Status of the Control System for the Energy Recovery Linac bERLinPro at Helmholtz-Zentrum Berlin

Thomas Birke on behalf of controls group, project team and HZB staff

ERL 2019 – September 16-20, Berlin, HZB

Contents

- ~~Introduction to bERLinPro~~

- **Device Integration**
  - Standard Components
  - Personal Safety System
  - Machine Protection System
  - Low Level RF
  - Beam Diagnostics
  - Photoinjector Laser and Laser Beam Transfer Line

- **Operation Applications**

- **Summary**

Device Integration

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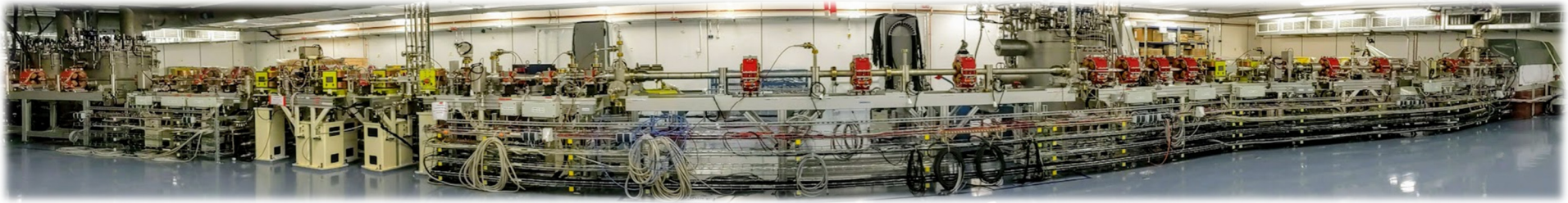
Components to integrate:

- Vacuum pumps, gauges, valves
- Power supplies driving magnets
- Cryo system
- RF transmitters & Low Level RF
- Timing system
- Beam-diagnostics
- Personal safety system
- Machine protection system
- Photocathode Laser and Laser Beam Transfer Line
- Motors, Temperatures, …



Departments and Workgroups involved regarding Controls

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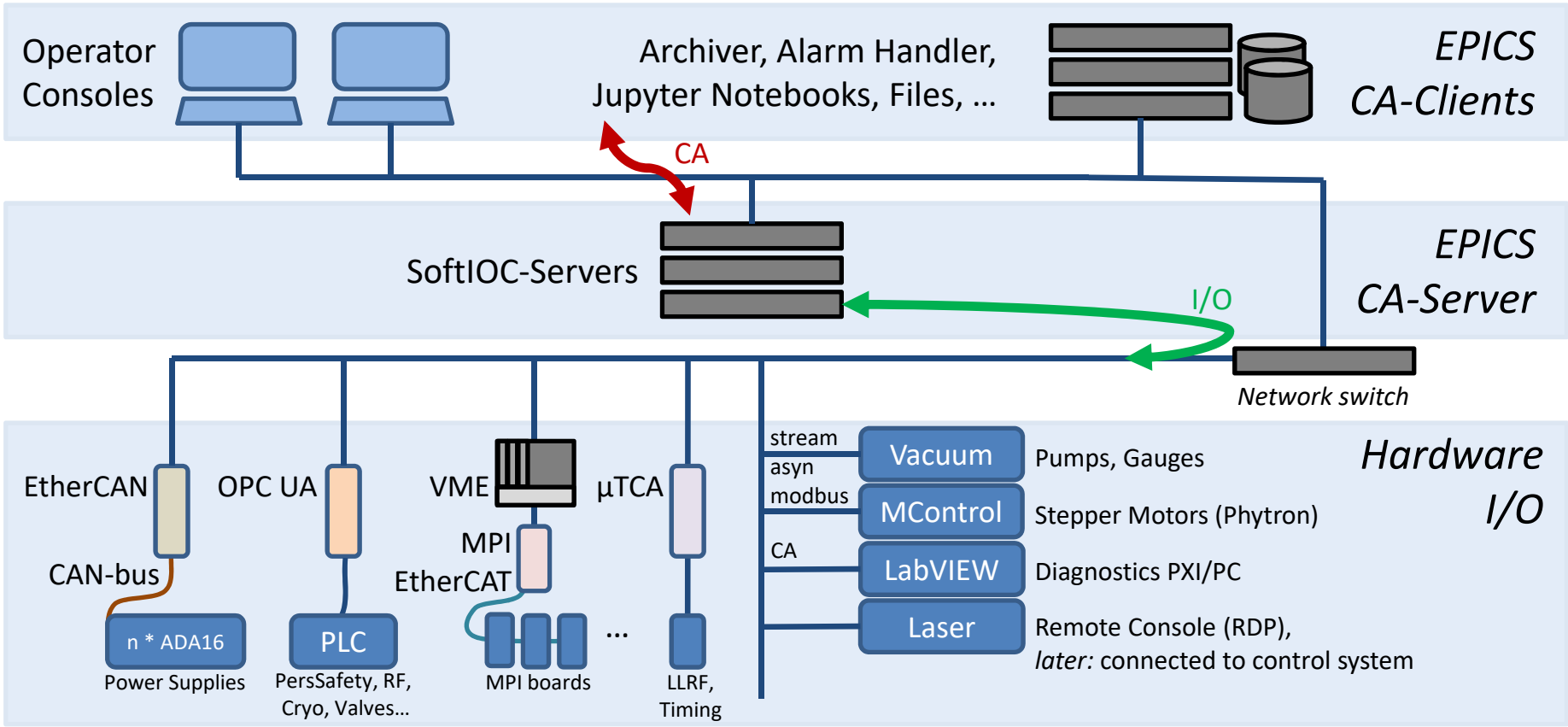
NP-ABS = User Platform / Department Accelerator Operation
FG-ISRF = Institute for Superconducting RF Science & Technology

