XFEL and FLASH

Machine Protection System – MPS

µTCA-based

2nd MTCA/ATCA Workshop for Research and Industry
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HELMHOLTZ ASSOCIATION

DESY

Outline

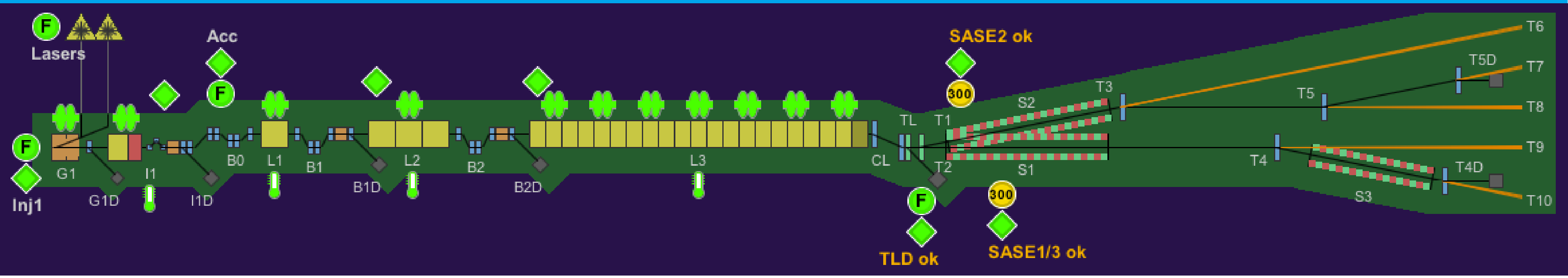
1. Architecture – design goals, purpose, concepts
2. Chosen µTCA-boards
3. Monitored and controlled systems
4. Signal processing – response actions
5. Graphical user interface

Design Goals of MPS – 1./2

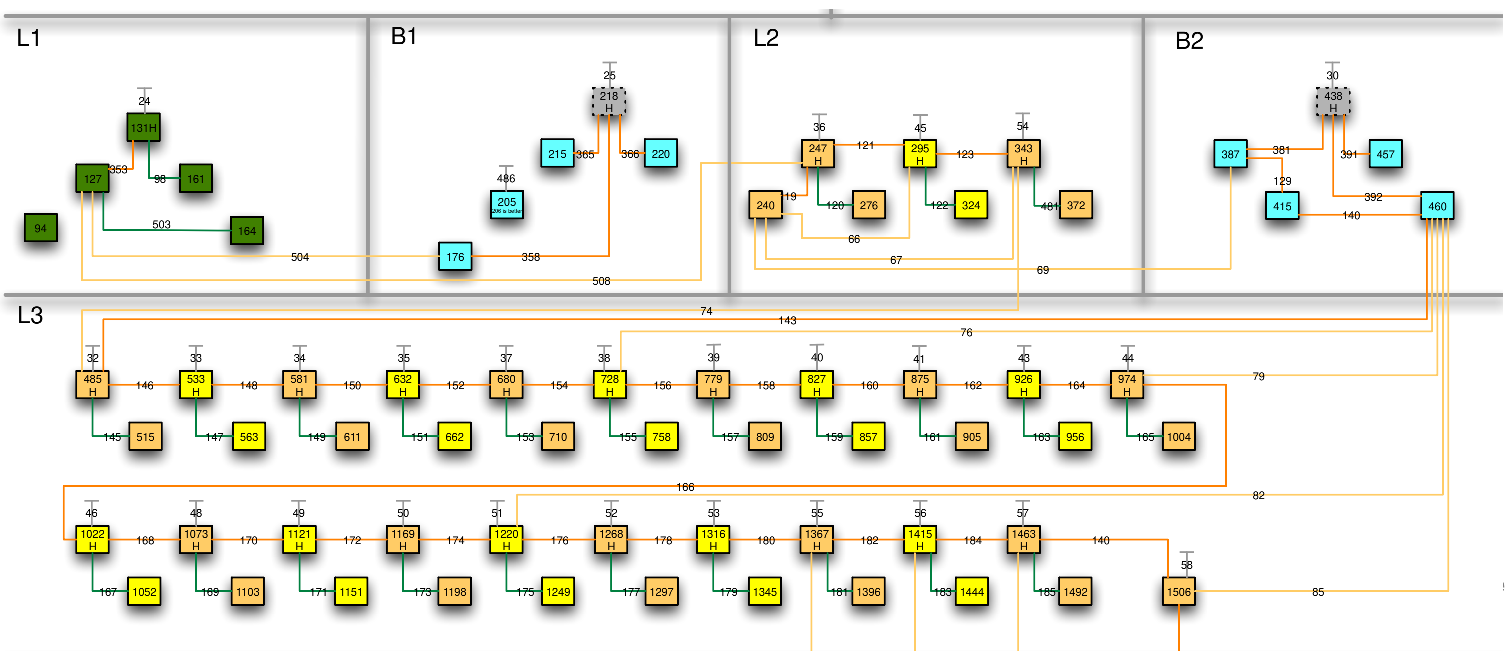
- Designed for **pulsed** FEL-type accelerators
  - Bunch train oriented machines
- **Scalable** in number of monitored inputs and controlled outputs
- **Configurable** alarm-response actions
- **Distributed** over the accelerator – board installations and logic
- Core function **independent** from network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

