

XFEL and FLASH

Machine Protection System – MPS

μ TCA-based



2nd MTCA/ATCA Workshop for Research and Industry
25-Aug-2021 – DESY Contribution

Outline

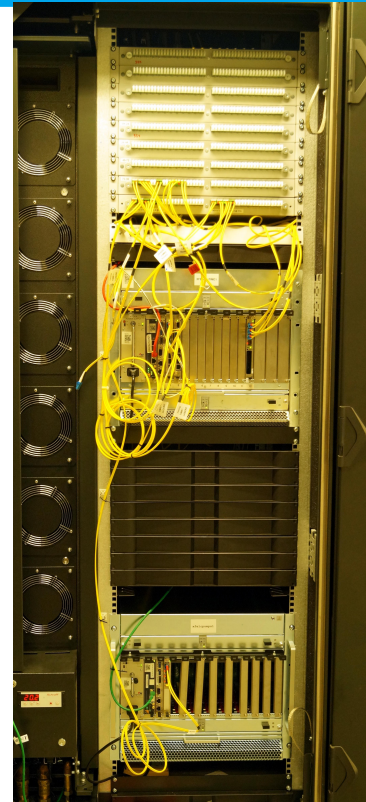
1. Architecture – design goals, purpose, concepts
2. Chosen μ TCA-boards
3. Monitored and controlled systems
4. Signal processing – response actions
5. Graphical user interface



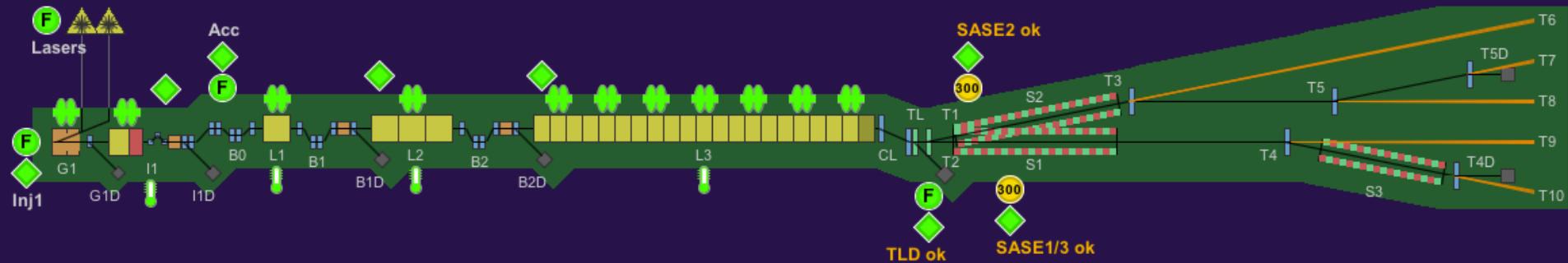
Design Goals of MPS – 1./2

- Designed for **pulsed** FEL-type accelerators
 - Bunch train oriented machines
- **Scalable** in number of monitored inputs and controlled outputs
- **Configurable** alarm-response actions
- **Distributed** over the accelerator – board installations and logic
- Core function **independent** from network and operating systems
- **μTCA.4** based

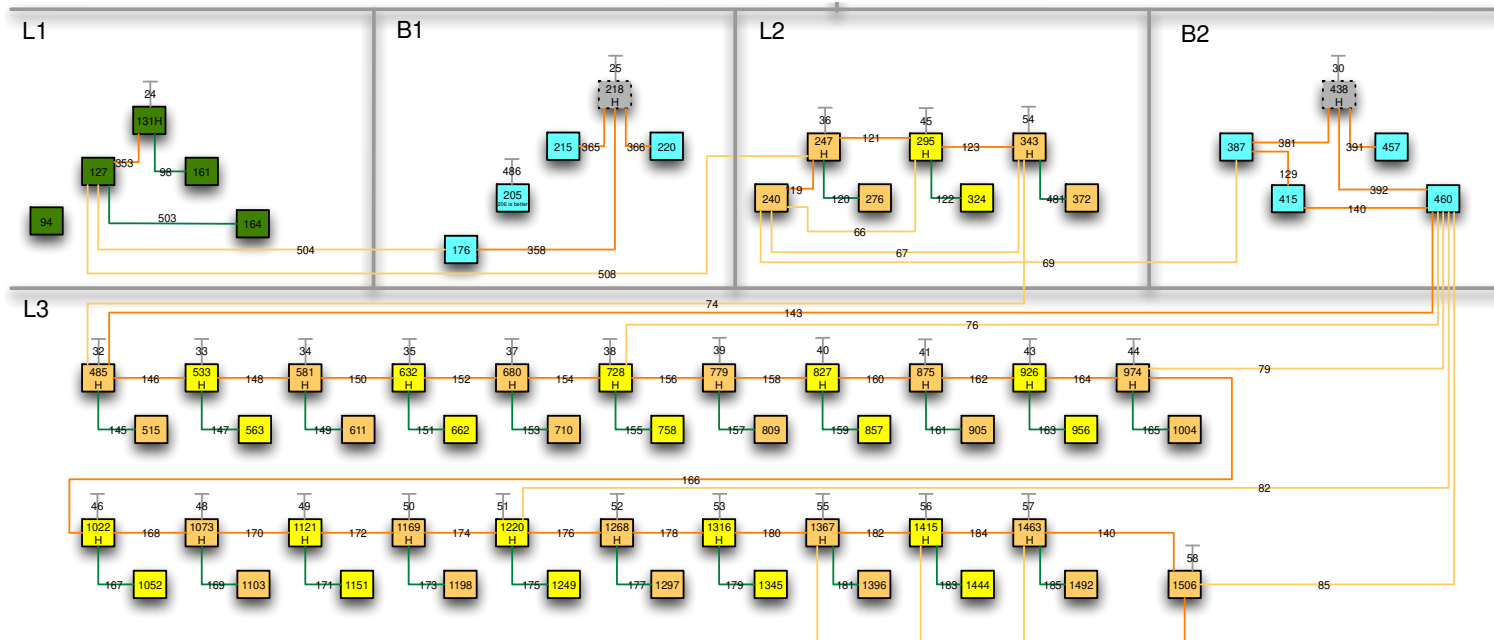
Design and implementation have started in 2010
Extensions and adaptations are ongoing