- **NP-ABS/DIAG – Diagnostics**
  - Beam diagnostics
- **NP-ABS/ELIS – Electronic, Interlock Systems & Timing**
  - Personal Safety + Timing
- **FG-ISRF/SCRF**
  - RF + Cryo
- **3rd Party**
  - Low Level RF (DESY, FG-ISRF/SCRF Accelerating Structures)
  - Photocathode Laser (MBI – Max Born Institute, NP-ABS/LCT)
- **NP-ABS/ACS Accelerator Control Systems**
  - Core Control System (Vacuum, Power Supplies, Motors, misc. I/O, …)
  - Infrastructure (SW & HW), Services, Applications
  - Integration of all of the above

Simplified Structure of the bERLinPro Control System



Device Integration: Vacuum, Power Supplies

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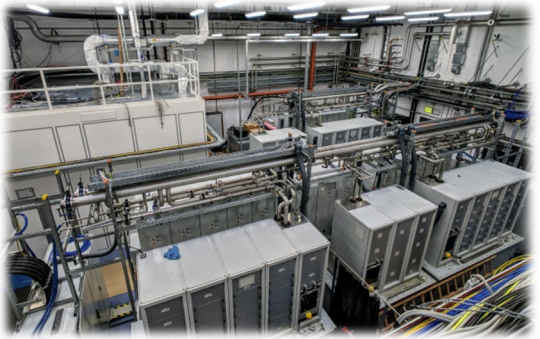
- **Vacuum**
  - **Ion getter pumps, gauges**
    - Network serial I/O, Modbus
    - Cosylab microIOC – LOCO
  - **Valve control and vacuum interlock**
    - PLC / OPC UA
  - **CS-installation follows hardware-installation**

- **Power Supplies driving Magnets**
  - **digital & analog I/O via CAN-bus and ADA16**
    VME CAN cardsreplaced by EtherCAN
  - Some components re-used, installation started

Device Integration: RF- & Cryo-System

- **RF Transmitters**
- **Cryo-System**

RF transmitter hall & laser hutch



PLC based using OPC UA

Local controls console available

- OPC-Server and SoftIOC on Windows-PC communicating with PLC or
- OPC UA directly to PLC or via uaGate – networked I/O using Linux SoftIOC
- RF transmitters
    - Hardware installation complete
    - Control system interfaces ready
- Cryo-System will follow

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Personal Safety System

Personal safety radiation protection gate

PLC based using OPC UA

- OPC UA directly to PLC (UA gateway integrated in PLC)
- Linux SoftIOC reflects status as EPICS PVs in control system
- Components and setup compliant to all relevant EN ISO standards of the EU
- Hardware installation 100% complete (sensors, search buttons, door-switches, permits, …)
- Tests and commissioning in progress (70% complete)
- Dosimetry 100% complete
- Laser interlock setup in progress (hutch doors, laser shutter, … 40% complete)
- **Next:** Booster RF transmitters, air condition

Device Integration: Personal Safety System - Hardware

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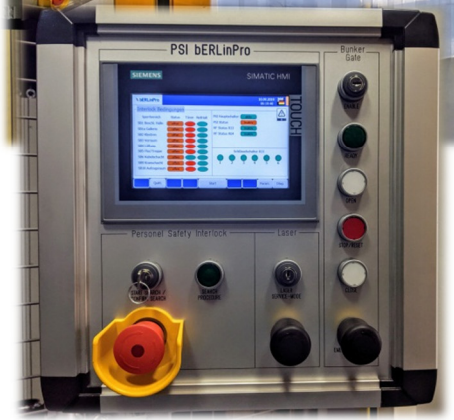
Radiation Protection Bunker Gate

- Opening: 3.1m x 3m
- Gate: 4.1m x 3.5m x 1.32m
- 77.3t of concrete and steel!



Main control panel

- Master PLC
- 4 I/O Blocks
- ~250 I/O Points
- Profibus

Up to 15 Dosimetry stations

Device Integration: Timing System

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Timing System

Requirements

- Distribute 3 ultra low jitter phase coherent reference signals
- Compensate long term phase drift through temperature monitoring
- Provide precise triggers to subsystems
- High scalability of trigger generation
- LLRF requirement in terms of phase noise and jitter: 0.1 deg ~ 200 fs

Solution

- Customized MO developed by AXTAL GmbH
- Internal ultra-low phase noise reference OCXO
- External 10MHz reference input not affecting internal phase noise
- Monitoring of OCXO temperature and PLL locking status