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

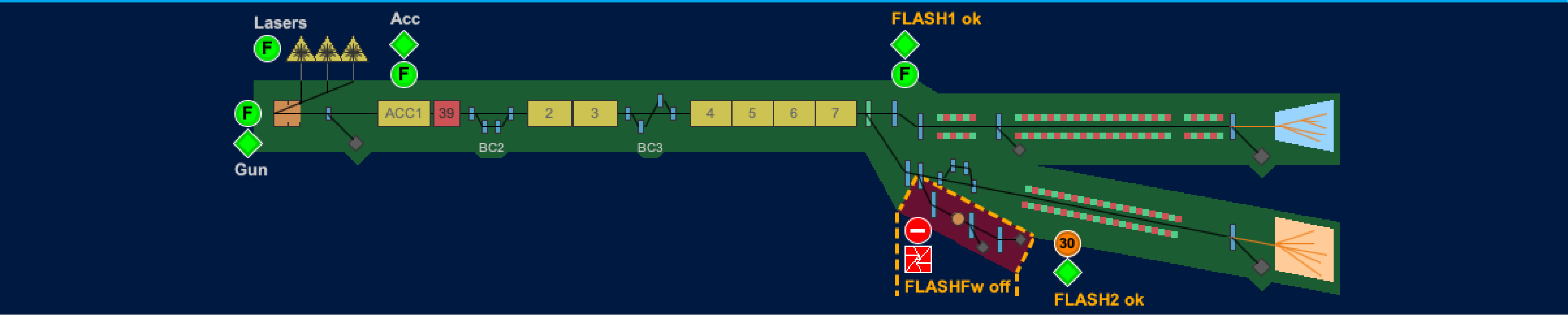
XFEL Architecture – Communication Topology