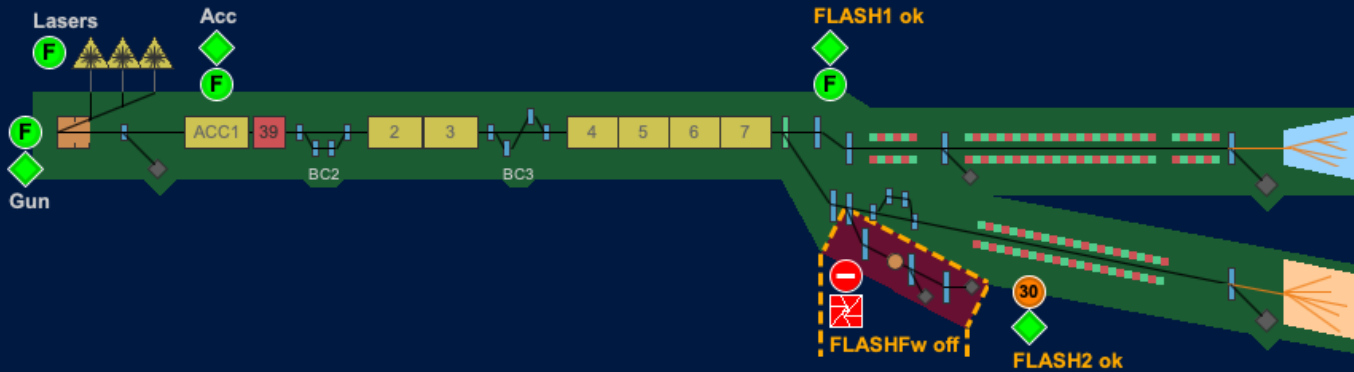
XFEL Architecture – Communication Topology



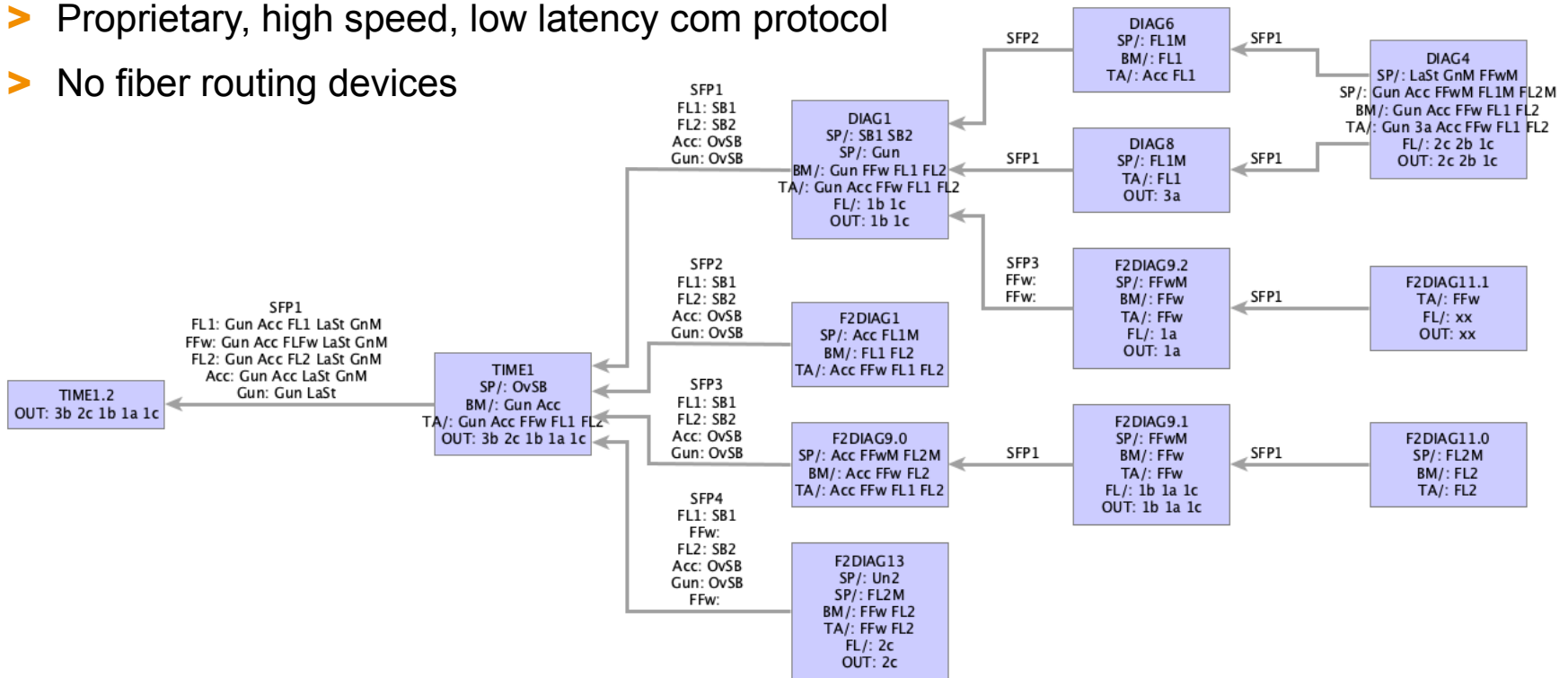
- In XFEL: Currently **152** MPS-boards distributed over **3.5km**
- Dedicated **fiber optics** network with point-to-point communication
- **Cascaded** communication topology with transfer direction from end to start of accelerator