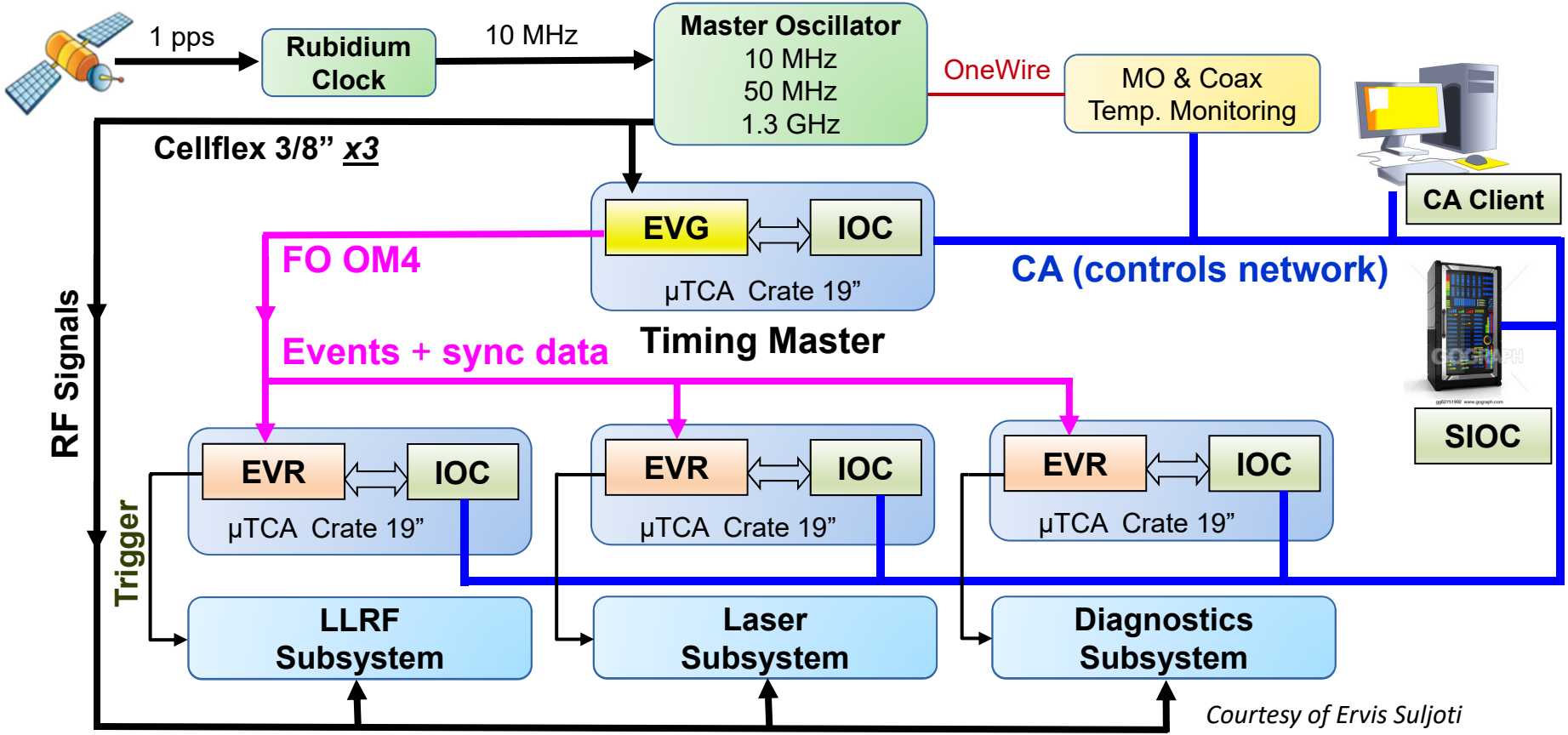
Reference Signal	Short RMS Phase Jitter	Max RMS Phase Jitter	Power	#Outputs	Description
10 MHz	60 fs	70 fs	13 dBm	4	Diagnostics RF, misc.
50 Mhz	60 fs	70 fs	13 dBm	4	Laser RF ref.
1.3 GHz	50 fs	60 fs	13 dBm	4	Cavity RF ref.

Trigger Distribution

- Built on µTCA and Micro Research Finland (MRF) Event Master & Receiver
- Active delay compensation
- Conditional sequencing events
- Time stamping capabilities
- Different trigger voltages through modular interface
- EPICS device support

Courtesy of Ervis Suljoti

Device Integration: Timing System - Schematic



Courtesy of Ervis Suljoti

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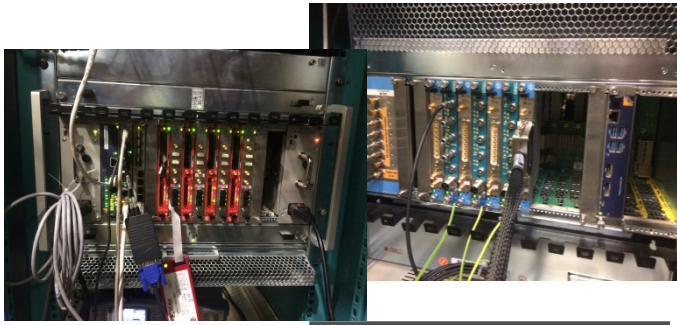
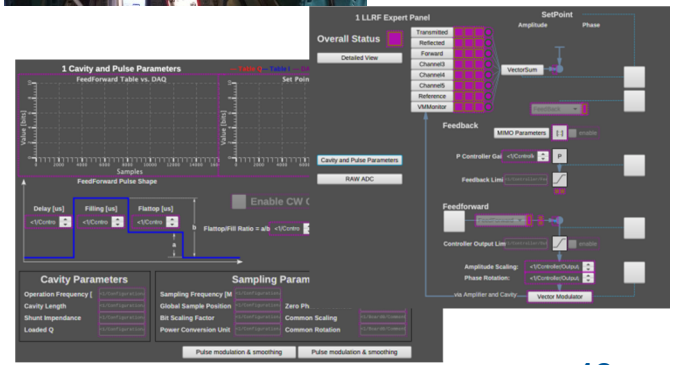
- **Low Level RF (LLRF)**

Same technology used at XFEL (DESY), ELBE (HZDR) and MESA (JGU)

- Tight cooperation with colleagues from DESY
- MicroTCA system performing LLRF
- builtin EPICS-IOC/-CA-Server
- Operator displays (CSS – control system studio)



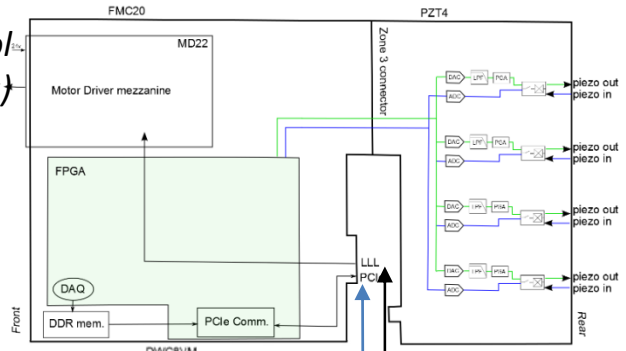


All EPICS DBs and logic unchanged but aliases have been added and operator displays modified to map DESY-PV-names to PV-names that conform to the BESSY/HZB device naming convention.

