

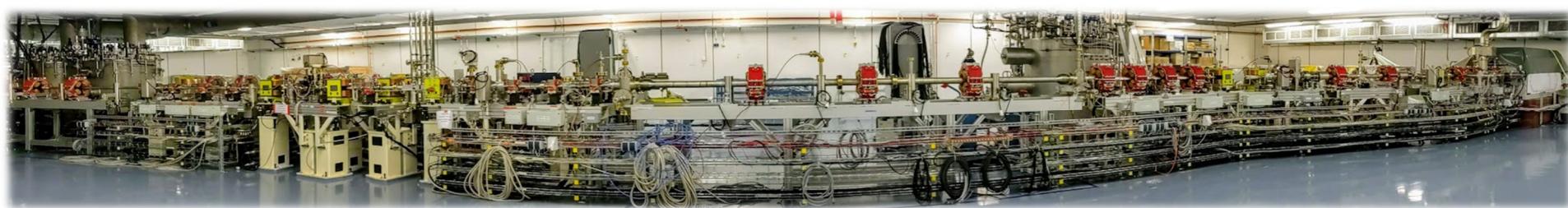
# Status of the Control System for the Energy Recovery Linac bERLinPro at Helmholtz-Zentrum Berlin

Thomas Birke on behalf of controls group, project team and HZB staff  
ERL 2019 – September 16-20, Berlin, HZB

- **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**

## 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, ...



- **NP-ABS/DIAG – Diagnostics**

- Beam diagnostics

- **NP-ABS/ELIS – Electronic, Interlock Systems & Timing**

- Personal Safety + Timing

- **FG-ISRF/SCRF**

- RF + Cryo

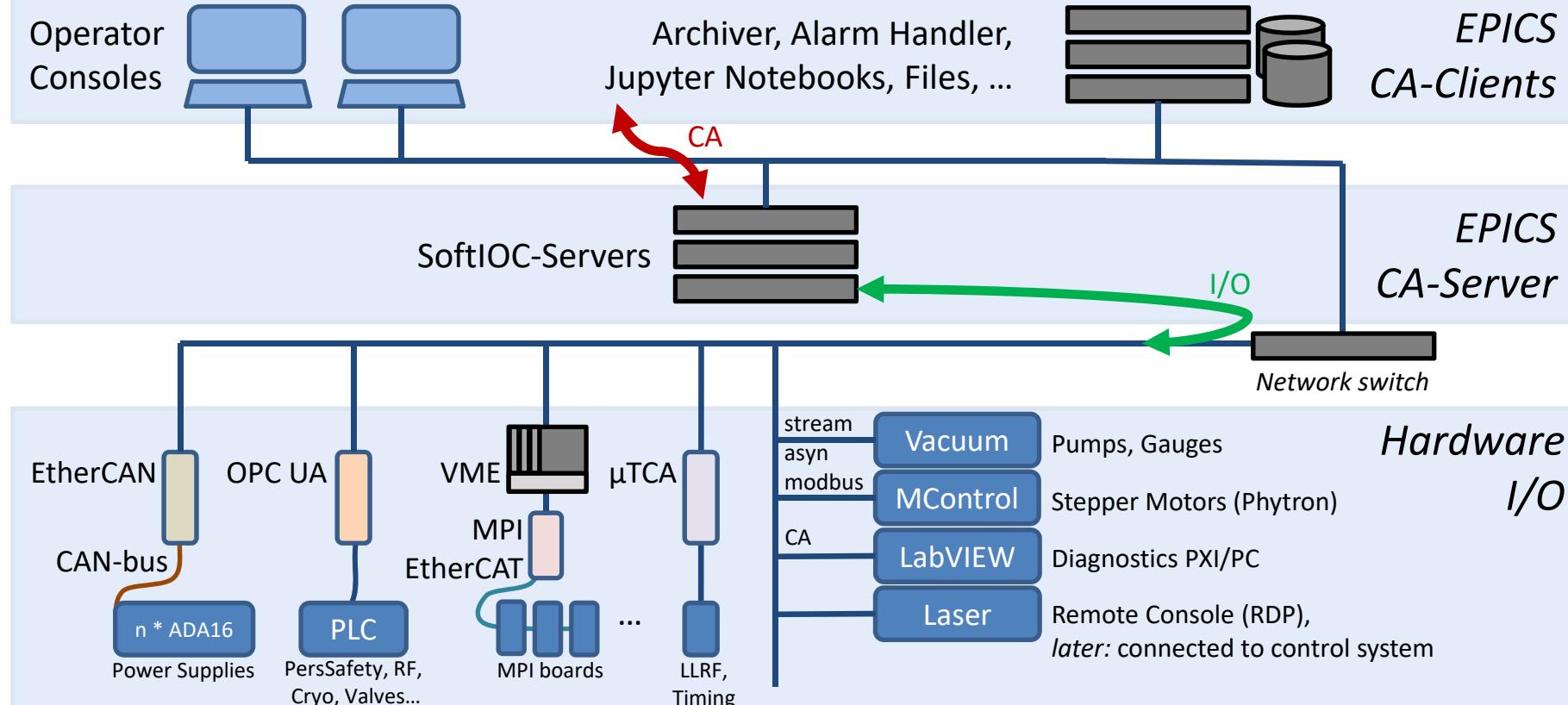
- **3rd Party**

- 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





## ■ Vacuum

- **Ion getter pumps, gauges**
  - Network serial I/O, Modbus
  - Cosylab microLOC – 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 cards replaced by EtherCAN
- Some components re-used, installation started



