f_{RF,e}$ | 2.9979 GHz | $f_{LPLL}/2$ |
| 2×Laser mode-locker, $2f_{ML}$ | 176.347 MHz | $f_{RF,e}/17$ |
| Laser mode-locker, $f_{ML}$ | 88.1735 MHz | $f_{RF,e}/34$ |
| 2×SPS RF system freq., $2f_{RF,SPS}$ | 400.8 MHz | $2f_{ML}\times25/11$ |
| Common frequency, $f_c$ | 8.68 kHz | $f_{ML}/10164$ |
| Pulse repetition rate, $f_{rep}$ | 9.97 Hz | $f_c/870$ |



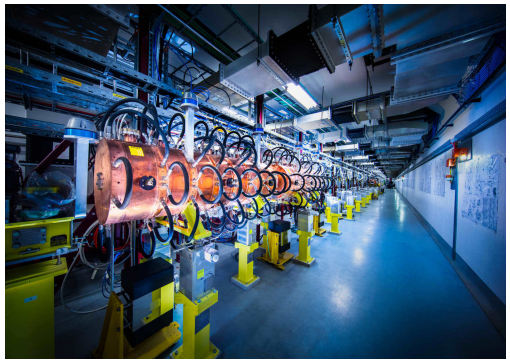

**Simultaneous arrival of beams in AWAKE**

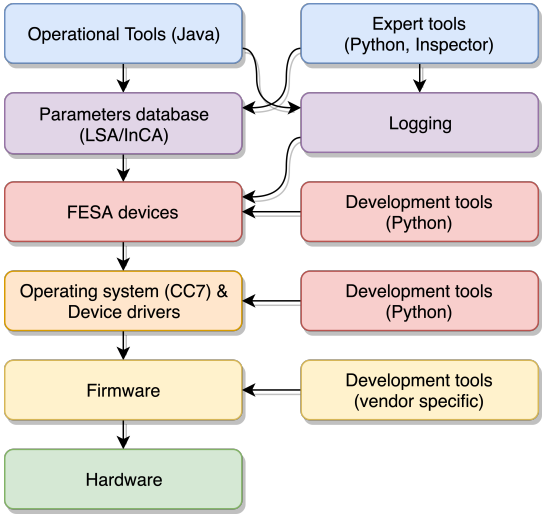
# Awake Phase Measurement Scheme Aug 2019