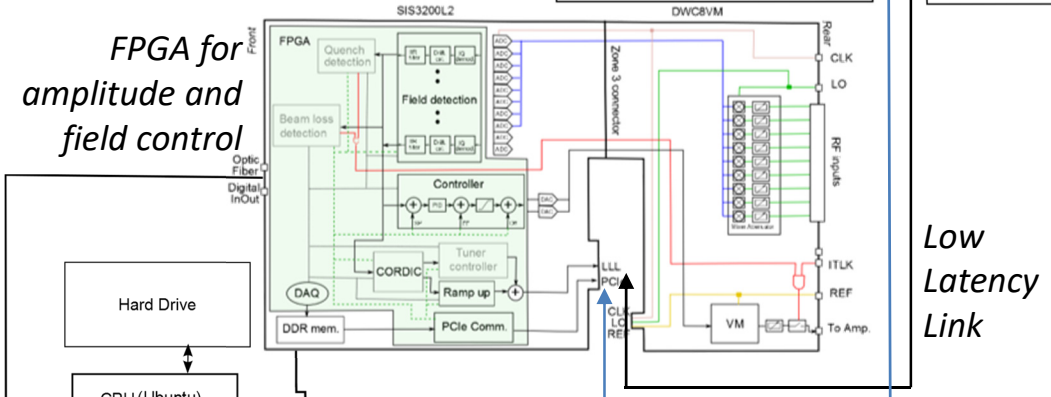
Device Integration: Low Level RF - Overview

- **Low Level RF (LLRF)**
  - 1 RF amplifier per cavity
    → no Vector Sum needed
  - 6 SRF cavities (GUN, 3xbooster, 2xLINAC) + 1 NC cavity
    (Transverse deflecting cavity in diagnostics line)
  - ~600ns of latency

FPGA for tuner control (motor and piezos)



FPGA for amplitude and field control



CPU for slow control algorithms and comms (LLRF server + ChimeraTK adapter → EPICS)

Low Latency Link

PCIe

Courtesy of Pablo Echevarria

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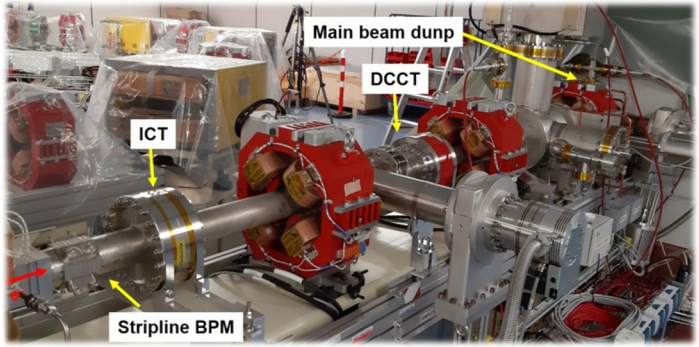
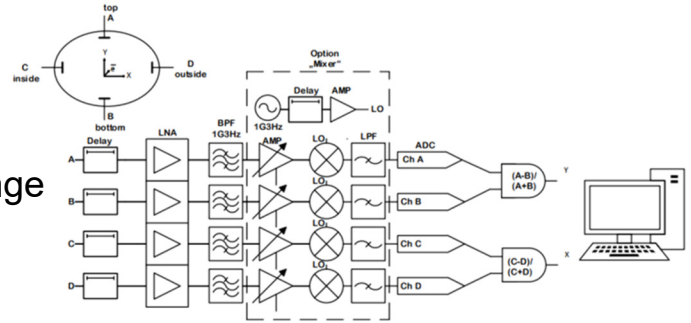
Beam-Diagnostics

- **LabVIEW** on PC or PXI SoftIOC using CA Lab* or **RDP** and **vncviewer** for imaging systems
- **Slow diagnostics** / destructive / I < 50µA
  - 18 Screen monitors / cameras
  - 1 Synchrotron radiation-halo, 1 -profile and 1 THz monitor
- **Fast diagnostics** – only non-destructive
  - 2 faraday cups, 2 beam dumps + main dump
  - 2 DCCT + 4 ICT
  - 24 Stripline BPMs w. analog processing for high dynamic range
    - Exact scheme of CS-integration not yet decided