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

**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

*RF transmitter hall  
& laser hutch*



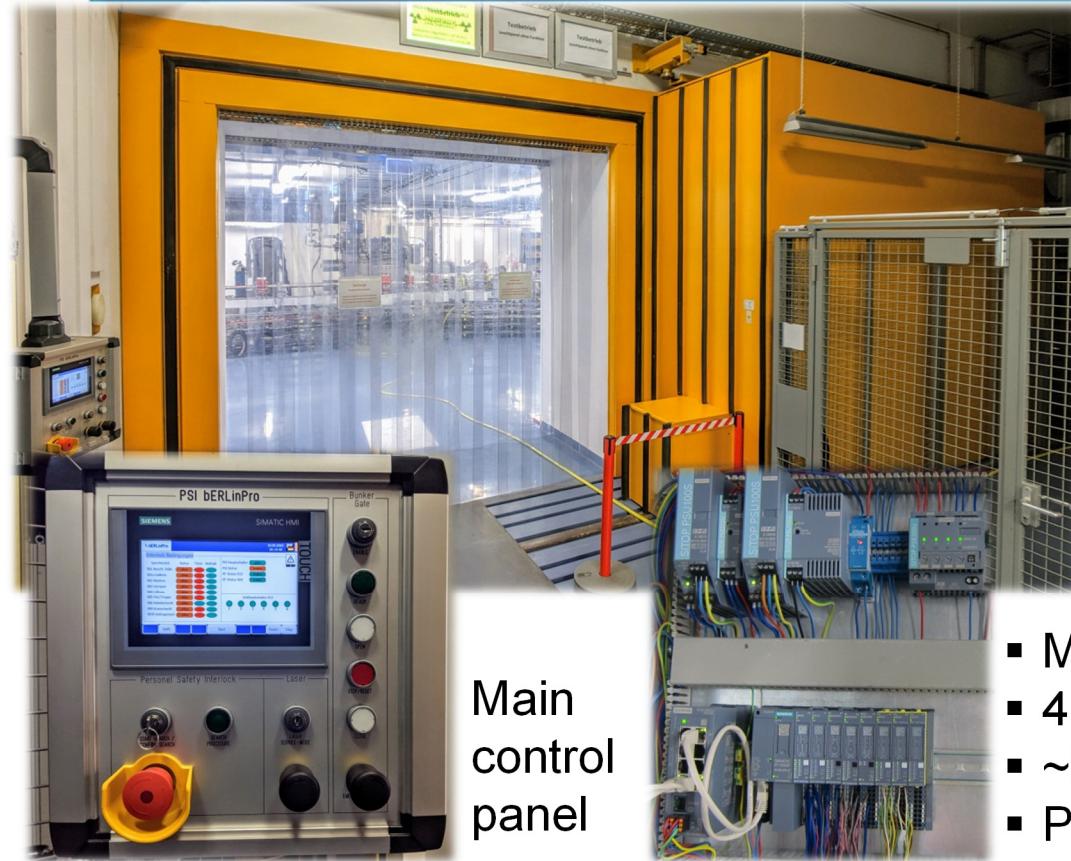
## ■ Personal Safety System

*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





## Radiation Protection Bunker Gate

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



Up to 15  
Dosimetry  
stations

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



## ■ 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

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.



### Solution

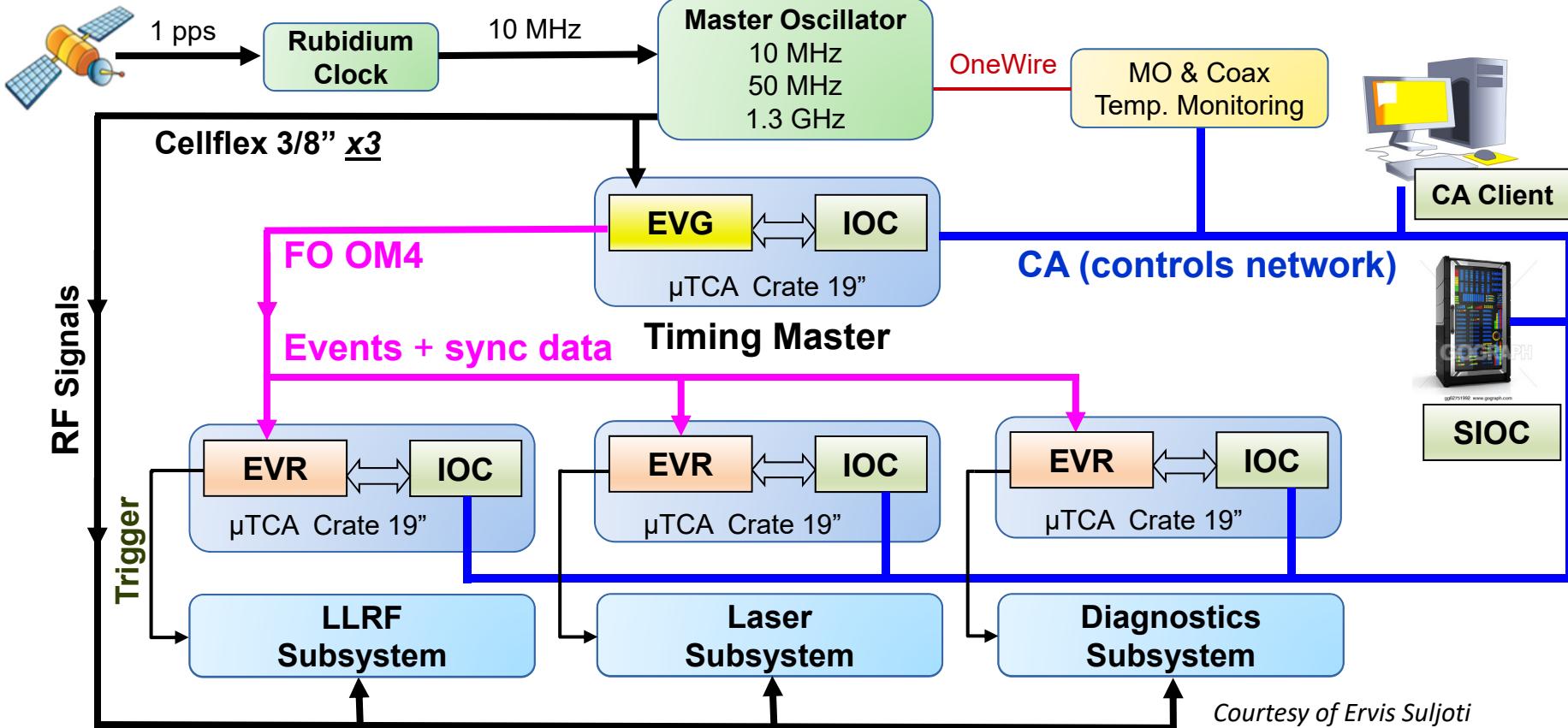
- Customized MO developed by AXTAL GmbH
- Internal ultra-low phase noise reference OCXO
- External 10MHz reference input not affecting internal phase noise
- Monitoring of OCXO temperature and PLL locking status