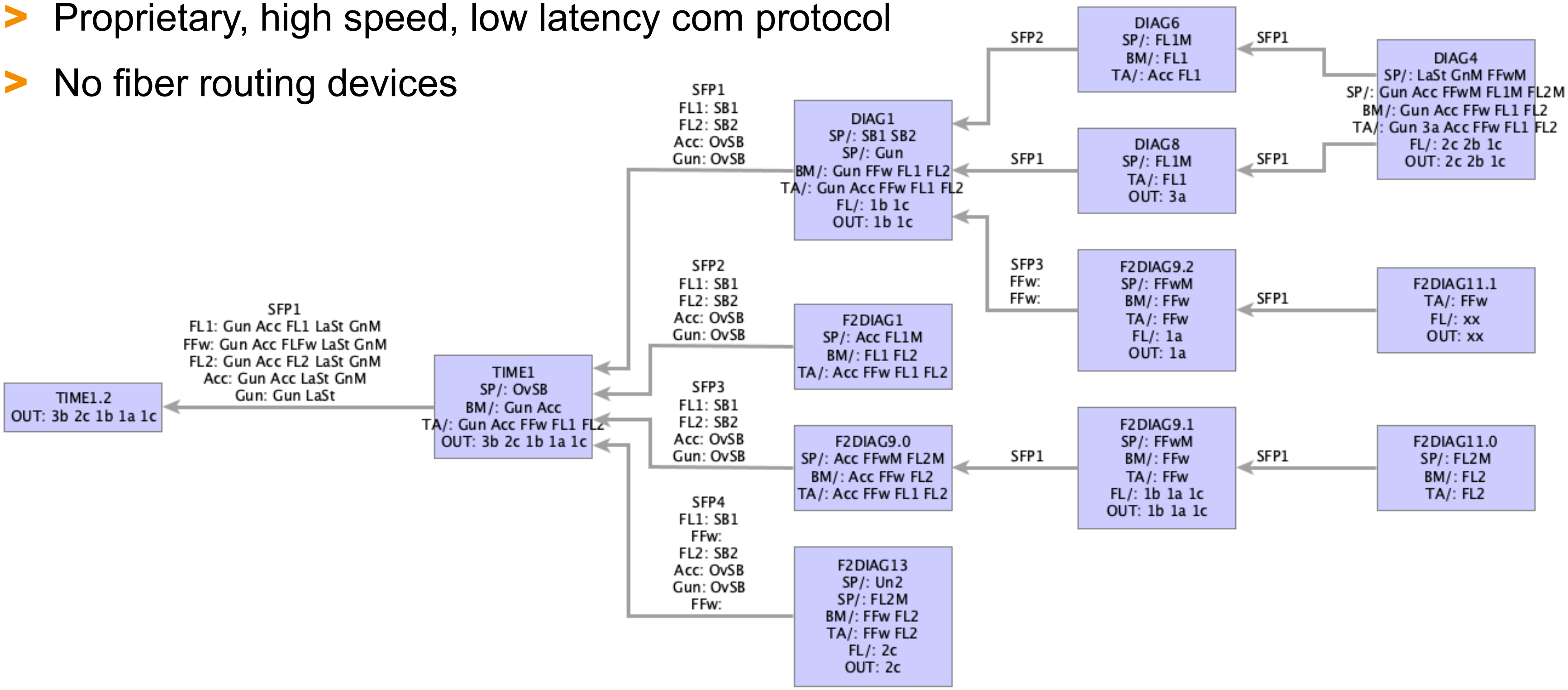
- In XFEL: Currently **152** MPS-boards distributed over **3.5km**
- Dedicated **fiber optics** network with point-to-point communication
- **Cascaded** communication topology with transfer direction from end to start of accelerator



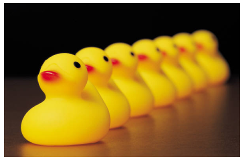
FLASH Architecture – Communication Topology



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



Purpose



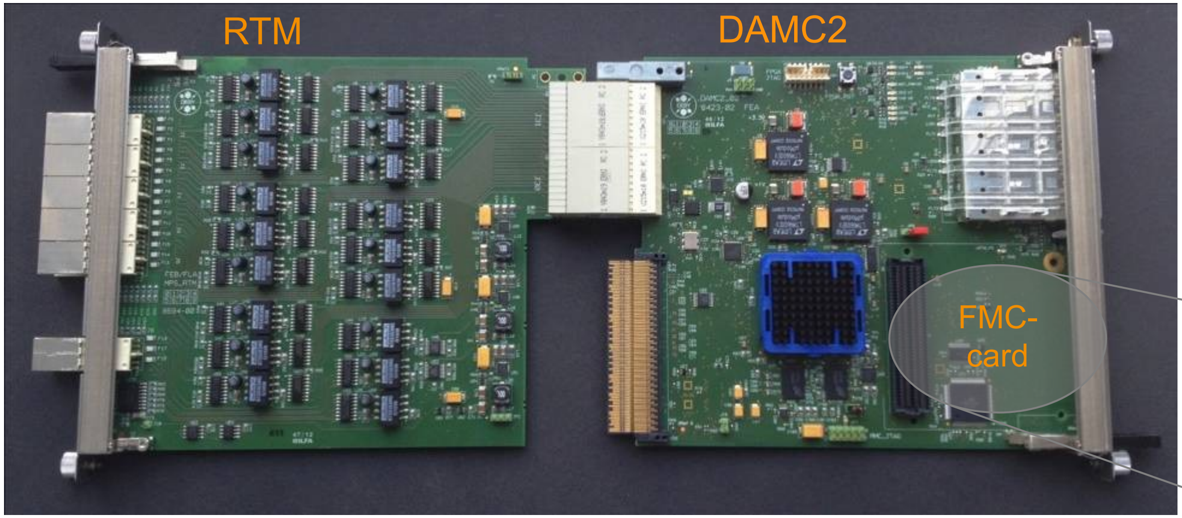
- MPS shall **protect** the accelerator equipment from damage