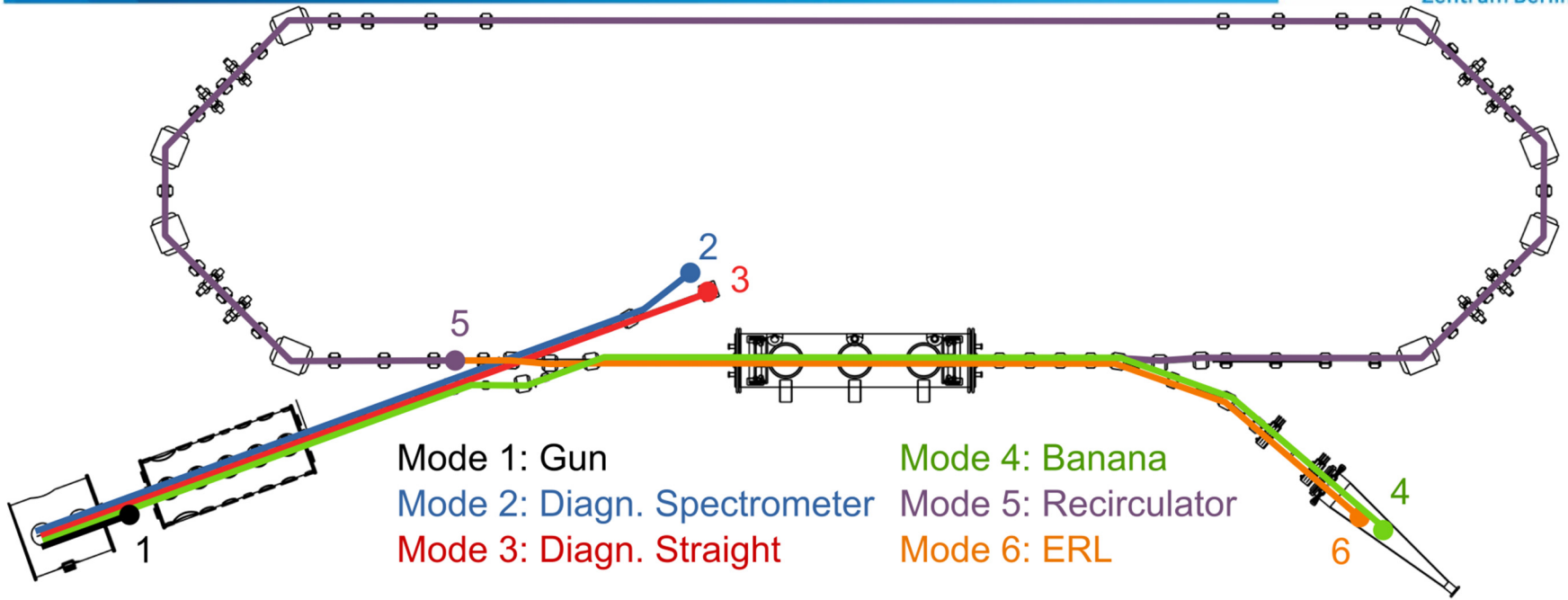




*To start up, a **"cost effective minimum" of diagnostic equipment** should be defined – as much as necessary, as little as possible (MAC5).*

Courtesy of Ji-Gwang Hwang

Excursion – Machine Operation Modes



#	Name	Dump	Pwr limit	E_{kin}	Current limit
1	Gun	Faraday cup	~300 W	2.7 MeV	~100 µA
2	Diagn. Spectr.	Faraday cup	~300 W	6.5 MeV	~45 µA
3	Diagn. Straight	LELP dump	35 kW	6.5 MeV	5 mA

#	Name	Dump	Pwr limit	E_{kin}	Current limit
4	Banana	LEHP dump	650 kW	6.5 MeV	100 mA
5	Recirculator	HELP absorber	50 W	50 MeV	1 µA
6	ERL	LEHP dump	650 kW	6.5 MeV	100 mA

Courtesy of Meghan McAteer

Device Integration: Machine Protection System – Logic

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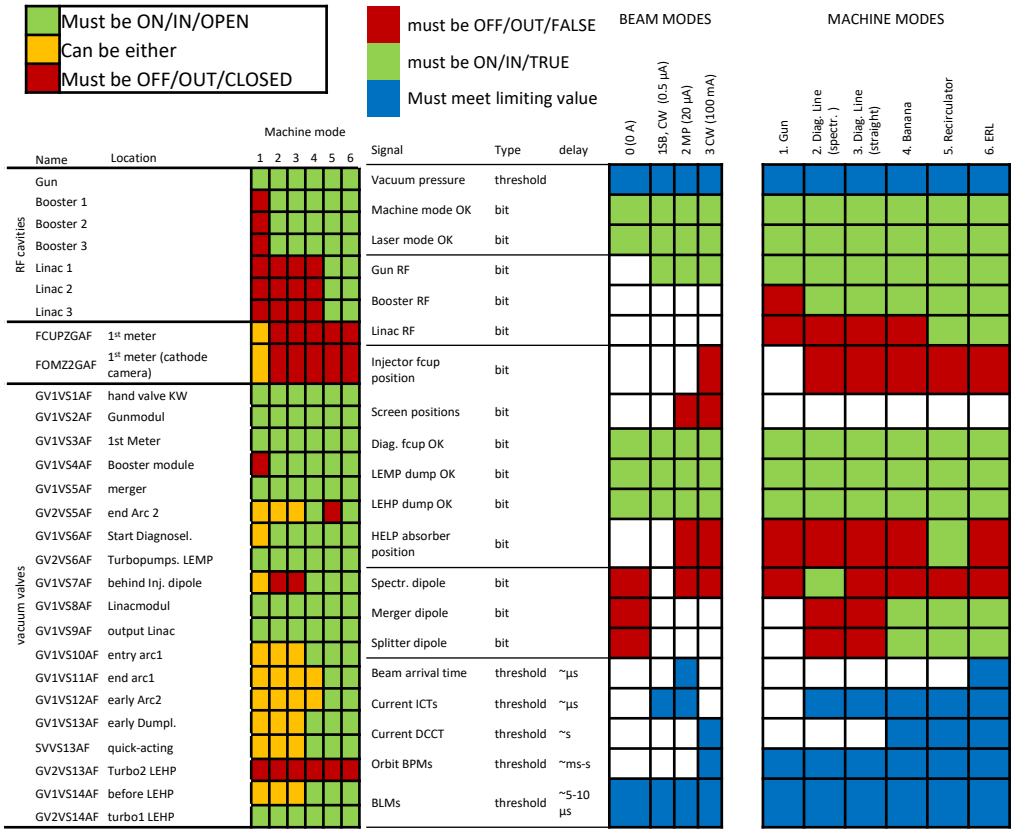
Machine Protection System