## 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



# Device Integration: Timing System - Schematic

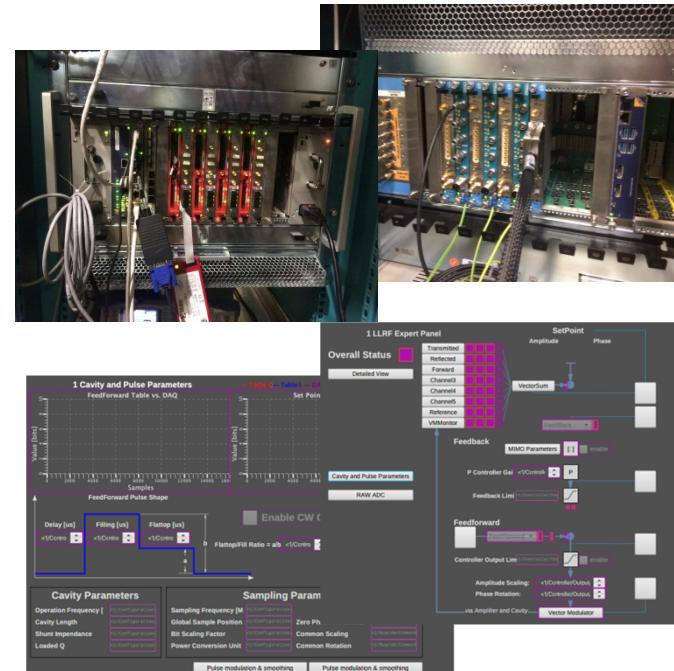


## ■ Low Level RF (LLRF)

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

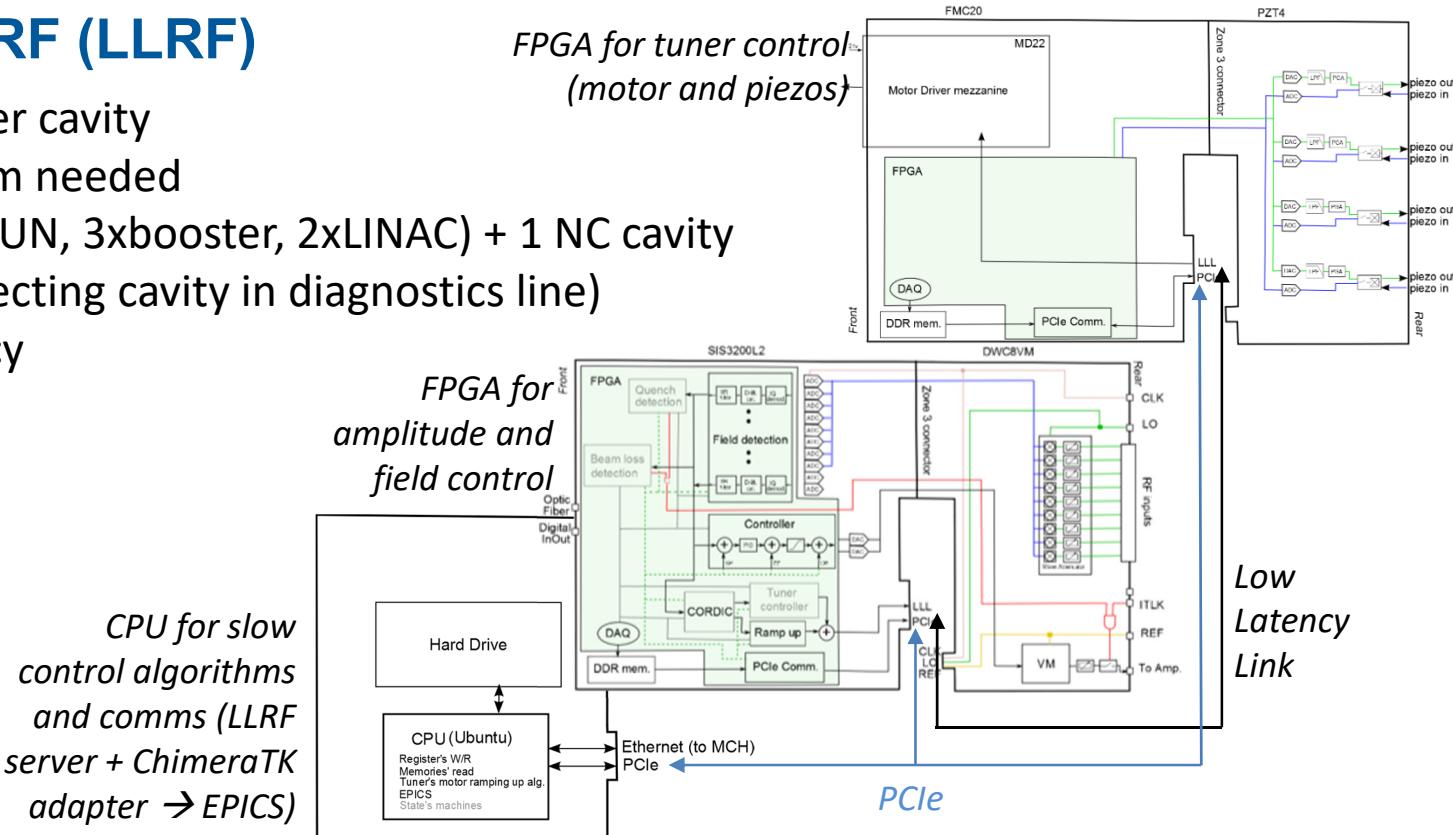
- Tight cooperation with colleagues from DESY
- MicroTCA system performing LLRF
- builtin EPICS-IOC/-CA-Server
- Operator displays (CSS – control system studio)