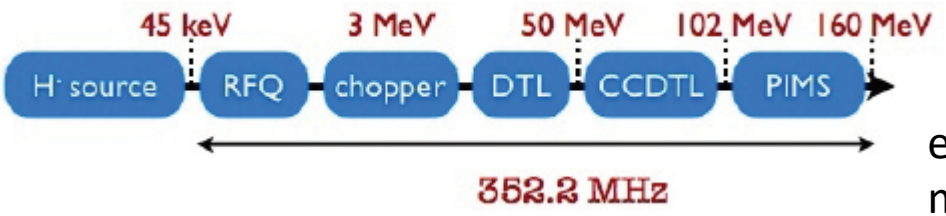



Talk: Ben Woolley

# LINAC4 evolution: connection to PSB 2020

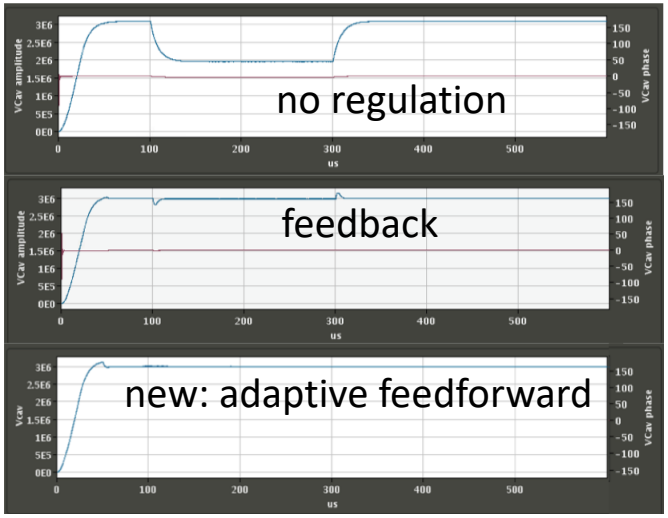


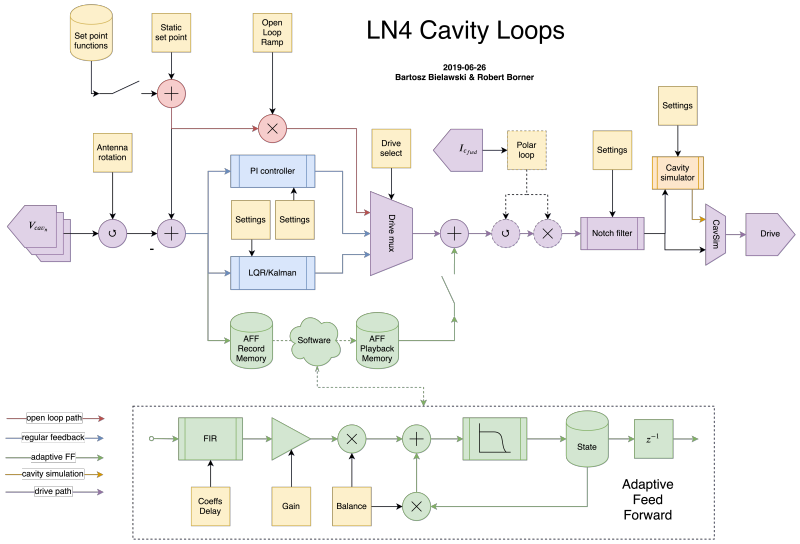



extensive test runs, transfer line test 2019
move to put more functionality in software