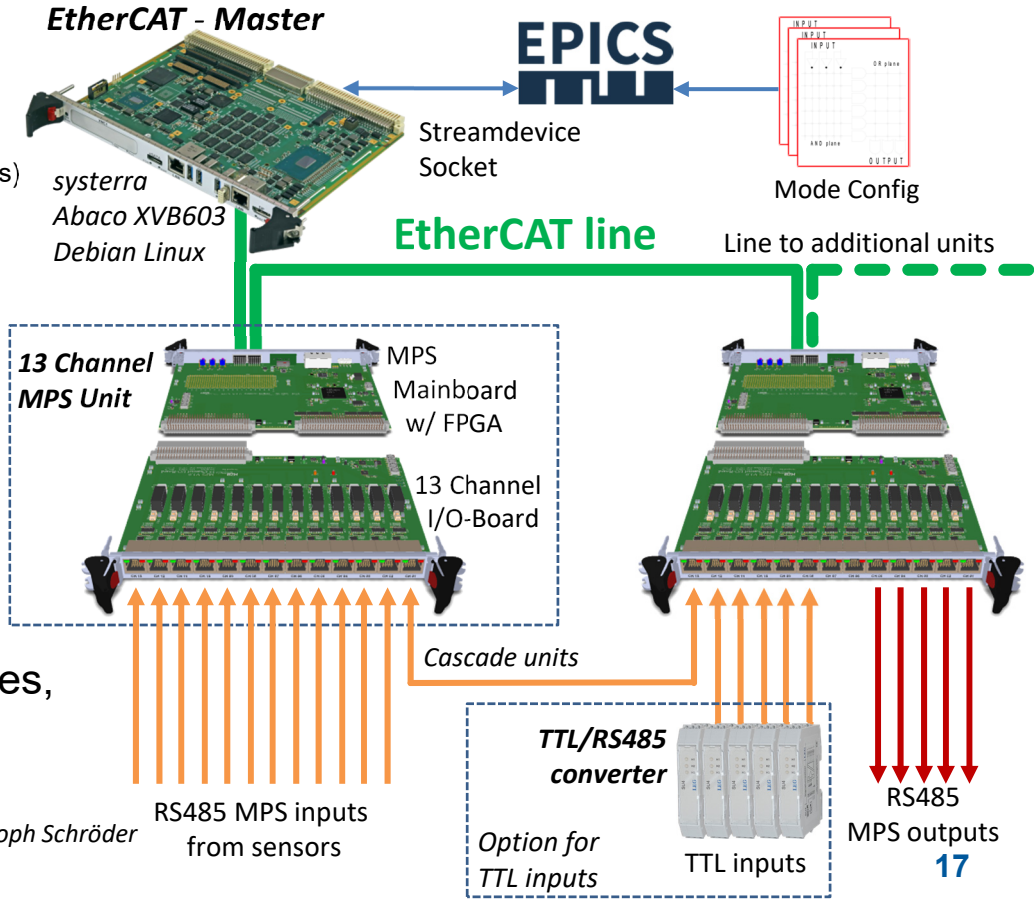
- Permit operation in any of the machine operation modes
- Guarantee well defined status of all components or block laser/gun
- Realized with EtherCAT, FPGA and RS485 I/O, scalable
- Inputs, Outputs and Logic defined in config and distributed to FPGA



Courtesy of Meghan McAteer

Device Integration: Machine Protection System - Features

- Synchronization of units via **EtherCAT**
- 13 configurable I/O-Ports per unit
- Up to 21 units per VME-Crate (max. 2^{16}-1 units)
- **Cable break detection** on **RS485** lines
- Allows for post mortem analysis
- Mode switch by software, distributed, **synchr. switch within 200ns** all units
- Reaction time on MPS unit:
  typ. ~120ns signal processing
  Inputs → FPGA processing → Outputs
- **Overall Reaction Time ≪ 5µs** (req.)
  incl. cable lengths (up to ~80m), cascades, RS485↔TTL conversions and FPGA processing



Courtesy of Christoph Schröder

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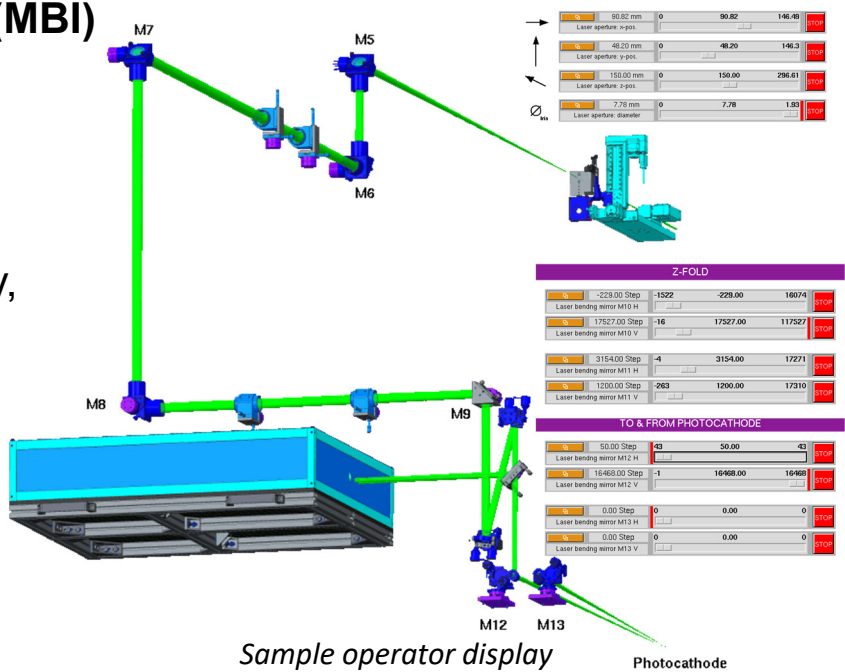
Photoinjector Laser and Laser Beam Transfer Line