  caused by unexpected high impact of electron bunches

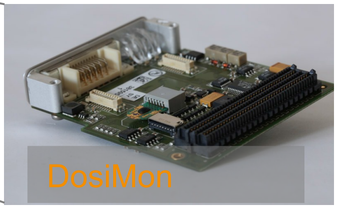
  - e.g. induced radioactivity of beamline parts due to e-beam misalignment
  - e.g. overload of a beam dump due to an inappropriate beam mode
  - e.g. loss of beam line vacuum due to a damage of vacuum valves, diagnostic screens, wire scanners, collimators etc.

- 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

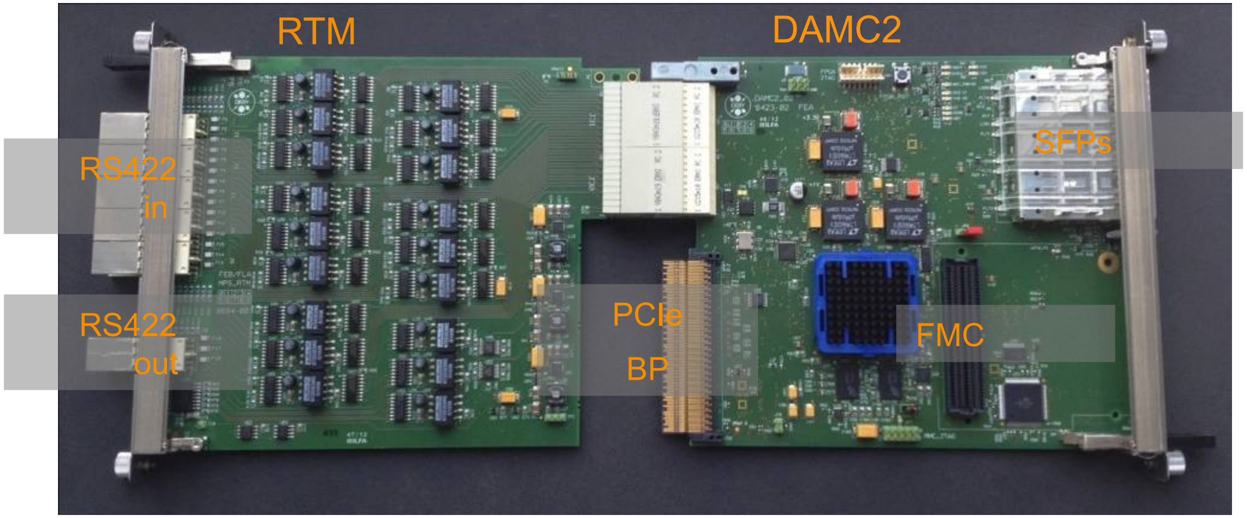


- XILINX Virtex-5 FPGA
- MMC support
- onboard flash-memory
- 1 Gbit SDRAM
- optional dosimetry FMC-card



- 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 Compression Mon	
OTR Screens	Wire Scanners	Faraday Cups	Collimators	Dosimetry Monitoring	
Equipment Protection 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...10µs 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 µTCA backplane

  - e.g. “Cut off the rest of the current bunch train for beam line SASE2”