cavity voltage

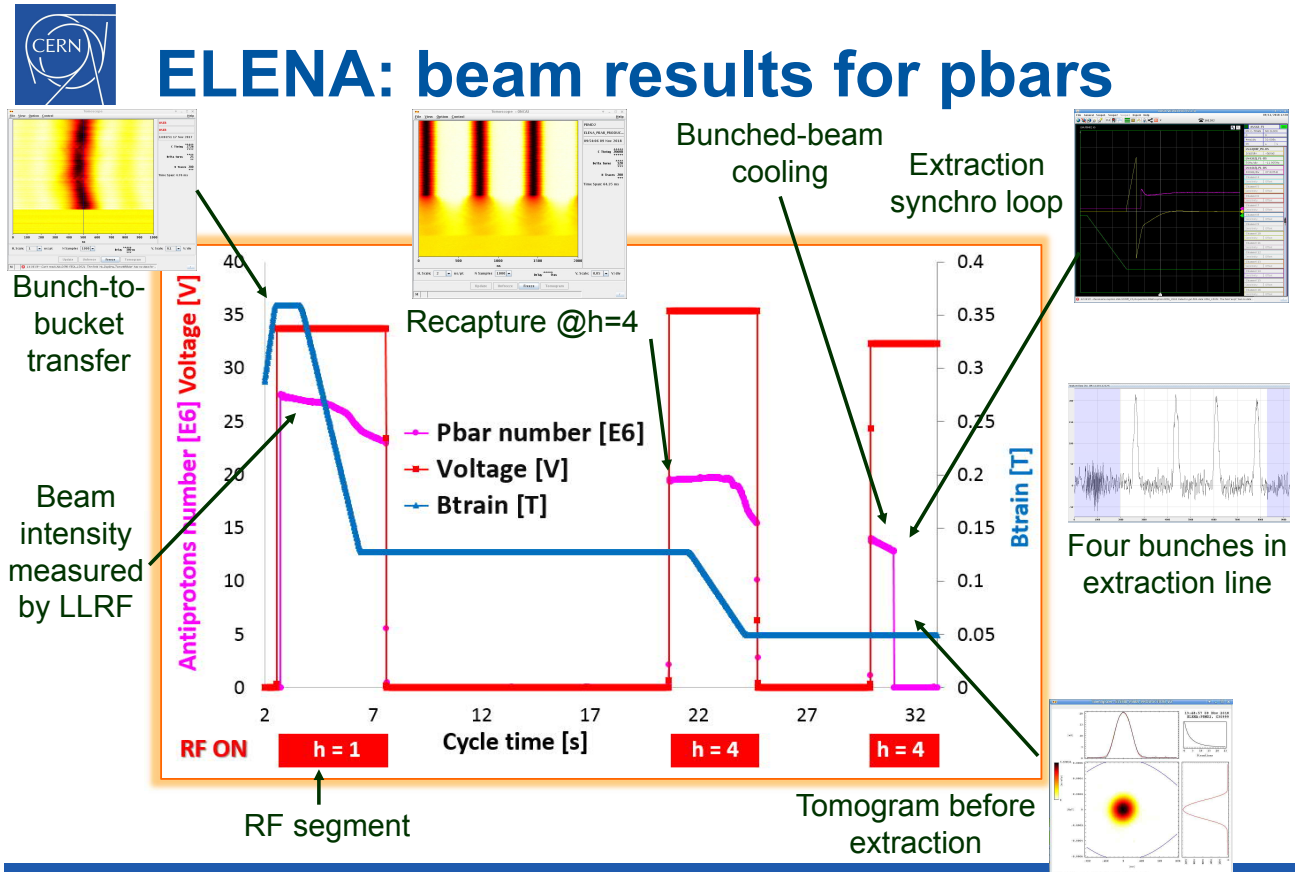



Poster: B. Bielawski

# LEIR, PSB, AD, ELENA

- Example beam results for ELENA (pbar), deceleration from 100 MeV/c to 13.7 MeV/c and delivery of anti-protons to Gbar experiment in 2018
- PSB: restart in 2020 with new finemet RF system and digital LLRF RF system on all four rings

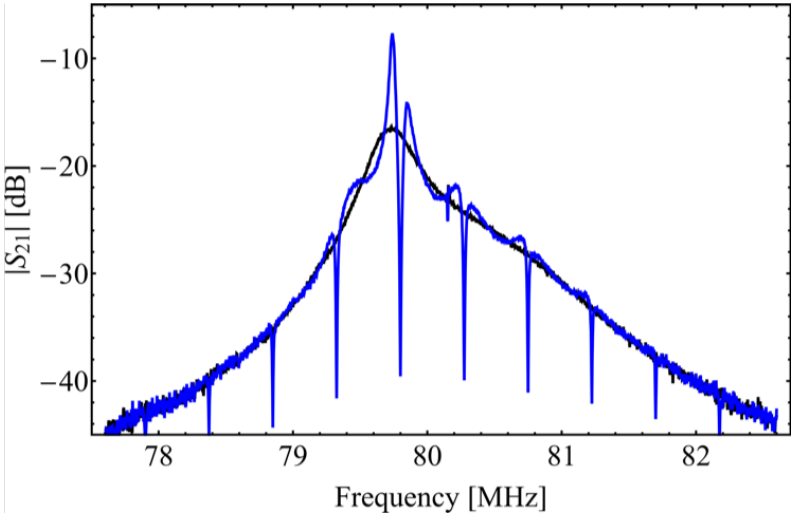


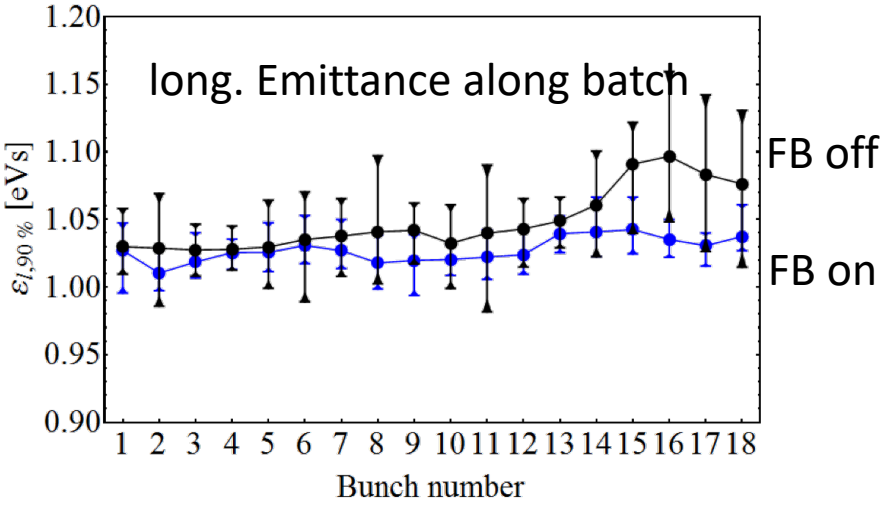



Talk: M.E. Angoletta

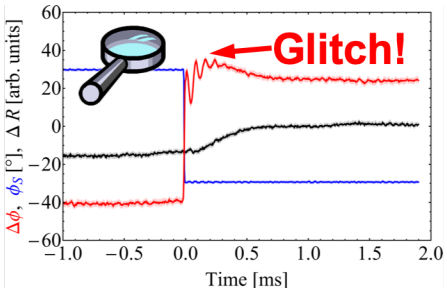
# PS Multi harmonic feedbacks and beam control