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.



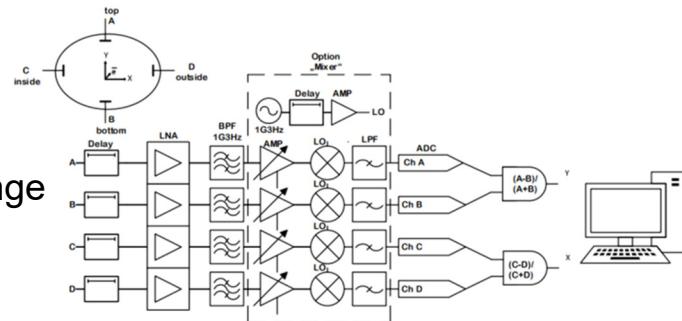
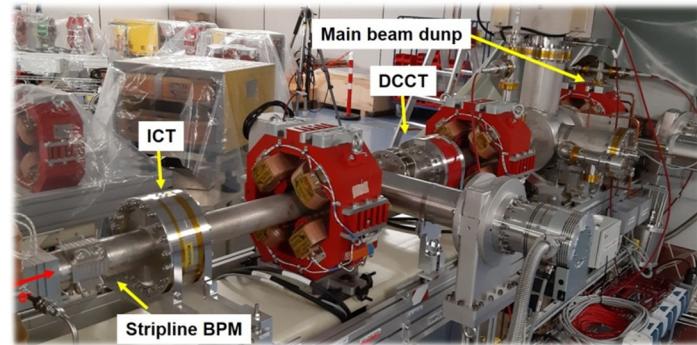
## ■ Low Level RF (LLRF)

- 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



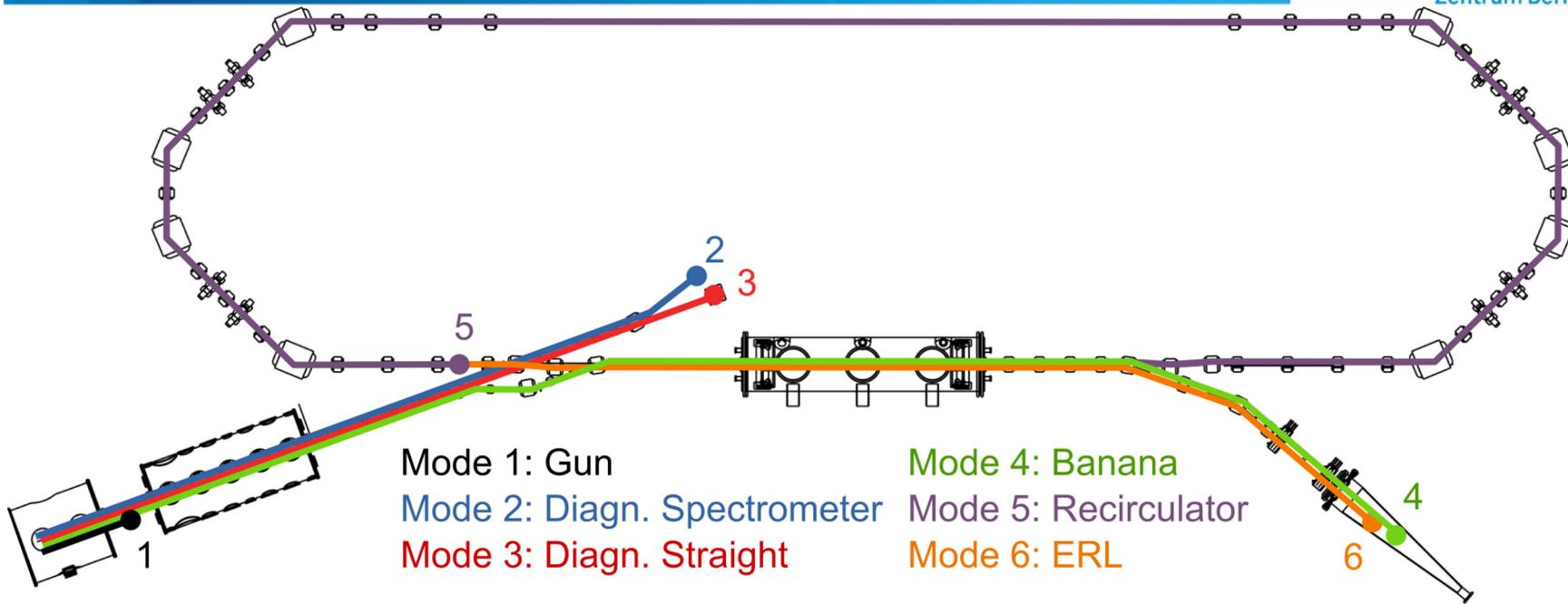
## Beam-Diagnostics

- **LabVIEW** on PC or PXI SoftIOC using CA Lab\* or RDP and vncviewer for imaging systems
- **Slow diagnostics** / destructive /  $I < 50\mu A$ 
  - 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).

