XFEL & DESY FLASH – MPS

Machine Protection System (MPS) based on MicroTCA (µTCA)

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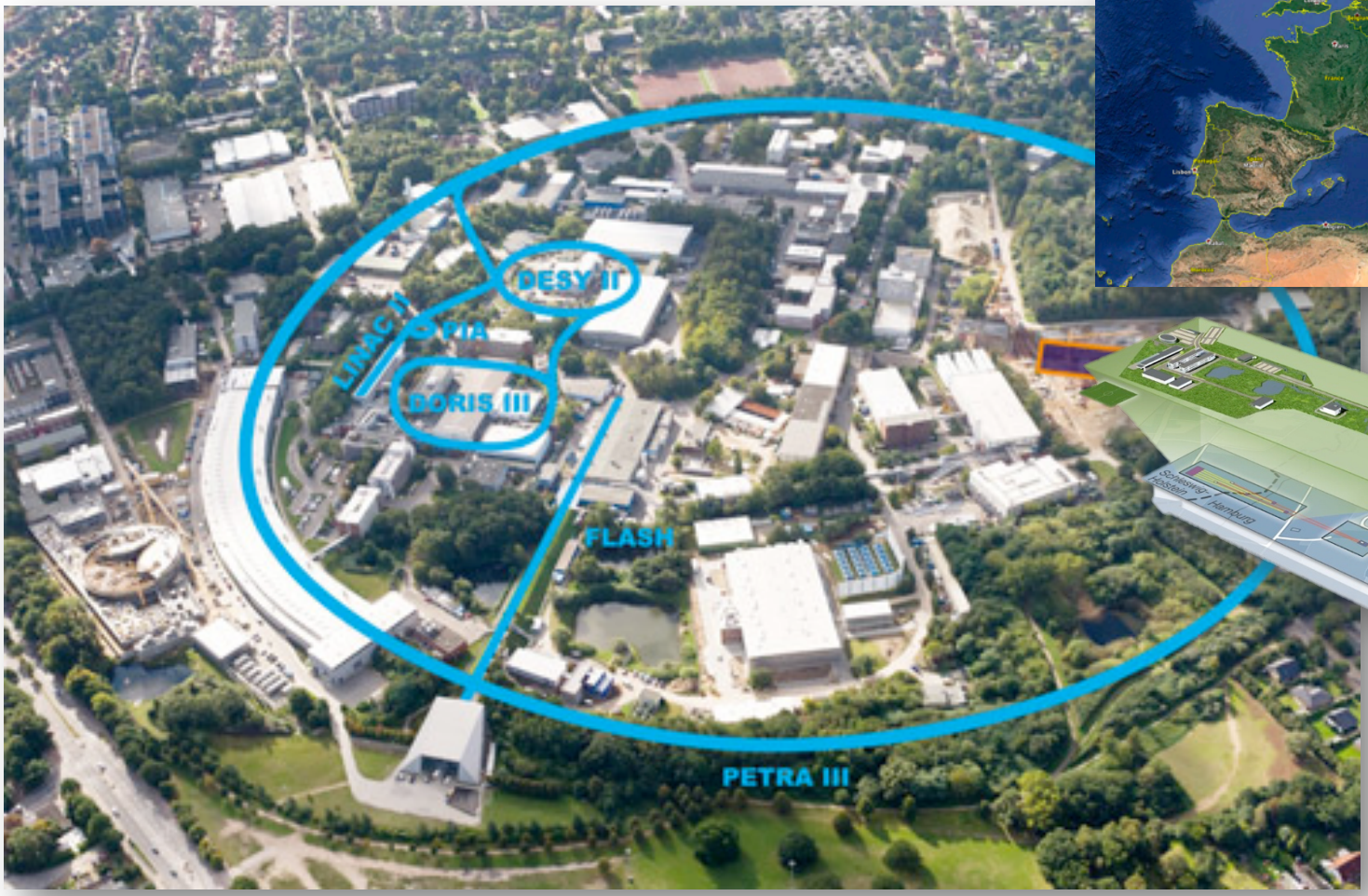
HELMHOLTZ ASSOCIATION