FLASH Architecture – Communication Topology



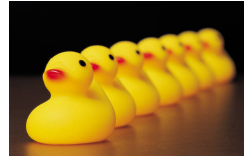
- In FLASH: Currently **14** MPS-boards over **350m**
- Proprietary, high speed, low latency com protocol
- No fiber routing devices



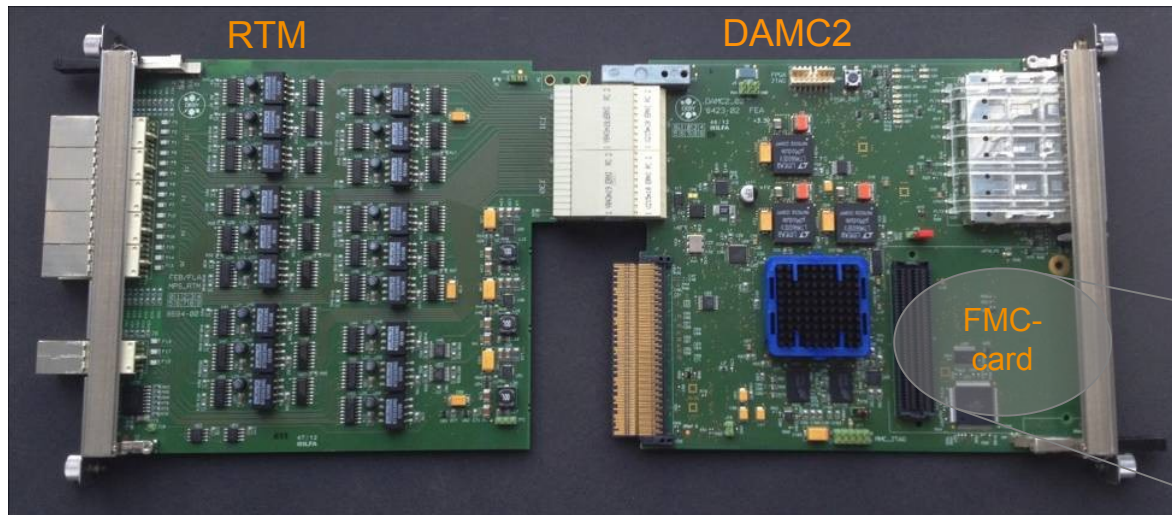
- ❖ MPS shall **protect** the accelerator equipment from damage caused by unexpected high impact of electron bunches
 - e.g. induced radioactivity of beamline parts due to e-beam misalignment
 - e.g. overload of a beam dump due to an inappropriate beam mode
 - e.g. loss of beam line vacuum due to a damage of vacuum valves, diagnostic screens, wire scanners, collimators etc.

- ❖ MPS **detects** such a situation through a multitude of alarm, error, interlock and status signals provided by some (diagnostic) systems
 - e.g. beam loss monitors, transmission interlock systems, magnet power supplies, ...

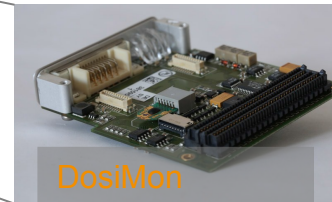
- ❖ MPS **reponds** appropriately by stopping or limiting the e-beam
 - e.g. closing Pockels-cell of the injector laser, ...



Chosen Hardware – MTCA.4-compliant Boards

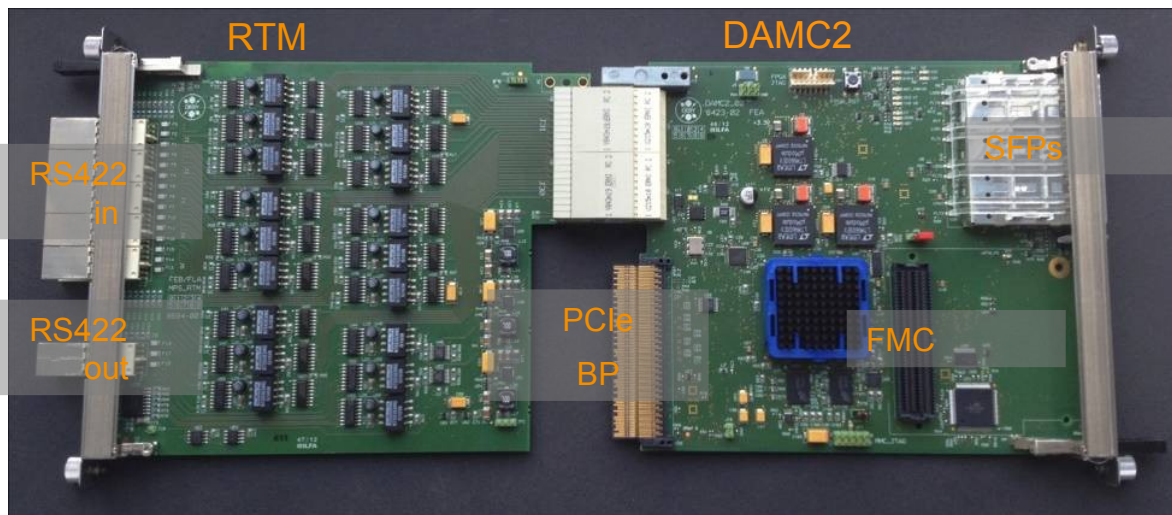


- XILINX Virtex-5 FPGA
- MMC support
- onboard flash-memory
- 1 Gbit SDRAM
- optional dosimetry FMC-card