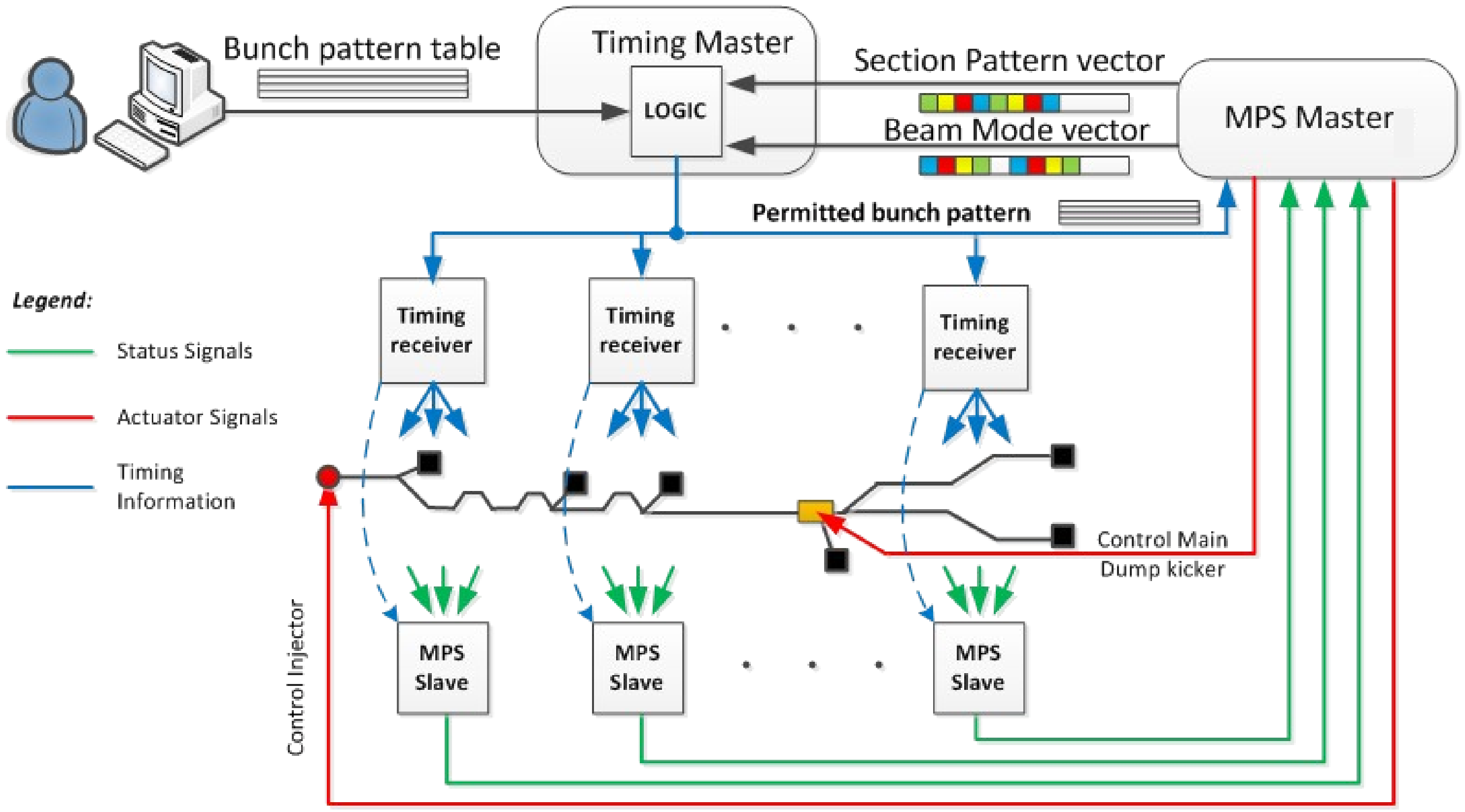
Timing Master

> 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

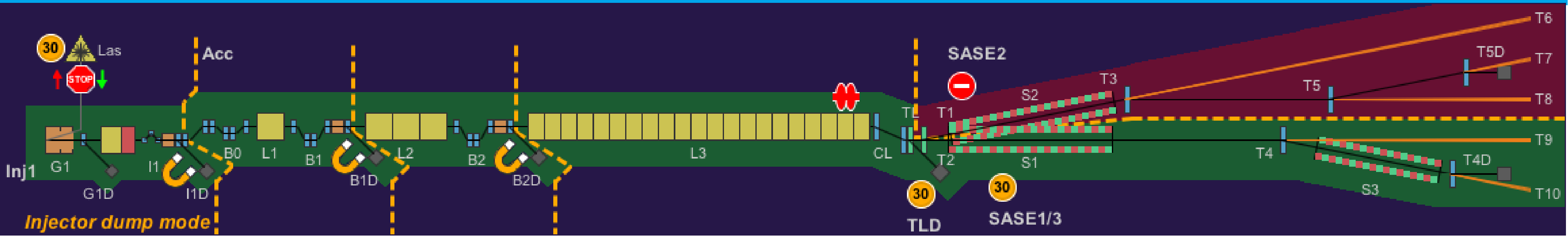
  - e.g. “Reduce to 30 electron bunches per bunch-train for common accelerator section!”
    e.g. “Reduce to 2 electron bunches per bunch-train within injector section!”