# Excursion – Machine Operation Modes



#	Name	Dump	Pwr limit	$E_{kin}$	Current limit	#	Name	Dump	Pwr limit	$E_{kin}$	Current limit
1	Gun	Faraday cup	~300 W	2.7 MeV	~100 $\mu$ A	4	Banana	LEHP dump	650 kW	6.5 MeV	100 mA
2	Diagn. Spectr.	Faraday cup	~300 W	6.5 MeV	~45 $\mu$ A	5	Recirculator	HELP absorber	50 W	50 MeV	1 $\mu$ A
3	Diagn. Straight	LELP dump	35 kW	6.5 MeV	5 mA	6	ERL	LEHP dump	650 kW	6.5 MeV	100 mA

## Machine Protection System

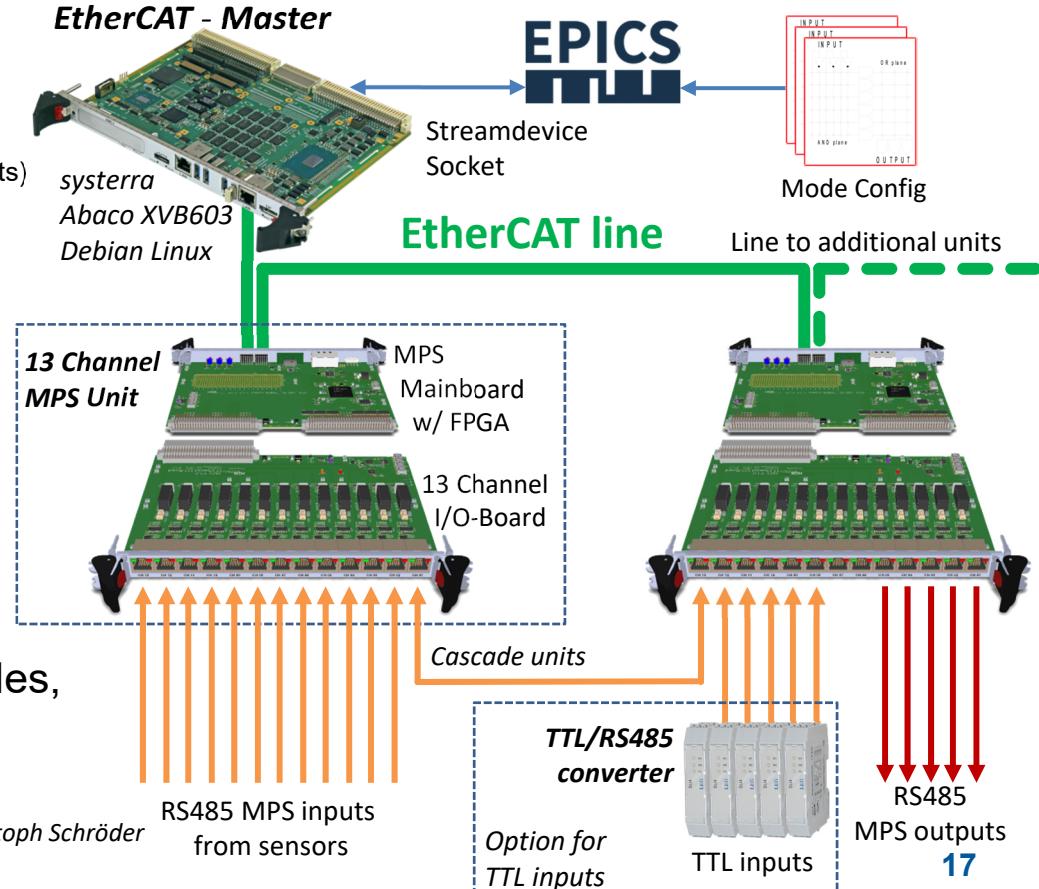
- Permit operation in any of the machine operation modes
- Guarantee well defined status of all components or block laser/gun
- Realized with EtherCAT, FPGA and RS485 I/O, scalable
- Inputs, Outputs and Logic defined in config and distributed to FPGA