- ❖ DAMC2 has been developed at DESY's group FE
 - Besides MPS, other groups have developed firmware for their projects, e.g. BLM-controller
- ❖ Interface RTM has been developed at DESY groups FLA and FE
 - Besides MPS, it also used by other systems, e.g. laser pulse controller
- ❖ Radiation dosimetry monitoring FMC-card has been developed at DESY's MDI

Requirements Fulfilled by the Chosen Hardware



- 45 digital inputs (RS422)
- 7 digital outputs (RS422)
- 3 input lines from backplane
- 2 output lines to backplane
- 3 digital inputs from FMC-card
- I²C-bus to FMC-card
- PCIe-bus to all FPGA-registers
- 4 double-fibred bi-directional optical links (SFPs)
- IPMI and JTAG for firmware updates
- Boards and RTMs are hot-swappable

✓ Maintainability & scalability

- Each MPS-board runs same firmware
- Each crate runs same MPS front-end server
- But they are differently configured from board to board
- All alarm inputs, response actions and outputs can be configured through DOOCS/JDDD panels, even during machine run time

I/O – MPS' Monitored Systems

Vacuum
Valves

Cryogenics
Ok

Steering
Magnet P/S

Bending
Magnet P/S

Undulators
Open

Dump
Diagnostics

Coupler
Interlock

Klystron
Interlock

Klystron
Lifetime Mgt

Modulator
Interlock

Beam Loss
Monitors

Beam Halo
Monitors

Transmission
Interlock Sys

Beam
Position Mon

Beam Com-
pression Mon

OTR
Screens

Wire
Scanners

Faraday
Cups

Collimators

Dosimetry
Monitoring

Equipment Pro-
tection Systems

Fast Valves
& Shutters

Tune Up
Dumps

Burn Thru
Monitors

Active Instrument
Beam Stops

Crystal Lens
Arrays

- In XFEL: **25 types** of systems provide ~**2000** alarm and status **signals** to MPS
- In FLASH: **10 types** of systems provide ~**280** alarm and status **signals** to MPS
- Complexity of alarm providing systems can vary between very high and simple
- Alarm response actions can be configured signal-individually in MPS



I/O – MPS' Controlled Systems

Laser Pulse
Controller

Dump Kicker

LLRF

> For quick, asynchronous responses

- within 80ns...10 μ s time range
- for alarms that require responses within the currently running bunch train
- MPS can control laser pulse controller, dump kicker and LLRF directly
- MPS transmits responding inhibit signals via twisted-pair copper (RS422) or via μ TCA backplane

◇ e.g. "Cut off the rest of the current bunch train for beam line SASE2"

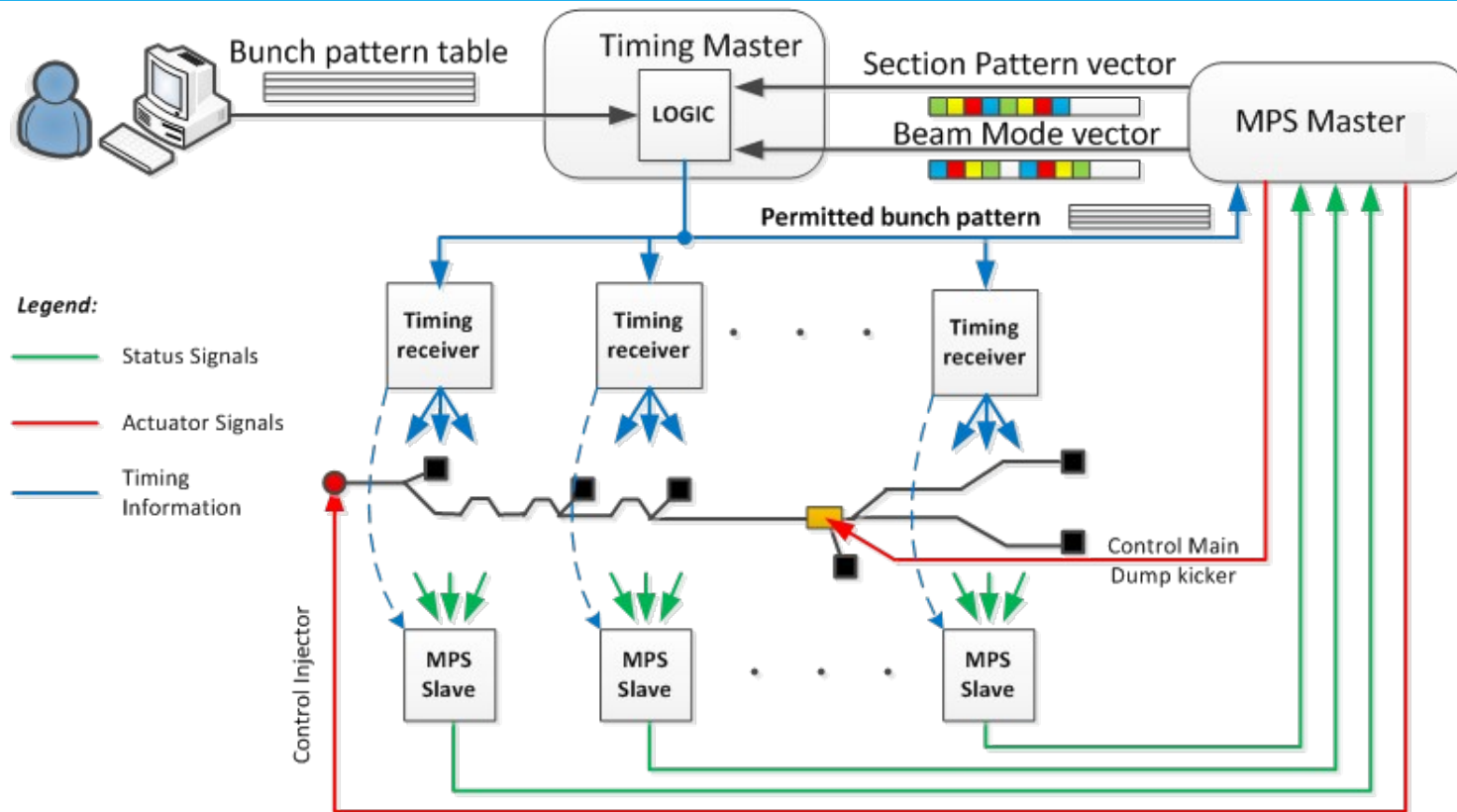
> For "slower", bunch train-synchronous responses