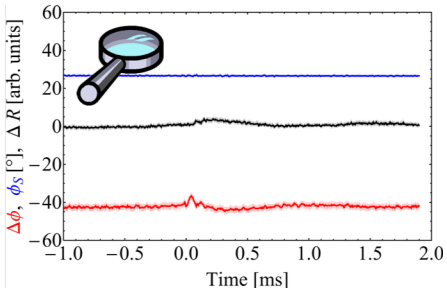
- multi-harmonic feedback in PS in operation for 80 MHz system
  - independent control of feedback at 11 revolution harmonics




- Transition crossing improved by new beam control scheme
  - glitch-free




Posters: H. Damerau

# SPS LLRF Upgrade (1)

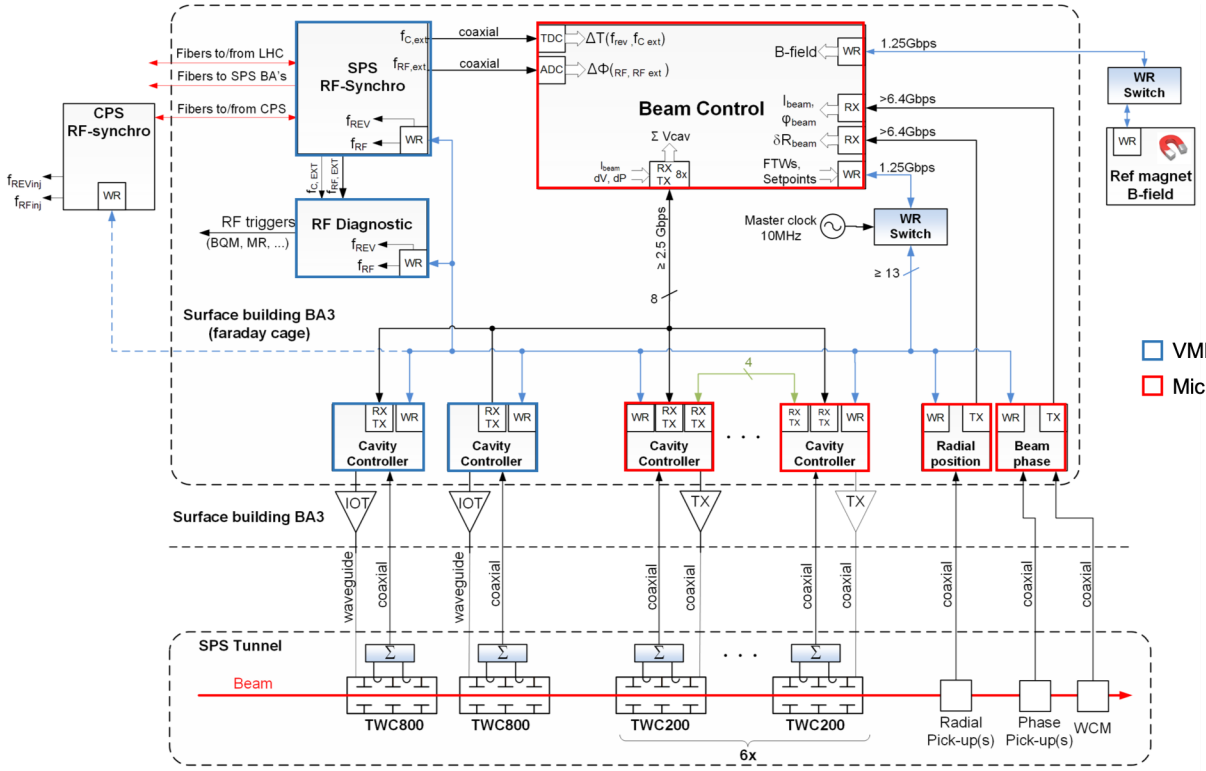
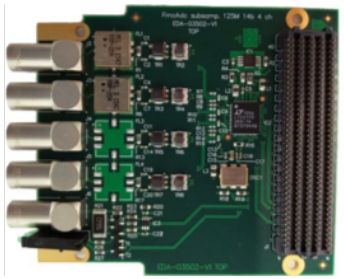
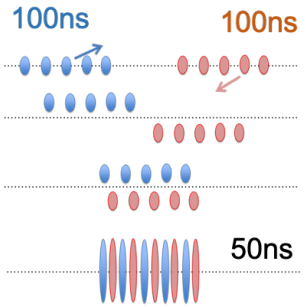