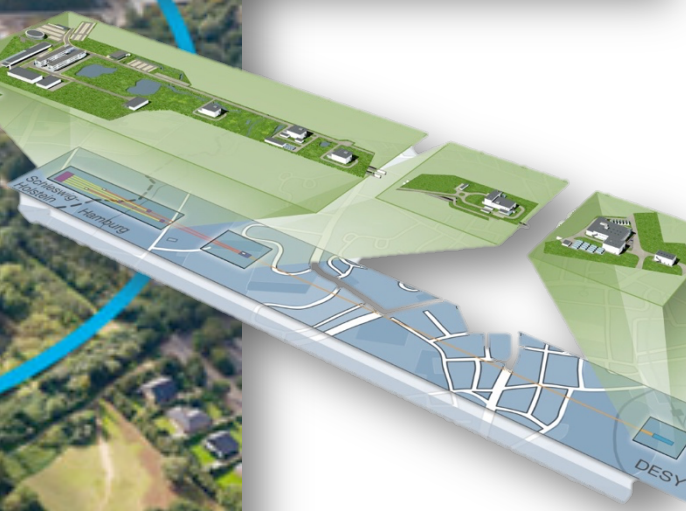
DESY

Outline

1. Purpose of MPS
2. Overall requirements
3. Interfaces
4. Architecture
5. Features
6. Design
7. Summary
8. Status

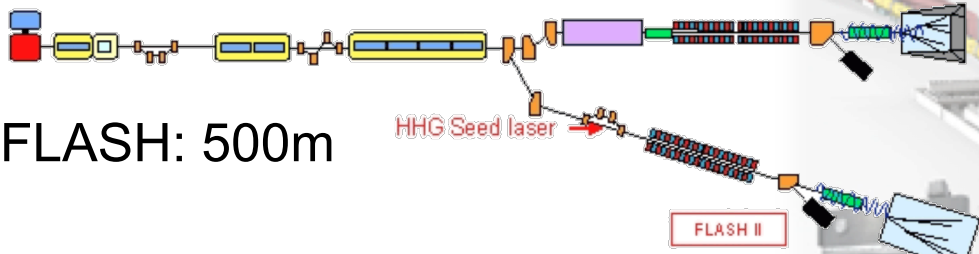
Location





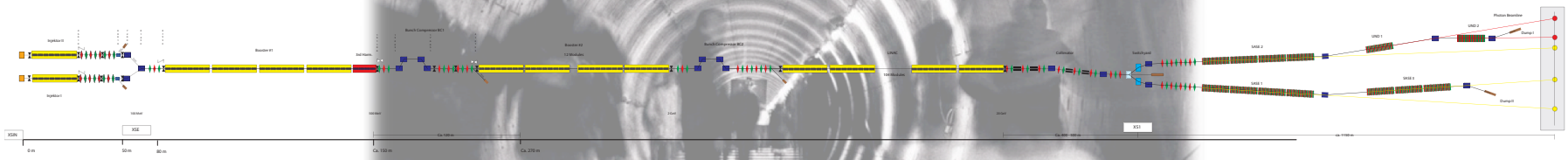
XFEL and FLASH - DESY

Overall lengths:



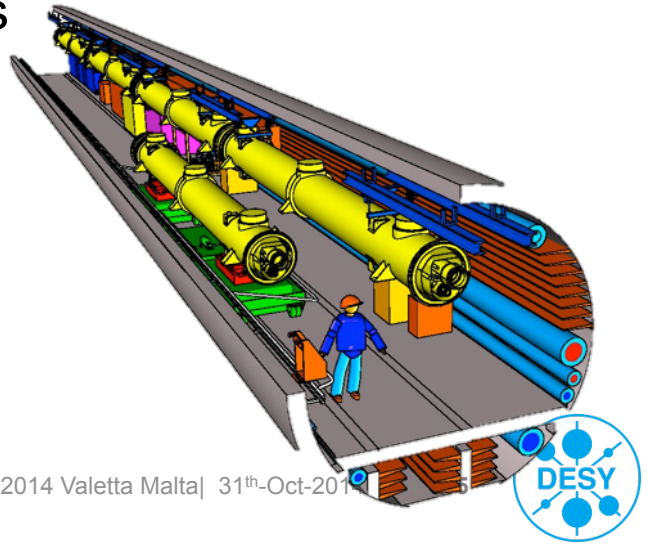
FLASH: 500m

XFEL: 5.4 km

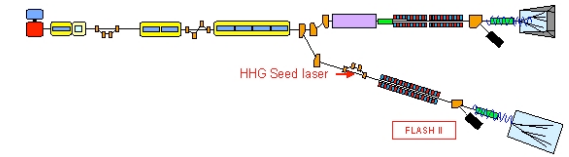


MPS Design Goals

- Maintenance without shutdown the accelerator
- Remote firmware update
- Remote investigation of problems
- Reduce costs
- Reduce manpower
- Reduce latency of alarms
- Reduce number of cables and fiber optic lines
- Reliability of components
- No programming – but configuring
- Scalability
- same hardware as the rest of XFEL