- within 100ms time range
- for beam limitations valid by next upcoming bunch train
- MPS master controls the timing system master
- MPS sends limiting information via backplane

◇ e.g. "Reduce to 30 electron bunches per bunch-train for common accelerator section!"
e.g. "Reduce to 2 electron bunches per bunch-train within injector section!"

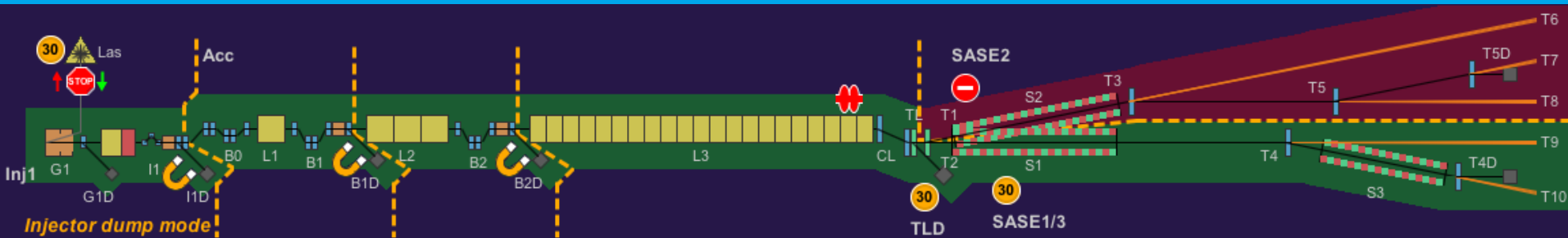
Timing
Master

Cooperation Concept



- A operator sets the demanded bunch distribution in the timing system master via graphical bunch pattern builder (top left)
- MPS slaves assess alarm and status signals from providing (diagnostic) systems and sends to MPS master (green lines)
- MPS master sends the combined limits to timing system master (top middle)
- Timing system master combines operators wishes and MPS limits and broadcasts the resulting bunch pattern table (blue)
- Timing receivers/transmitters inform diagnostic systems and trigger others accordingly, e.g. laser pulse controller
- MPS is also able to bypass the timing system temporarily and control laser pulse controller and dump kicker directly (red)

Beam Destination vs. Operation Mode



A operator has to select **beam destinations** for the bunch trains

- one for the whole bunch train, e.g. gun dump, injector dump, bunch compressor 1 dump
- or multiple for several parts of the bunch train, e.g. SASE1/3, SASE2, TLD

MPS detects the current **operation modes**

- thru the status of the corresponding dump dipole magnet. The power supplies provide that info according to their operating current
- and thru the open/close status of the corresponding vacuum valves. The vacuum PLC provides that

If **beam destinations** and **operation modes** do not correspond to each other

- timing system does not trigger injector laser pulse controllers for certain destinations anymore
- and laser pulse controllers do not accept triggers from timing system for certain destinations anymore

FLASH Control Room – GUI

Send to eLog

Overall Beam Vetoes

According to Current Operation Mode

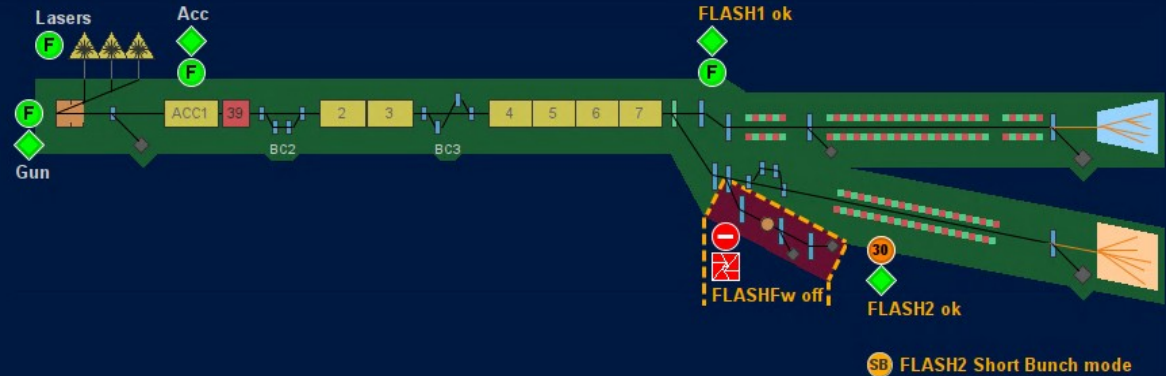


Set limit of ... to ...:

Overall Bunch Mode ...