*Figure 4 – SPS LLRF architecture*

AFCZ (Creotech)
OHWR, employs Zync



FMC ADC subsamp 125M
14b 4 cha (CERN - OHWR)




Courtesy T. Argyropoulos

*Figure 1 – Ions Slip-stacking*

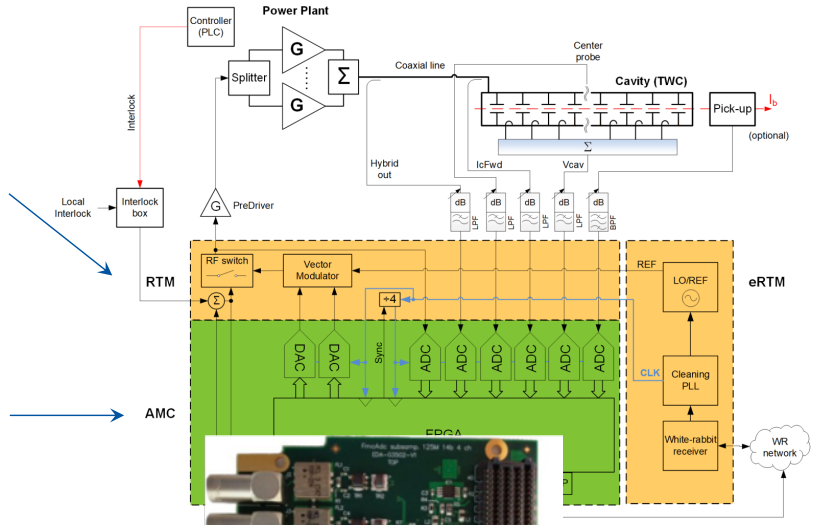
- Beam control and cavity controller for new SPS 200 MHz RF system
  - mix of new µTCA hardware and VME hardware
  - big challenge: slip stacking for ions at intermediate energy plateau to half the bunch spacing
  - white rabbit protocol for to digitally link modules (frequency, phase)

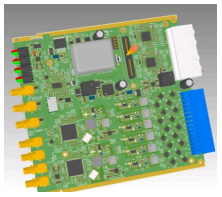
Poster: A. Spierer

# SPS LLRF Upgrade (2)

DRTM_DS8VM1
(DESY, Struck Innov. Sys GmbH)

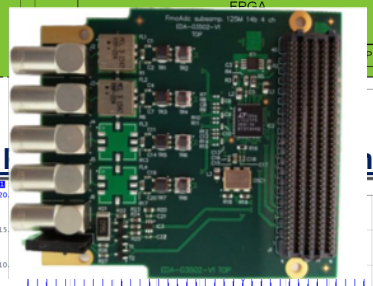
SIS8300-KU
(DESY, Struck Innov. Sys GmbH)