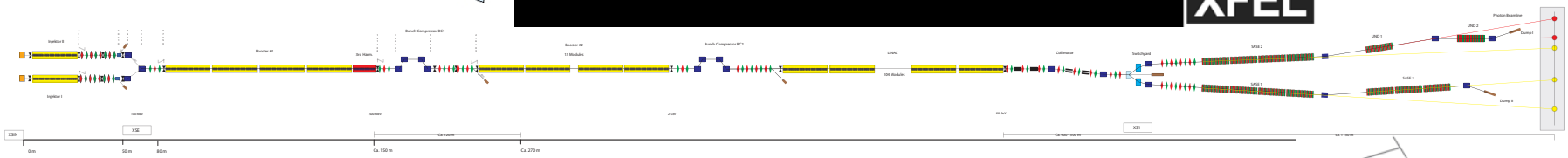
Scalability - FLASH, XFEL, ILC

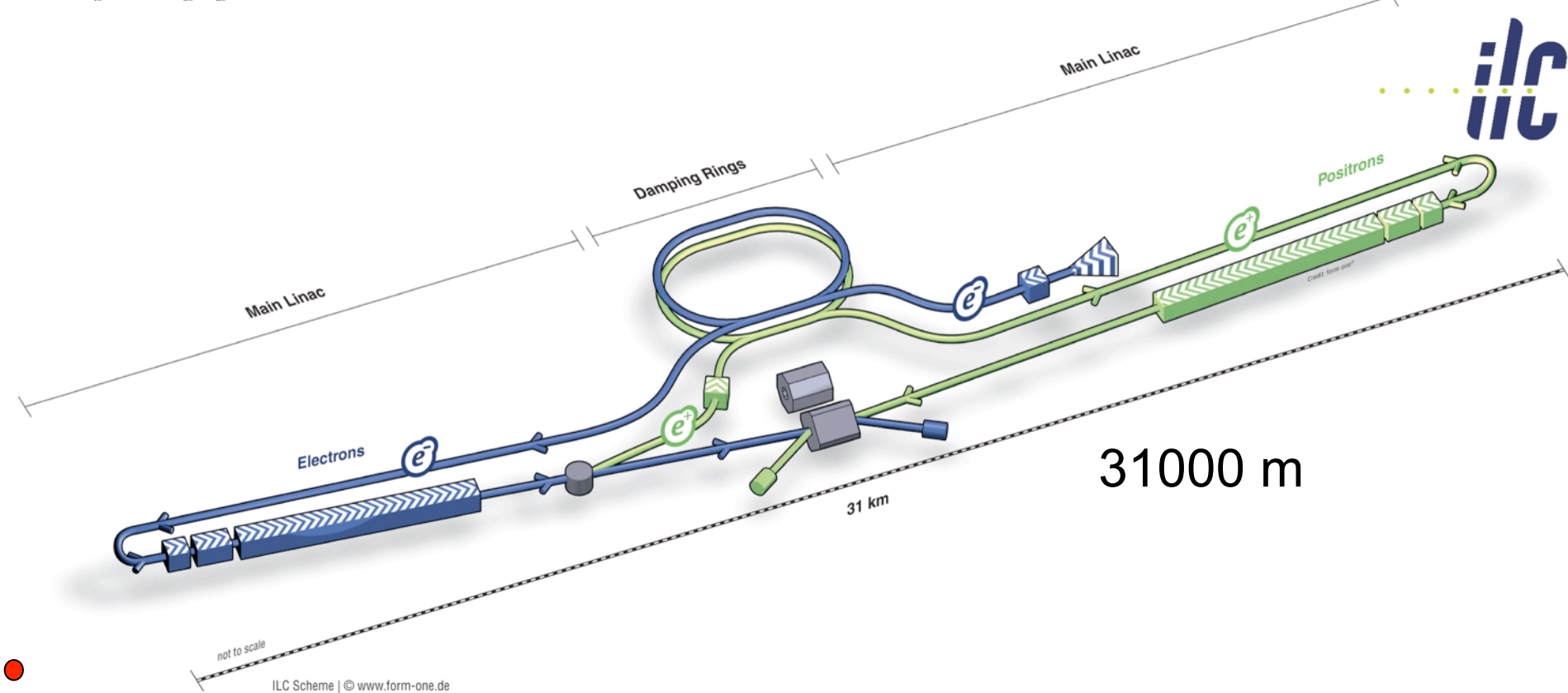


FLASH.
Free-Electron Laser FLASH

European XFEL

3400 m





31000 m

Why do we need an MPS at all?

- MPS produces work
- MPS reduces uptime
- MPS always wants to know the status
- MPS limits freedom

Define the purpose of XFEL MPS

- MPS **protects** the accelerator from damage
  - esp. produced by electrons or photons directly or indirectly
  - e.g. caused by orbit drifts, beam misalignments of many kinds …
  - e.g. caused by subsystems' failures …
  - e.g. caused by inappropriate beam modes during diagnostic routines
    - wire scanning, TDS-activity

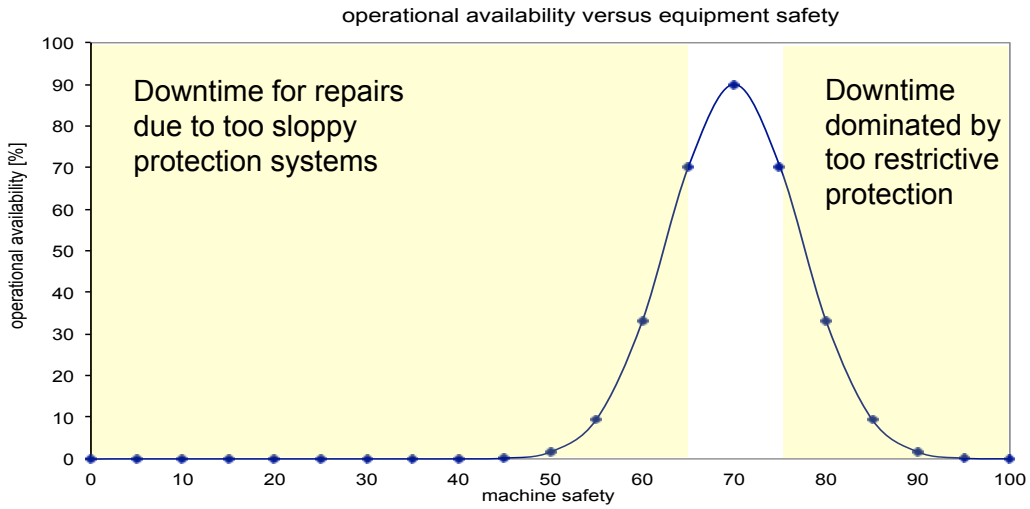
- MPS **detects** that indirectly through a whole lot of interlock, alarm, warning and status signals from a multitude of (diagnostic) systems
- MPS **reacts** accordingly by stopping or throttling the electron beam
  - How, when and by means of …? – will be shown on the next slides