FLASH1 Bunch Mode ...

FLASH2 Bunch Mode ...



Show also green light:

2021-08-23/16:27:11

Further panels:

- FL1 Slow Protection
- FL2 Slow Protection
- Vetoes per Server

BIS panels:

- Screens etc. via BIS
- BIS Alarm Details
- Further Power Supplies
- BIS Expert Info

Gun	Acc	FLASH1	FLASH2 Extr	FLASH2	FLASHFw		
<ul style="list-style-type: none"> Housekeepings Short mode limit Beam perm FL1 BIS Gun Gun mode limit BLM GUN TPS 3GUN 	<ul style="list-style-type: none"> BLM BC2 BLM DBC2 BIS Acc BLM BC3 BLM ACC7 Coupler-I Acc1..4 Coupler-I Acc 5..9 Vac SSK FL1 	<ul style="list-style-type: none"> Short mode limit TPS 3GUN BIS FL1 WS FL1 TPS 4FL2EXTR BLM TCOL BLM ECOL BLM ORS BLM SFUND1..2 BLM SFUND3..4 BLM SFLEC 	<ul style="list-style-type: none"> Short mode limit TPS 3GUN Beam perm FL2 TPS 4TCOL OTR 4FL2EXTR BLM FL2EXTR1..6 BLM FL2EXTR7..12 BLM FL2EXTR15..18 Vac SSK FL2 	<ul style="list-style-type: none"> BIS FL2 OTR FL2SEED4..5 OTR FL2SEED6..7 BLM 4..6FL2BC BLM FL2SEED3..4 BLM FL2SEED5..6 BLM FL2SEED7 BLM FL2SASE3..4 BLM FL2SASE5..6 BLM FL2SASE7..8 BLM FL2SASE9..10 	<ul style="list-style-type: none"> BLM slow prot OTR BCM crisp BLM FL2SASE11..12 BLM FL2SASE13..14 BLM 2..4FL2XTDS BLM 8FL2XTDS BLM 2..7FL2DUMP BLM 10FL2DUMP BLM FL2SASE5..6 Dump flow PhotonBL FS-BT OTR 9FL2XTDS 	<ul style="list-style-type: none"> BIS limit FLFw Mag Oper FLFw Vac Valves FLFw Vac V0 BLM 5FLFEXTR BLM FLFCOMP BLM 3FLFMAFF OTR 14FLFCOMP OTR 8FLFMAFF BLM 13FLFMAFF BLM 3FLFDIAG 	<ul style="list-style-type: none"> OTR 5FLFDIAG BLM 1FLFXTDS Vac XTDS FLFw OTR 7FLFDIAG BLM FLFUND1 BLM 5FLFXTDS BLM FLFDUMP OTR 3FLFUND1 OTR 11FLFXTDS OTR 8FLFDUMP Beam power

An operator may see current:

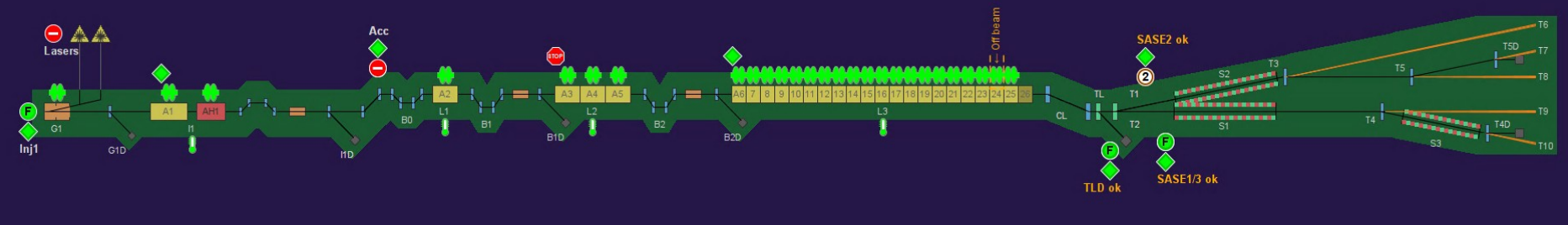
- > operation modes, section availabilities and max allowed number of bunches per bunch train per section
- > alarm states of the different (diagnostic) systems and their contribution to the beam limitation
- > states of alarm maskings according to bunch modes