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

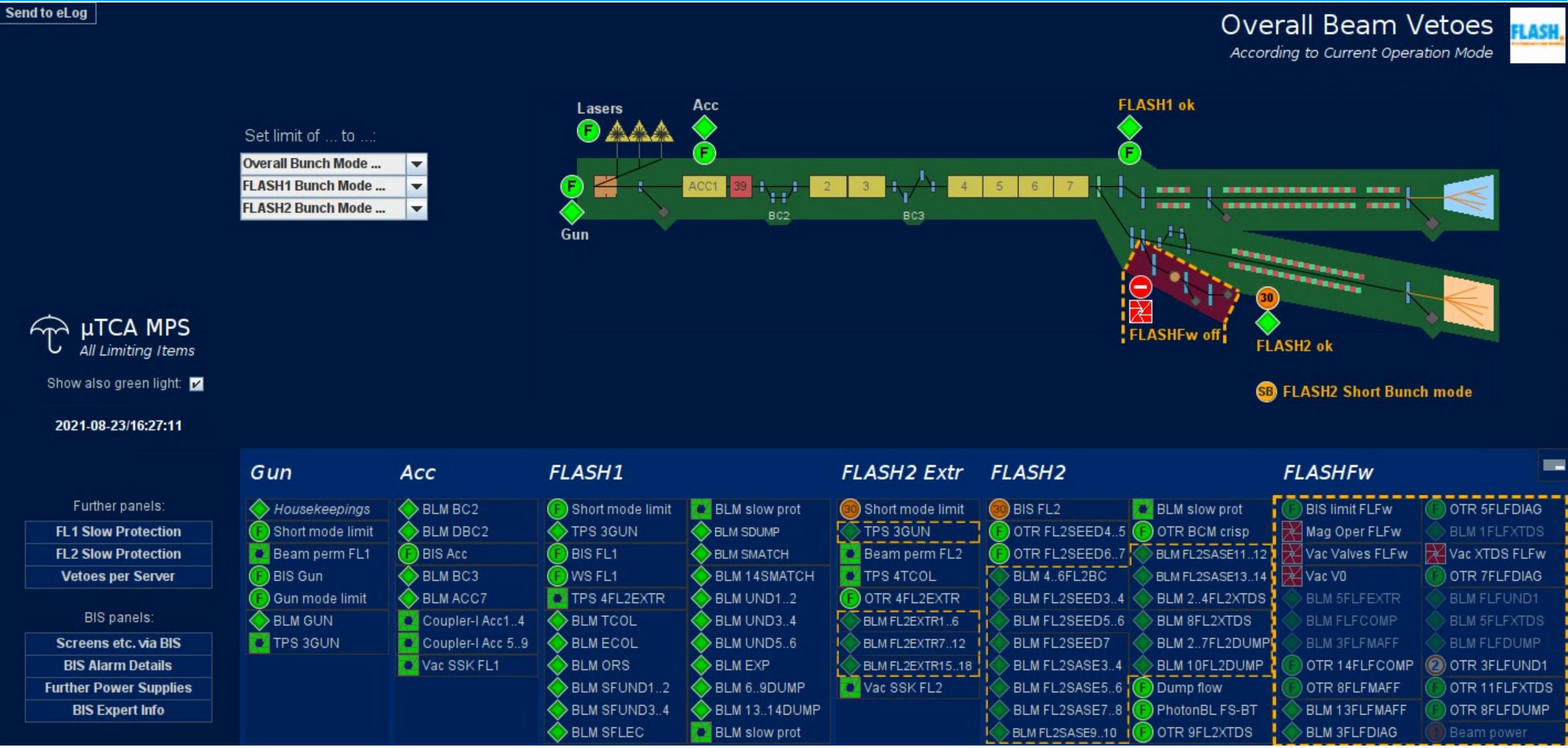
- timing system does not trigger injector laser pulse controllers for certain destinations anymore
- and laser pulse controllers do not accept triggers from timing system for certain destinations anymore