Clarify what XFEL MPS is NOT

- does not accept beam mode wishes from the operator
  - it limits his or her wishes; based on the actual settings in the Timing System
- does not control subsystem's operation, e.g. wire scanners
  - it limits the beam if operator has forgotten that
- does not evaluate any parameter against threshold limits
  - that is the responsibility of the supplying subsystems
- does not protect staff personnel
  - but the working group named 'MPS' does

Overall Requirements

- MPS must be **bullet-proved**
  - XFEL benefits from **FLASH2** as the new µTCA-based MPS is used there first
- MPS' alarm-responses shall be **well-balanced**
  - protection shall be as sensitive as necessary, but also as tolerant as reasonable possible to still enable a properly operable system



- MPS shall be as **invisible** as possible
- should be look like as **one** comprehensive MPS
  - besides the equipment protection system for the photon beamline and
  - the personnel interlock system

List of Interlock Supplying Systems

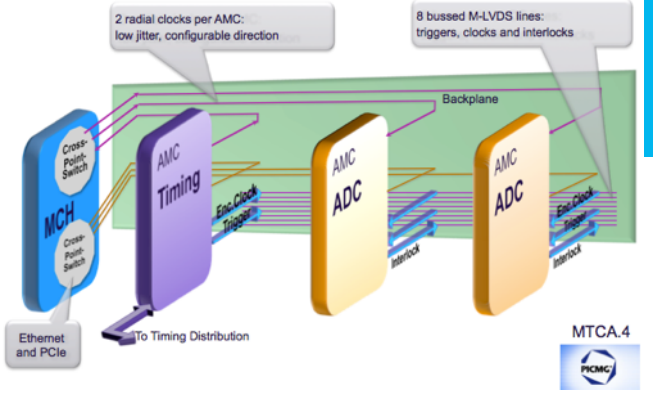
As agreed upon the MPS-CDR

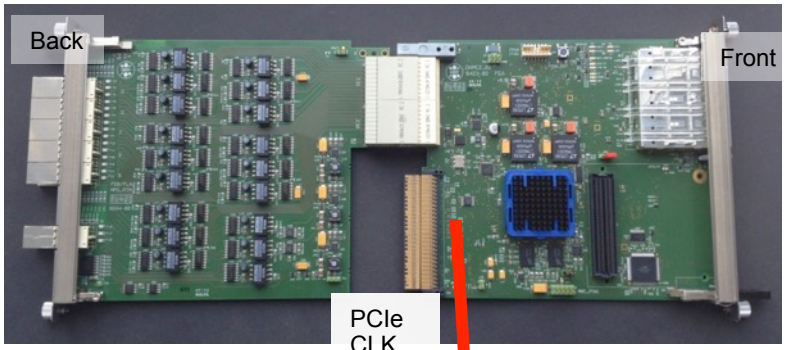
- MPS will receive ~2000 interlock, alarm, warning and status signals from ~27 types of systems
- MPS usually accepts only summary interlock signals
- Signal levels must be RS422-conform
  - a TTL-signal level converter can be provided