XFEL Control Room – GUI

Send to eLog

Overall Beam Vetoes
According to Current Operation Mode



Injector		Acc		TLD		SASE1/3		SASE2				
Housekeepings	TIS 46	Housekeepings	TIL A3	TIS 479	Klystron-I A12	KLM A19	TIS 1459	Preset limit TLD	Housekeepings	BLM 2934-2948	Housekeepings	Masked
Preset limit Inj	Mirror 24	Preset limit Acc	KLM A3	BLM 472	Modulator-I A12	Klystron-I A19	BLM 1459-1542	TIS 2122.TLD	Preset limit SA1	BLM 2952-2956	Preset limit SA2	TIS 2682
Op mode G1D	F-cup 24	OTR 99-118	Klystron-IA3	TIL A6	Mag 782-818	Modulator-I A19	WS 1523	OTR 1995.TLD	BLM 2072-2098	BHM 3098.T4D	OTR 2038	TIS 2744
Beam parm Inj	Screen 24	TIS 116	Modulator-I A3	KLM A6	TIL A13	Mag 1124-1160	OTR 1523	TIS 1995.TLD	Mag 2072-2247	BLM 3095-3098	TIS 2038	BLM 2647-2859
Bunch pattern svr	F-cups 25	BLM 70-118	Mag 249-285	Klystron-IA6	KLM A13	TIL A20	WS 1597	BLM 2047.TLD	Few masked	BLM 3072-3105	BLM 2042-2083	Mag 2756-3007
TIL Gun	TIL A1	Mag 134-170	TIL A4	Modulator-I A6	TIL A4	KLM A20	OTR 1597-1635	Mag 1983	TIS 3065.T4D	TIS 3098.T4D	Mag 2030	TIS 2977
Klystron-I Gun	TIL AH1	Op mode B1D	KLM A4	Mag 488-524	Modulator-I A13	Klystron-I A20	WS 1635	Mag 2095-2113	BLM 2117-2132	Valve 3001OF	Mag 2077-2227	TIS 3040.T5D
Modulator-I Gun	Cryo ok Inj	Mag 63-96.B0	Klystron-I A4	TIL A7	Mag 830-866	Modulator-I A20	TIS 1658	Mag 1996-2096	DumpDiag TLD	PhotScreen 3098	Mag 2041-2124	BLM 2922-2966
TIS 25	Klystron-I A1	Mag 179-233.B1	Modulator-I A4	TIL A7	TIL A14	Mag 1171-1208	BLM 1615-1698	Mag 1980-2087	BLM 2177-2230	TIS 3098.T4D	Mag 2025-2052	BLM 3052-3081
BLM 23-25	Modulator-I A1	Mag 229-32.B1D	Mag 297-333	Klystron-IA7	KLM A14	TIL A21	Col 1690-1726	Mag 2095-2113	OTR 2169-2212	DumpDi XSDU2	BLM 2125-2154	TIS 3149.T5D
SSK Inj	Linac Cryo Ok	Mag 345-381	Modulator-I A7	TIL A7	KLM A14	KLM A21	OTR 1689-1725	Mag 1996-2096	TIS 2228	OTR 3077-3097	BHM 3181.T5D	BLM 3149-3188
Valves up to I1D	Col 98	Mag 536-572	TIL A5	Mag 536-572	Modulator-I A14	Klystron-I A21	TIS 1765	Mag 1996-2096	TuneDmp SA1	Mag 2946-3089	DumpDiag TLD	BLM 3149-3188
Op mode I1D	TIL A2	TIL A8	KLM A5	TIL A8	Mag 878-914	Modulator-I A21	BLM 1710-1782	Mag 1980-2087	BLM 2241-2284	Masked	WS 2164	DumpDi XSDU1
Mag 46-61	KLM A2	Klystron-IA5	KLM A8	TIL A15	TIL A15	Modulator-I A21	BLM 1794-1827	Mag 1980-2087	BLM 2260-2333	Valve (I1)1030F	Mag 3052-3159	BLM 3190
Soleno 23	Klystron-I A2	Modulator-I A5	KLM A8	Klystron-I A8	KLM A15	TIL A22	OTR 1797-1833	Mag 1980-2087	BLM 2339-2382	Masked	TIS 2190	TIS 3181.T5D
Mag 62-64.I1D	Modulator-I A2	Op mode B2D	Modulator-I A8	Modulator-I A8	Klystron-I A15	KLM A22	Col 1798-1834	Mag 1980-2087	BLM 2388-2424	Vacuum SA1	WS 2775-2779	OTR 3160-3181
BLM 65-66	TIS 175	Mag 387-472.B2	Mag 584-620	Mag 584-620	Modulator-I A15	Klystron-I A22	TIS 1865	Mag 1980-2087	TIS 2462	AIBS FXE	OTR 2146-2174	CRL HED
BLM 55-63	BLM 176-192	Mag 467-77.B2D	TIL A9	TIL A9	Mag 929-965	Modulator-I A22	BLM 1834-1884	Mag 1980-2087	BLM 2431-2461	AIBS SPB	TuneDmp SA2	CRL MID
BLM 48-51	BCM 180	SSK B2	KLM A9	KLM A9	TIL A16	Mag 1270-1307	WS 1899-1914	Mag 1980-2087	CRL SA1	AIBS SQS	BLM 2203-2246	AIBS HED
TIS 60	TIS 203	Valves up to B2D	Klystron-IA9	Klystron-IA9	KLM A16	TIL A23	BCM 1934	Mag 1980-2087	PhotScreen 2615	AIBS SCS	Crystal 2250	AIBS MID
OTR 55-56	BLM 194-205	BLM 387-403	Modulator-I A9	Modulator-I A9	Klystron-I A16	KLM A23	BLM 1894-1959	Mag 1980-2087	Valve 1001OF	EPS FXE	BLM 2252-2295	Masked
OTR 58-59	OTR 180-205	BCM 391-416	Mag 635-671	Mag 635-671	TIL A10	Klystron-I A23	OTR 1899-1929	Mag 1980-2087	Masked	FastValve FXE	MBU 2286	Masked
DumpDiag I1D	Mag 84-118.B0	TIS 387	TIL A10	TIL A10	Mag 977-1013	Modulator-I A23	WS 1929	Mag 1980-2087	BLM 2582-2688	Masked	BLM 2301-2344	Masked
BHM 66.I1D	Mag 176-224.B1	Col 403	KLM A10	KLM A10	TIL A17	Klystron-I A23	BLM 1982-1997	Mag 1980-2087	WS 2718	Masked	Crystal 2305	Masked
TIS 64.I1D	Col 192	BLM 405-428	Klystron-I A10	Klystron-I A10	KLM A17	TIL A24	BLM 2005-2027	Mag 1980-2087	Mag 2468-2873	Few masked	BLM 2350-2392	Masked
OTR 64.I1D	SSK B1	TIS 415	Modulator-I A10	Modulator-I A10	Klystron-I A17	KLM A24	TIS 2011	Mag 1980-2087	WS 2755-2779	Valve 3(1)1030F	TIS 2424	Masked
OTR 48-50	Valves up to B1D	OTR 392-438	Mag 683-719	Mag 683-719	Modulaotr-I A17	Klystron-I A24	OTR 1978-2023	Mag 1980-2087	OTR 2718-2779	Masked	BLM 2398-2584	Masked
TIS 94	OTR 118-224	BLM 435-464	TIL A11	TIL A11	Mag 1025-1061	Modulator-I A24	BLM 2057	Mag 1980-2087	Masked	Vacuum SA3	CRL SA2	Masked
BCM 205	BLM471-77.B2D	KLM A11	KLM A11	KLM A11	TIL A18	Mag 1396-1405	SSK L3	Mag 1980-2087	TIS 2793	SA3 Pre-absorb	PhotScreen 2576	Masked
OTR 236.B1D	OTR 450-461	Klystron-IA11	KLM A18	Klystron-IA11	KLM A18	TIL A25	Mag 1475-1907	Mag 1980-2087	BLM 2750-2831	Masked	FastValve XTD1	Masked
TIS 232-236	TIS 471	Modulator-I A11	Klystron-I A18	Modulator-I A11	TIS 471	KLM A25	Mag 1660-2027	Mag 1980-2087	TuneDmp SA3	Masked	OTR 2146-2174	Masked
DumpDiag B1D	OTR 446	Mag 731-767	Modulator-I A18	Modulator-I A18	TIL A12	Klystron-I A25	Mag 1629-1964	Mag 1980-2087	BLM 2837-2880	Masked	CRL SA2	Masked
BLM231-38.B1D	OTR 478-78.B2D	TIL A12	KLM A12	TIL A12	Mag 1076-1112	Modulator-I A25	Mag 1695-1982	Mag 1980-2087	BLM 2886-2928	Masked	Vacuum SA2	Masked
BLM 228-235	DumpDiag B2D	KLM A12	TIL A19	TIL A19	Mag 1417-1453	Valves to L3 end		Mag 1980-2087	TIS 2967.T4D	Masked	EPS SA2	Masked