- Developed and installed by **Max-Born-Institute (MBI)**
- Tight synchronicity with RF master oscillator
- 35m long laser beam transfer line
- Laser beam spot-size, -position, -position stability, pulse-duration and -energy as well as generated bunch charge at the photo-cathode and its according diagnostics are controlled
- Stepper- and servo motors
- CCD-cameras
- Safe state through MPS-enforced laser shutters



Sample operator display of laser installation at gun test stand.

Courtesy of Guido Klemz

Device Integration: Misc. I/O

- **Motors**
  - EPICS motor record and Phytron motor controls interfaced using Modbus are used as standard motor control interface

- **Temperatures, …**
  - Wago I/O Modules interfaced using Modbus are used as standard temperature measurement

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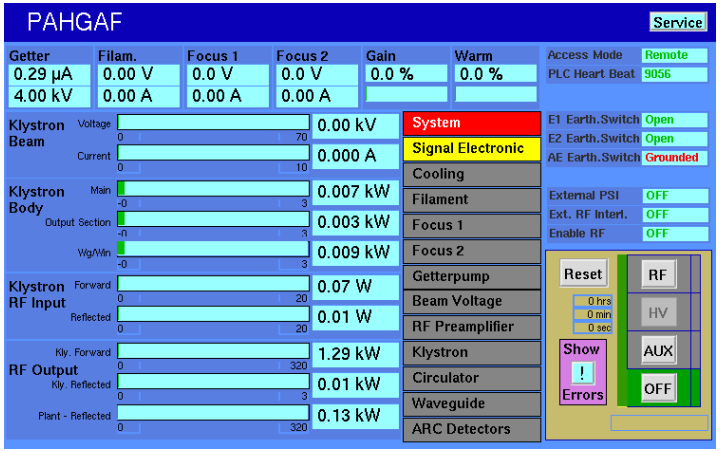
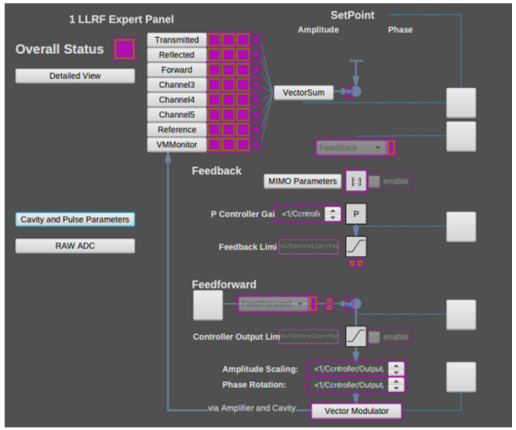
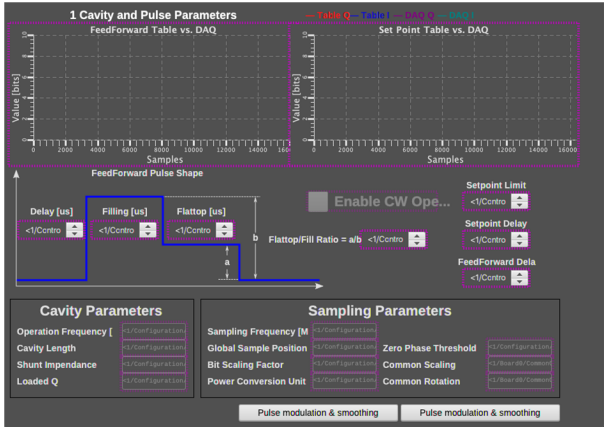
Operator Displays

- **edm** – generated displays (C++, Motif, X11, ~ year 2000)
- **CSS/phoebus*** – LLRF displays (Java, JavaFX, ~2017 according to git-repo) might be used for master control panels as well
- **PyDM** – evaluation







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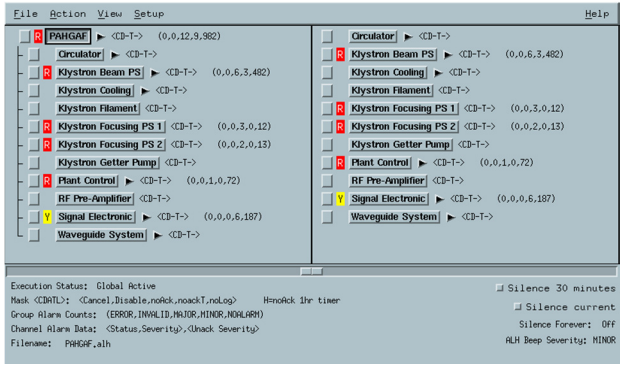
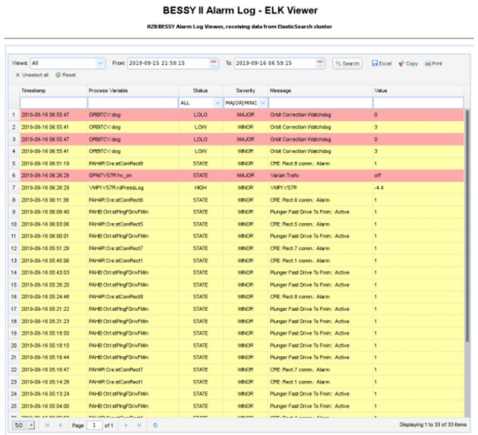
Alarm-Visualisation, -Notification and –Logging