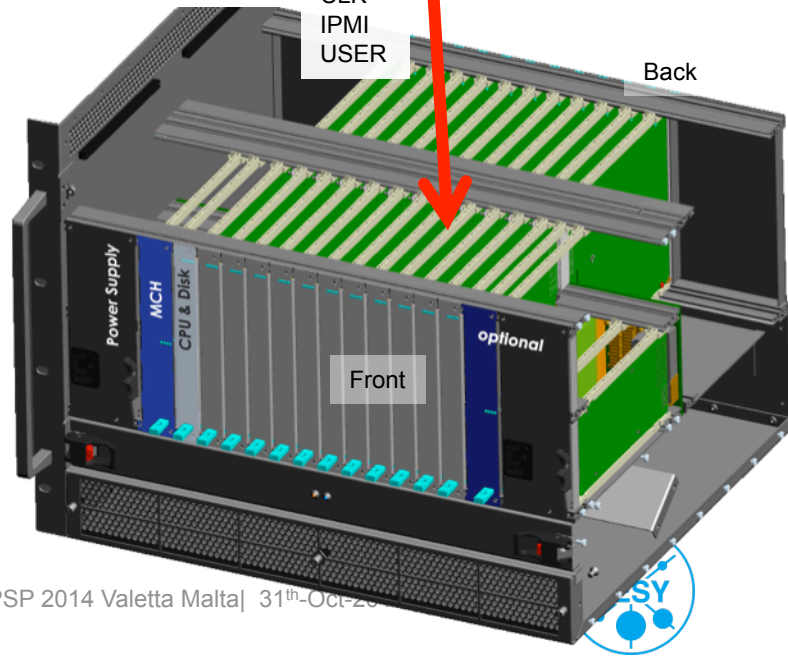
System	Approximate number of signals to MPS	Subsystems' task
Vacuum	30	Determine Operation Mode
Cryo	10	Determine Operation Mode
Magnets bending I & BC sections (warm)	5	Determine Operation Mode
Magnets bending undulator sections (warm)	5	Lead beam to linac dumps
Magnet steerers & quads (cold & warm)	600	Steer and focus beam
Coupler interlock	28 (+3 later)	RF protection
LLRF	56	Steering beam
Klystron interlock	28	RF for beam
Modulators	28	RF for beam
BLM	350	Monitor beam losses
BHM	24	Halo monitor
Wire scanner	44	Diagnostics
TPS	32*6	Monitor beam loss
BPM	72	Orbit position
Dump diagnostics	30	Protect dump and avoid radiation activation
Dump kicker	1	Dump beam
Distribution kicker	1	Distribute beam to SASE lines
Laser	1 per laser	Laser pulses
OTR screens	27	Diagnostics
OTR screens in TDS	8	Diagnostics
Photon Beamlines	9	Protect photon beamline components
Collimators	5	Protection of Undulator sections
Beam OFF	1	Switch all Beam OFF manually
Radiation monitors	390	Measure radiation
Personnel Interlock	12	Information
Timing System	150	Running information
MPS	2000	Alarm information

MicroTCA

- Remote maintenance
- Online update of FPGA firmware
- HOT SWAPable
- IPMI Management for 12 AMC modules
- Management for up to 4 Power Modules
- Management for up to 2 Cooling Units
- Optionally provides Shelf Management
- Front Panel Alarms
- Clock Distribution system
- Fabric Channel Uplink
- UPTIME 99.999%