Alarm-response Actions

- Each alarm response can be configured signal-individually
  - Possible response types:
    - inter bunch train stop – e.g. through Pockels-cell inhibit or dump kicker activation
    - section unavailablilty – e.g. injector laser shutter close
    - reduce numer of bunches per train – i.e. limit through timing system bunch counter
    - change operation mode – e.g. change into „injector dump mode“
    - masking/gating certain other input lines – e.g. if all undulators are open, ignore few BLMs
  - Response can depend on:
    - **type** of system, which reports the alarm – e.g. dipole magnets vs. BLMs
    - **meaning** of the alarm line – e.g. OTR screen moving or screen reached its position
    - **location** of alarm source – e.g. before or within SASE sections
- Example:

Section:	**Injector**		**Acc**				**SASE**	**SASE**
	G1	I1	L1	L2	L3	TLD	SA1/3	SA2
OTR screen moving:	P-cell inhibit	P-cell inhibit	P-cell inhibit	P-cell inhibit	P-cell inhibit	P-cell inhibit	Dump kicker	Dump kicker
valid pos reached:	Max 2 bunches	Max 2 bunches	Max 2 bunches	Max 2 bunches	Max 2 bunches	Max 2 bunches	Max 2 bunches	Max 2 bunches

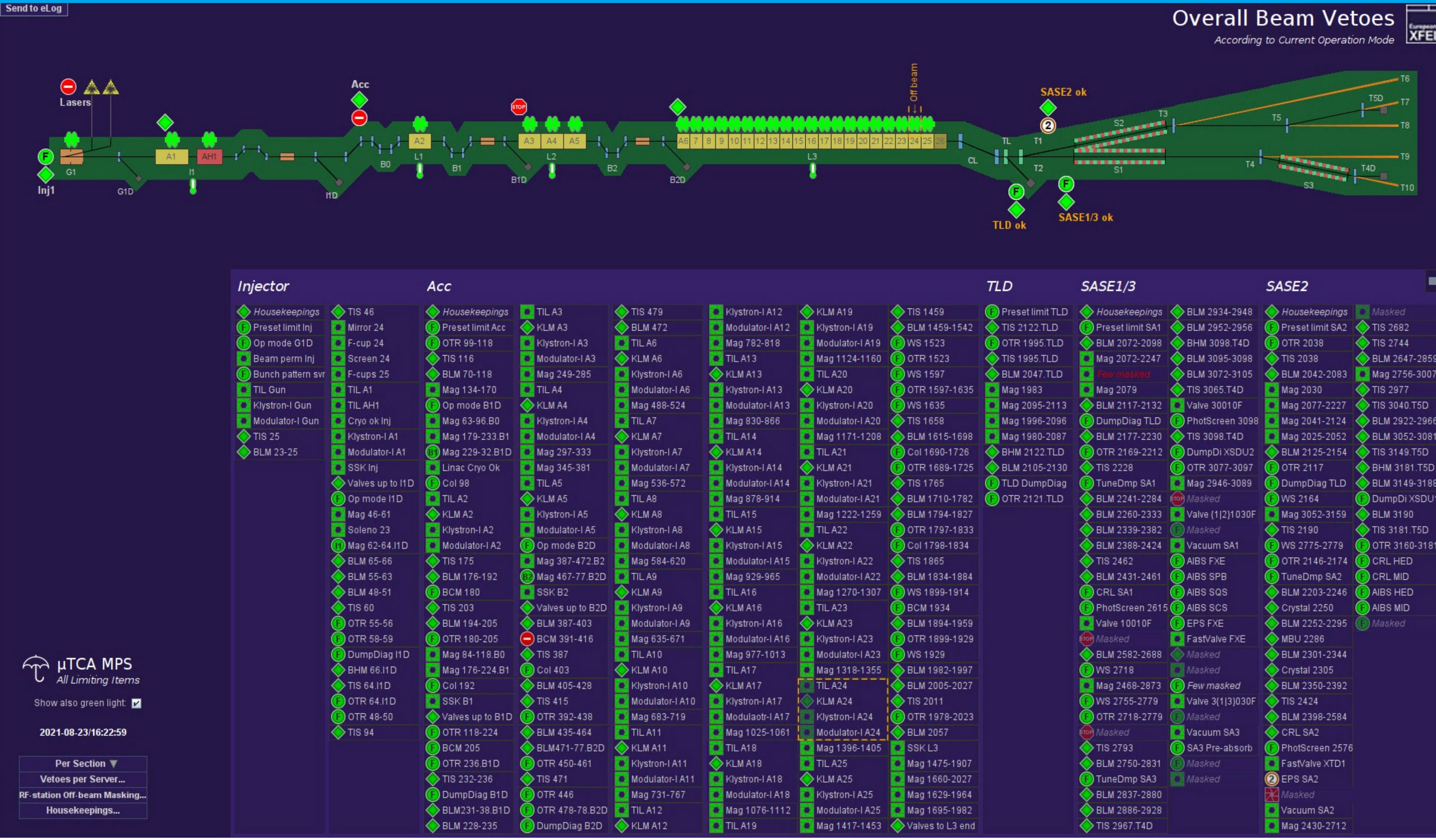
FLASH Control Room – GUI



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



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

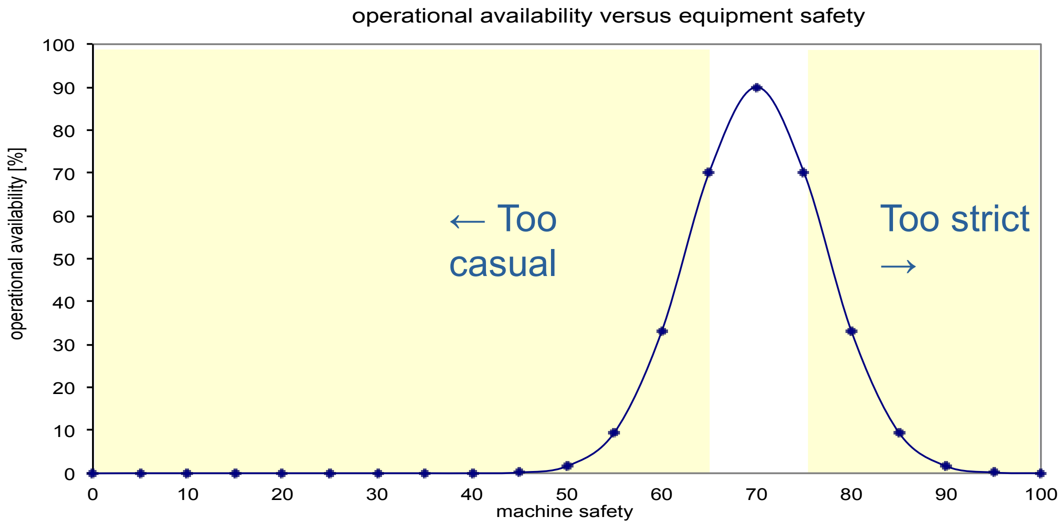


Figure by courtesy of CERN

Discussion…

Thank you for your attention

Comments, questions, proposals are welcome