μTCA MPS
All Limiting Items

Show also green light.

2021-08-23/16:22:59

Per Section ▾
Vetoes per Server...
RF-station Off-beam Masking...
Housekeepings...



Design Goals of MPS – 2./2

- MPS must be **bullet-proved**
 - ❖ implementation of MPS is a continuous improvement process
- As **simple** as reasonably possible for usability and reliability
- As **invisible** as possible
- As **stateless** as possible internally for operation safety and consistency
- Alarms and responses shall be **well-balanced** for operation availability

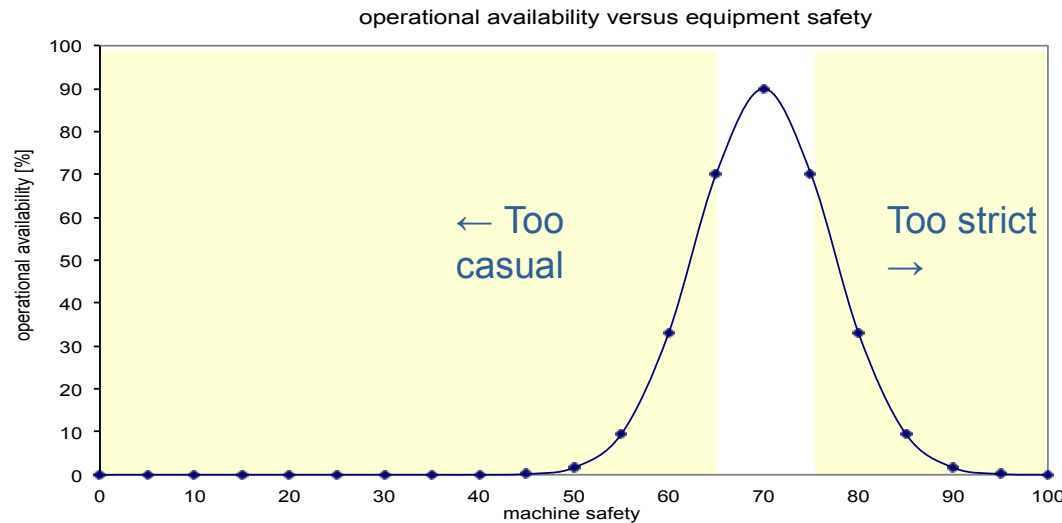


Figure by courtesy of CERN

Thank you for your attention
Comments, questions, proposals are welcome