		Machine mode						BEAM MODES			MACHINE MODES									
Name	Location	1	2	3	4	5	6	Signal	Type	delay	0 (0 A)	1SB, CW (0.5 μA)	2 MP (20 μA)	3 CW (100 mA)	1. Gun	2. Diag. Line (spectr.)	3. Diag. Line (straight)	4. Banana	5. Recirculator	6. ERL
Gun								Vacuum pressure	threshold		blue	blue	blue							
Booster 1								Machine mode OK	bit		green	green	green							
Booster 2								Laser mode OK	bit		green	green	green							
Booster 3								Gun RF	bit											
Linac 1								Booster RF	bit											
Linac 2								Linac RF	bit											
Linac 3								Injector fcup position	bit											
FCUPZGAF	1 <sup>st</sup> meter							Screen positions	bit											
FOMZ2GAF	1 <sup>st</sup> meter (cathode camera)							Diag. fcup OK	bit		green	green	green							
GV1VS1AF	hand valve KW							LEMP dump OK	bit		green	green	green							
GV1VS2AF	Gunmodul							LEHP dump OK	bit		green	green	green							
GV1VS3AF	1st Meter							HELP absorber position	bit		white	white	white							
GV1VS4AF	Booster module		red					Spectr. dipole	bit		red	red	red							
GV1VS5AF	merger		green	green				Merger dipole	bit		red	red	red							
GV2VS5AF	end Arc 2		yellow					Splitter dipole	bit		red	red	red							
GV1VS6AF	Start Diagnosel.		yellow					Beam arrival time	threshold	~μs										
GV2VS6AF	Turbopumps. LEMP		green	green				Current ICTs	threshold	~μs		blue	blue	blue						
GV1VS7AF	behind Inj. dipole		yellow	red				Current DCCT	threshold	~s										
GV1VS8AF	Linacmodul		green	green				Orbit BPMs	threshold	~ms-s		blue	blue	blue						
GV1VS9AF	output Linac		yellow	green				BLMs	threshold	~5-10 μs		blue	blue	blue						
GV1VS10AF	entry arc1		yellow	yellow																
GV1VS11AF	end arc1		yellow	yellow																
GV1VS12AF	early Arc2		yellow	yellow																
GV1VS13AF	early Dumpl.		yellow	green																
SVVS13AF	quick-acting		yellow	green																
GV2VS13AF	Turbo2 LEHP		red	red																
GV1VS14AF	before LEHP		yellow	green																
GV2VS14AF	turbo1 LEHP		yellow	green																

# Device Integration: Machine Protection System - Features

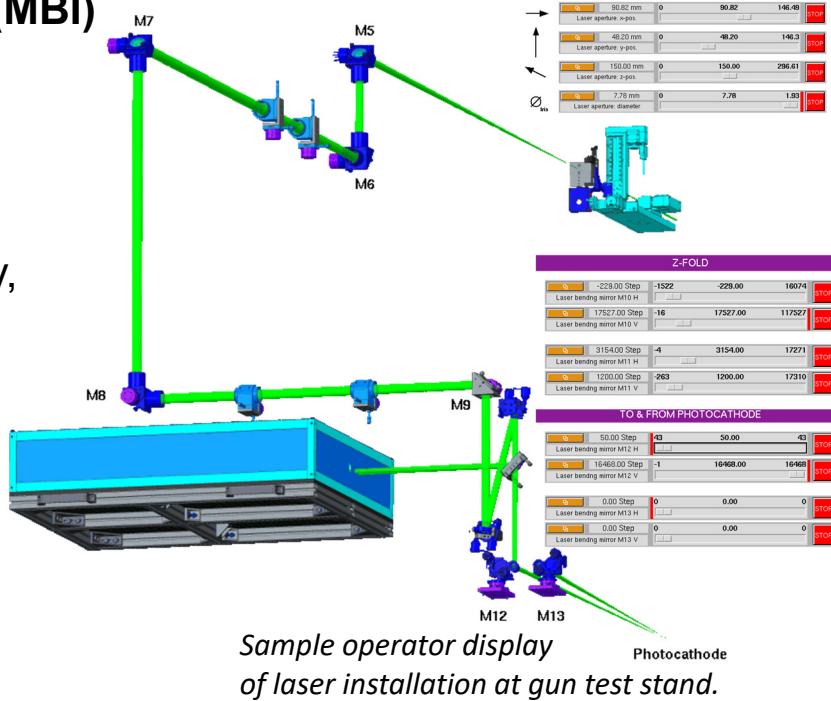
- Synchronization of units via **EtherCAT**
- 13 configurable I/O-Ports per unit
- Up to 21 units per VME-Crate (max.  $2^{16}-1$  units)
- **Cable break detection on RS485 lines**
- Allows for post mortem analysis
- Mode switch by software, distributed, **synchr. switch within 200ns** all units
- Reaction 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



## ▪ 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



- **Motors**

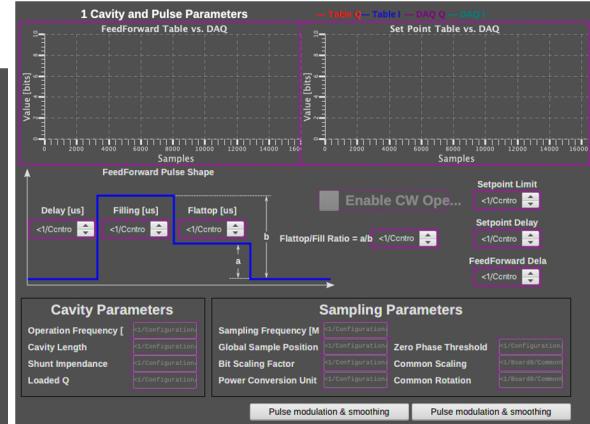
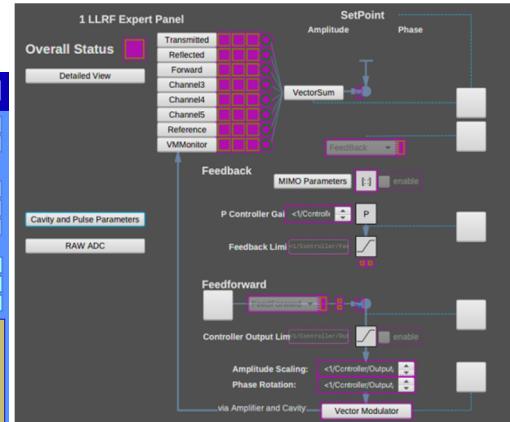
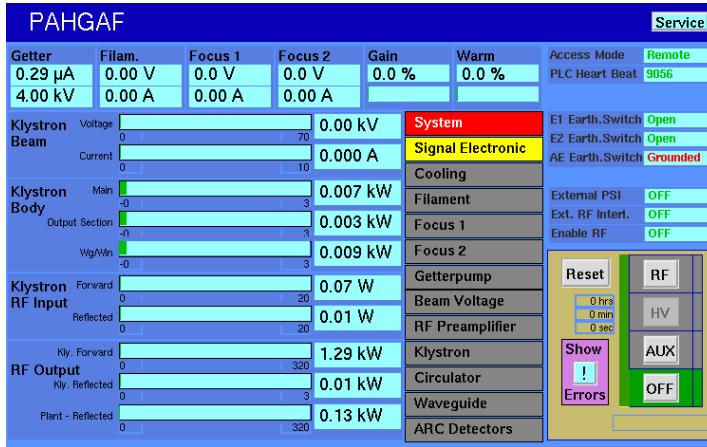
- EPICS motor record and Phytron motor controls interfaced using Modbus are used as standard motor control interface