- **alh** (C, Motif, late 1990s, still works fine!)
  - Visualisation on main console
  - Notification via message to operator DECT phone and/or email to component responsible staff
  - Logging into Elastic Stack





- Future:

  CSS/phoebus* alarm-server, -logger, -viewer…

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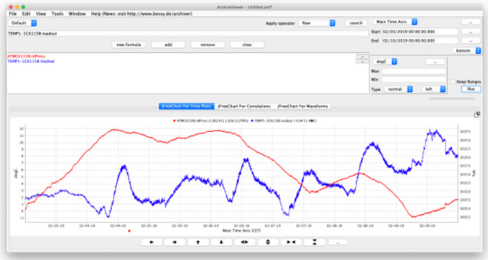
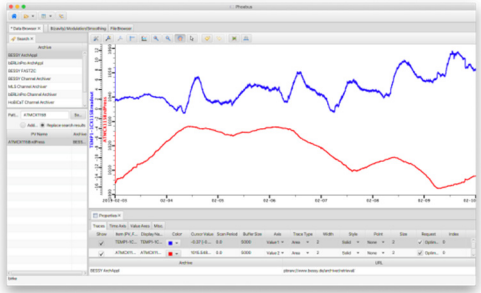
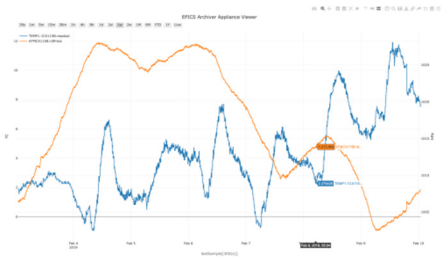
Archiving and Archived Data Retrieval

- **EPICS Archiver Appliance*** (AAPL, M. Shankar – SLAC)
- **ArchiverViewer** (adapted to AAPL, orig. ChannelArchiver)
  outphased although easiest to use (JavaWebStart)
  for unexperienced user in office or at home
  - max. Java8
  - JavaWebStart mechanism discontinued
- **CSS/phoebus*** DataBrowser
- **Web-app**? AAPL „EPICS Archiver Appliance Viewer“!
- **Python API** through jupyter notebooks and
  dedicated applications (as commissioning starts)





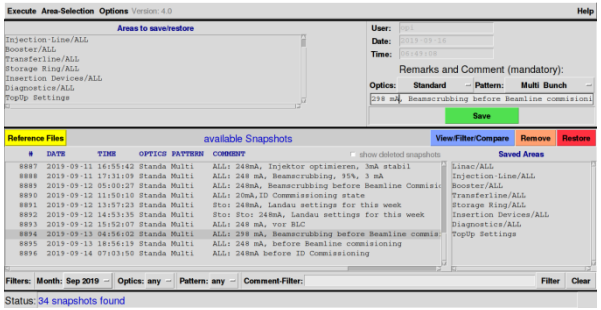


Operation Applications (contd.)

Others

- **StripTool** (C, Motif, late 1990s)

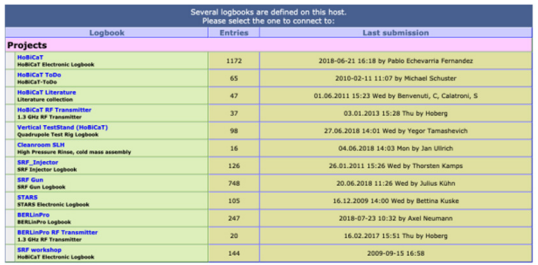
  will be replaced by CSS/phoebus* DataBrowser showing archived and live data
- **RDesktop** & **VNC** to acces 3rd party controls
  - Photo-cathode-laser – EPICS-interface in the works
  - Imaging diagnostic systems (LabVIEW on MS-Windows)



Commissioning Tools

- **Save/Restore/Compare** to handle machine setups

  (Tcl/Tk, ~1998, well accepted, working fine**)**
- **Electronic logbook** – elog* (PSI)
- Further requirements not yet specified



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Model integration / simulation / machine learning

- Simulation and modeling tools will be installed on request
  OPAL, elegant, …
- Jupyter notebooks running python kernels in Singularity* containers
  - Python3.7, jupyter notebooks, elegant, Bluesky/ophyd
  - loads of other required python modules will be added to Singularity containers
- More options with EPICS 7* - because:
  „The EPICS Software Framework Moves from Controls to Physics“*
  EPICS Core Developers Group – IPAC'19 – TUZZLPM3
  Evaluation and introduction planned

- **Special requirements for taylored applications for commissioning are not yet defined**
- **New generic applications supplied on demand**

Summary

- **Control System Infrastructure basically a copy of BESSY & MLS installation**
- **Reusing software as well as some hardware and a few new developments**
  - Novel requirements + need to reduce costs and get things done with available workforce
- **Take the chance to carefully evaluate and introduce novel tools and core software**
  - Control System Studio CSS/phoebus*, EPICS 7*, PyDM, …
- **Integration of 3rd party systems is in the works**
- **Control System installation and setup follows installation of components**
- **Further software requirements not yet defined!**
- **As commissioning approaches/starts:**
  - Integration of simulation- and machine-learning tools will continue
  - Development of dedicated/specialized software will start on demand

References

1. **bERLinPro** – https://www.helmholtz-berlin.de/projects/berlinpro/index_de.html
2. **EPICS** – https://epics-controls.org/
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8. **„The EPICS Software Framework Moves from Controls to Physics“** – IPAC'19 – https://ipac2019.vrws.de/papers/tuzzplm3.pdf

Status of the bERLinPro Control System

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Thank you very much for your attention!