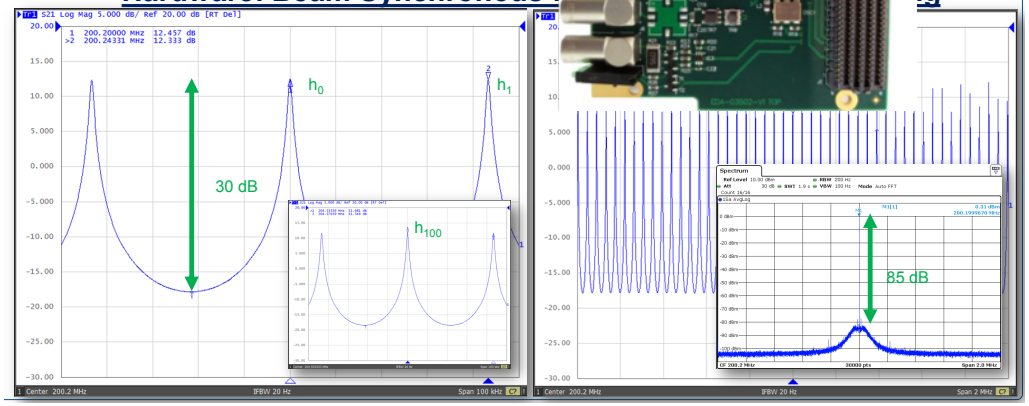



+

**eRTM**: eRTM14+eRTM15
(CERN, OHWR, BE-CO-HT)



**Hardware: Beam Synchronous l… ng**

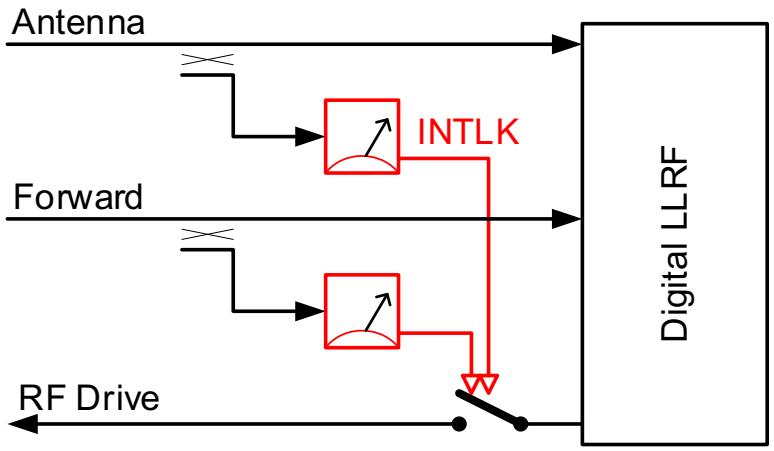


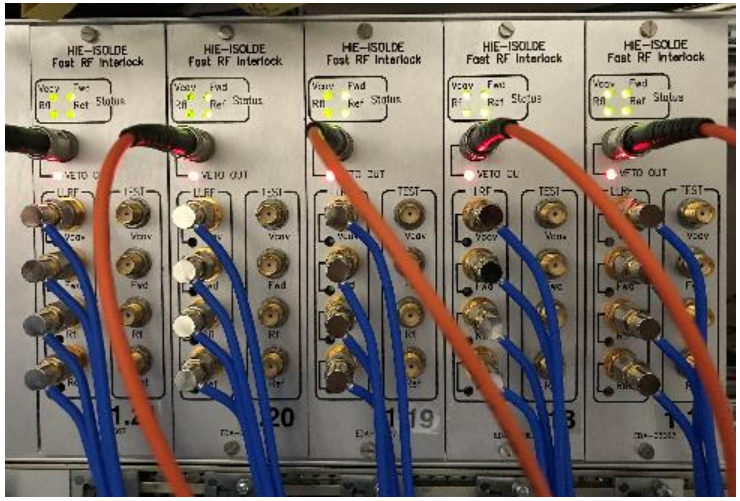

- SPS cavity controller (µTCA)
  - integrates 1-turn-feedback and voltage control (six 200 MHz travelling wave cavities after LS2)
  - fixed frequency clocking; SPS development also to be used for PS 200 MHz system

Posters: J. Egli, J. Galindo (student talk)

# Power interlocking and LLRF

- limiting and interlocking functionality required to protect RF power system
  - loops must be opened somewhere, when something goes wrong
  - intersection of responsibilities of power/cavities team and LLRF
- for HIE-Isolde and the new LINAC3 RF, functionality being closely examined and different layers of protection are being implemented
  - analogue limiters versus capabilities of a digital system




Talk: D. Valuch

# Summary and outlook

- LHC VME LLRF systems in operation for > 10 years, performing well; technology deployed also in injectors and LINACs; obsbox system addresses limits of data recording
- Paradigm change with developments both for SPS and PSB LLRF family with fixed frequency sampling
- μTCA selected as standard for SPS 200 MHz LLRF and feedback upgrade with “white rabbit” as synchronization link
- Experience increased with AWAKE in the precision synchronization with electron and laser beams