- **Temperatures, ...**

- Wago I/O Modules interfaced using Modbus are used as standard temperature measurement

## 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



## Alarm-Visualisation, -Notification and –Logging

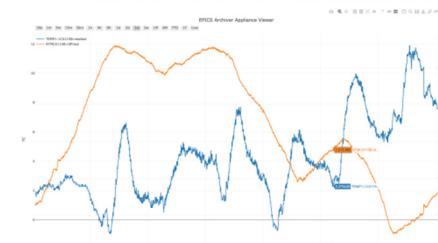
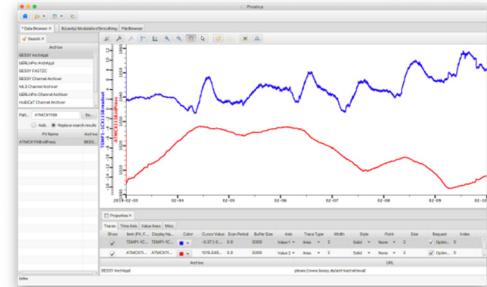
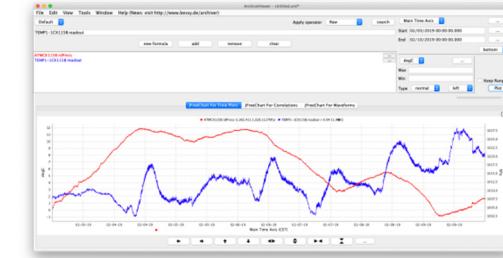
- **alh** (C, Motif, late 1990s, still works fine!)
  - Visualisation on main console
  - Notification via message to operator DECT phone and/or email to component responsible staff
  - Logging into Elastic Stack
- Future:  
**CSS/phoebus\*** alarm-server, -logger, -viewer...



BESSY II Alarm Log - ELK Viewer					
Timestamp	Process Variable	Status	Severity	Message	Value
2019-09-15 21:59:15	ALL	INFO	INFO		
1 2019-09-16 00:00:47	DRIFT_CV_dig	LOW	MAJOR	One Connection Watchdog	0
2 2019-09-16 00:01:47	DRIFT_CV_dig	LOW	MAJOR	One Connection Watchdog	3
3 2019-09-16 00:15:47	DRIFT_CV_dig	LOW	MAJOR	One Connection Watchdog	0
4 2019-09-16 05:55:19	DRIFT_CV_dig	LOW	MAJOR	One Connection Watchdog	3
5 2019-09-16 05:55:19	Alarms!One!alarm!ed	STATE	MAJOR	CORE! Prod 1! cores. Alarm	1
6 2019-09-16 06:26:29	QNPY!STR!alarm!_un	STATE	MAJOR	Varian!Traffic off	off
7 2019-09-16 06:26:29	MPI!STW!alarm!log	HIGH	MAJOR	MPI! STW	-4.4
8 2019-09-16 06:26:29	Pump!Fuel!drive!To!Free!	STATE	MAJOR	Pump! Fuel Drive To Free. Alarm	1
9 2019-09-16 06:30:40	Pump!Fuel!drive!To!Free!	STATE	MAJOR	Pump! Fuel Drive To Free. Active	1
10 2019-09-16 06:30:40	Pump!One!alarm!ed	STATE	MAJOR	CORE! Prod 1! cores. Alarm	1
11 2019-09-16 06:30:51	Pump!Fuel!drive!To!Free!	STATE	MAJOR	Pump! Fuel Drive To Free. Active	1
12 2019-09-16 06:51:29	Pump!One!alarm!ed	STATE	MAJOR	CORE! Prod 1! cores. Alarm	1
13 2019-09-16 06:51:29	Pump!Fuel!drive!To!Free!	STATE	MAJOR	CORE! Prod 1! cores. Alarm	1
14 2019-09-16 06:51:33	Pump!Fuel!drive!To!Free!	STATE	MAJOR	Pump! Fuel Drive To Free. Active	1
15 2019-09-16 06:51:33	Pump!One!alarm!ed	STATE	MAJOR	CORE! Prod 1! cores. Alarm	1
16 2019-09-16 06:51:33	Pump!Fuel!drive!To!Free!	STATE	MAJOR	Pump! Fuel Drive To Free. Active	1
17 2019-09-16 06:51:22	Pump!One!alarm!ed	STATE	MAJOR	Pump! Fuel Drive To Free. Active	1
18 2019-09-16 06:51:22	Pump!Fuel!drive!To!Free!	STATE	MAJOR	Pump! Fuel Drive To Free. Active	1
19 2019-09-16 06:51:30	Pump!One!alarm!ed	STATE	MAJOR	Pump! Fuel Drive To Free. Active	1
20 2019-09-16 06:51:10	Pump!Fuel!drive!To!Free!	STATE	MAJOR	Pump! Fuel Drive To Free. Active	1
21 2019-09-16 06:51:44	Pump!One!alarm!ed	STATE	MAJOR	Pump! Fuel Drive To Free. Active	1
22 2019-09-16 06:51:47	Pump!Fuel!drive!To!Free!	STATE	MAJOR	CORE! Prod 1! cores. Alarm	1
23 2019-09-16 06:51:28	Pump!One!alarm!ed	STATE	MAJOR	CORE! Prod 1! cores. Alarm	1
24 2019-09-16 06:51:28	Pump!Fuel!drive!To!Free!	STATE	MAJOR	Pump! Fuel Drive To Free. Active	1
25 2019-09-16 06:51:30	Pump!One!alarm!ed	STATE	MAJOR	CORE! Prod 1! cores. Alarm	1
26 2019-09-16 06:51:30	Pump!Fuel!drive!To!Free!	STATE	MAJOR	Pump! Fuel Drive To Free. Active	1

## 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)



## Others

- **StripTool** (C, Motif, late 1990s)  
will be replaced by CSS/phoebus\* DataBrowser showing archived and live data
- **RDesktop & VNC** to access 3<sup>rd</sup> party controls
  - Photo-cathode-laser – EPICS-interface in the works
  - Imaging diagnostic systems (LabVIEW on MS-Windows)

The screenshot shows a software application window titled "Execute Area-Selection Options Version: 4.0". The main area displays a table of "available Snapshots" with columns for DATE, TIME, OPTICS, PATTERN, and COMMENT. The table lists several entries from September 2013, such as "StandA Multi" at 16:51:42 and "StandB Multi" at 17:13:10. Below this is a "Logbook" section with a table showing projects like "HeliCAT", "Vertical Test Rig", and "BERLInPro", along with their submission dates and users.

	DATE	TIME	OPTICS	PATTERN	COMMENT
8887	2013-09-11	16:51:42	StandA Multi	All:	ALL: 248 mA, Injektor optimieren, 3mA stabil
8888	2013-09-11	17:13:10	StandA Multi	All:	ALL: 248 mA, Beamscrubbing, 3% 3 mA
8889	2013-09-12	01:59:12	StandA Multi	All:	ALL: 248 mA, Beamscrubbing before Beamlime Commissioning
8890	2013-09-12	02:00:12	StandA Multi	All:	ALL: 248 mA, ID Commissioning state
8891	2013-09-12	13:57:23	StandA Multi	Sto:	248mA, Landau settings for this week
8892	2013-09-12	14:19:33	StandA Multi	Sto:	248mA, Landau settings for this week
8893	2013-09-13	04:45:02	StandA Multi	All:	ALL: 248 mA, Beamscrubbing before Beamlime commis
8894	2013-09-13	04:45:02	StandA Multi	All:	ALL: 248 mA, Beamscrubbing before Beamlime commis
8895	2013-09-13	18:15:13	StandA Multi	All:	ALL: 248 mA, before Beamlime commissioning
8896	2013-09-14	07:05:50	StandA Multi	All:	ALL: 248mA before ID Commissioning

Projects	Entries	Last submission
HeliCAT	1172	2018-06-21 16:18 by Pablo Echevarria Fernandez
HeliCAT Electronic Logbook		
HeliCAT Test	65	2010-02-11 11:07 by Michael Schuster
HeliCAT Test	47	01.06.2011 15:23 Wed by Benvenuti, C, Calatroni, S
Vertical Test Rig	37	03.01.2013 15:24 Thu by Holberg
Vertical Test Rig Logbook		
Cherenkov SLR	98	27.06.2018 14:01 Wed by Yegor Tamashevich
RF Gun, gun, gun, cold mass assembly	16	04.06.2011 14:03 Mon by Jan Ulrich
RFP_Injector	126	26.01.2011 15:26 Wed by Thorsten Kampf
RF	748	20.06.2018 11:26 Wed by Julius Kühn
RF Gun Logbook	105	16.12.2009 14:26 Wed by Bettina Kuske
STAB	247	2018-07-23 10:32 by Axel Neumann
STAB Electronic Logbook		
BERLInPro	144	2018-09-15 16:58
BERLInPro Logbook		
BERLInPro RF Transmitter	20	16.02.2017 15:51 Thu by Holberg
BERLInPro RF Transmitter		
1.3 GHz RF Transmitter		
HeliCAT Electronic Logbook		

## 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

## 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 tailored applications for commissioning are not yet defined**
- **New generic applications supplied on demand**

- **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 3<sup>rd</sup> 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

1. **bERLinPro** – [https://www.helmholtz-berlin.de/projects/berlinpro/index\\_de.html](https://www.helmholtz-berlin.de/projects/berlinpro/index_de.html)
2. **EPICS** – <https://epics-controls.org/>
3. **EPICS Archiver Appliance** – SLAC, M. Shankar – [https://slacmshankar.github.io/epicsarchiver\\_docs/](https://slacmshankar.github.io/epicsarchiver_docs/)
4. **CA Lab** – HZB, C. Winkler – [https://www.helmholtz-berlin.de/zentrum/locations/it/software/exsteuer/calab/index\\_en.html](https://www.helmholtz-berlin.de/zentrum/locations/it/software/exsteuer/calab/index_en.html)
5. **CSS/phoebus** – SNS, K. Shroff, et al. – [https://controlssoftware.sns.ornl.gov/css\\_phoebe/](https://controlssoftware.sns.ornl.gov/css_phoebe/)
6. **Singularity** – LBL, Sylabs.io – <https://singularity.lbl.gov/>, <https://sylabs.io/singularity/>
7. **eLog** – PSI, S. Ritt – <https://elog.psi.ch/elog/>
8. „**The EPICS Software Framework Moves from Controls to Physics**“ – IPAC'19 – <https://ipac2019.vrws.de/papers/tuzzplm3.pdf>



**Thank you very much  
for your attention!**