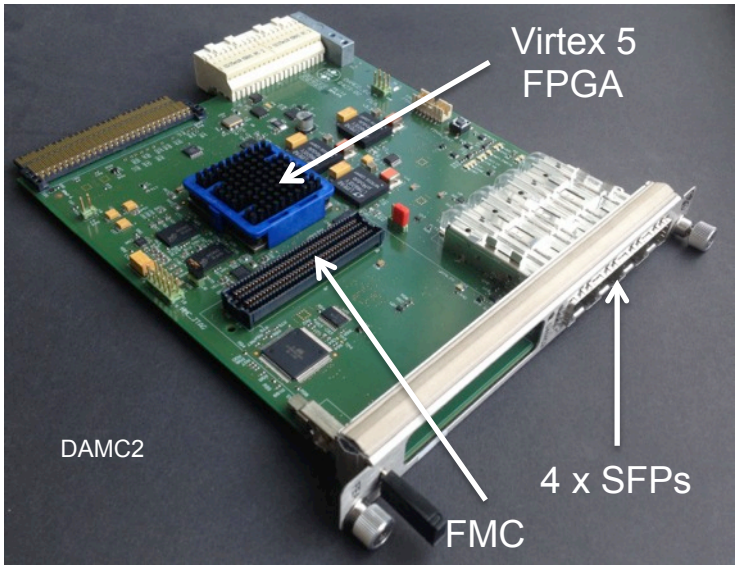


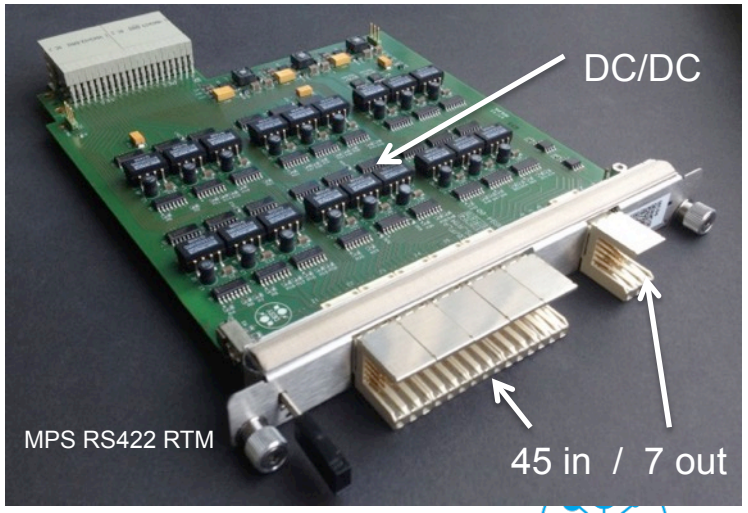




MPS DAMC2 hardware features

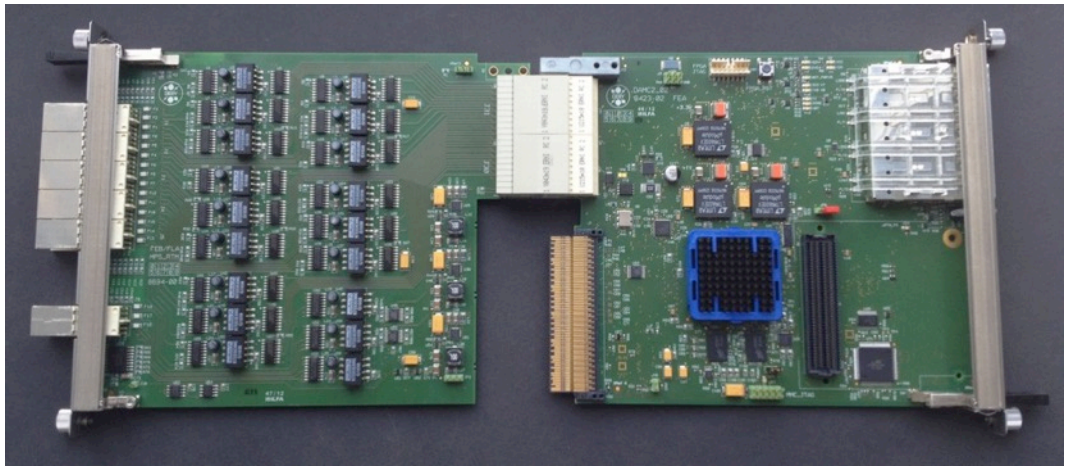
- FPGA driven
- 45 RS422 external input channels
- 3 internal input channels for FMC
- 7 RS422 output channels, 1 Backplane Output
- Galvanic isolation
- I^2C support to FMC
- 4 SFP I/O fiber optic lines (0-4 Inputs, 0-4 outputs)
- Indirect redundancy
- Fast internal RS422 link from in- to outputs
- Debug Register
- LED status indicator (heart beat, server connection, initialization)





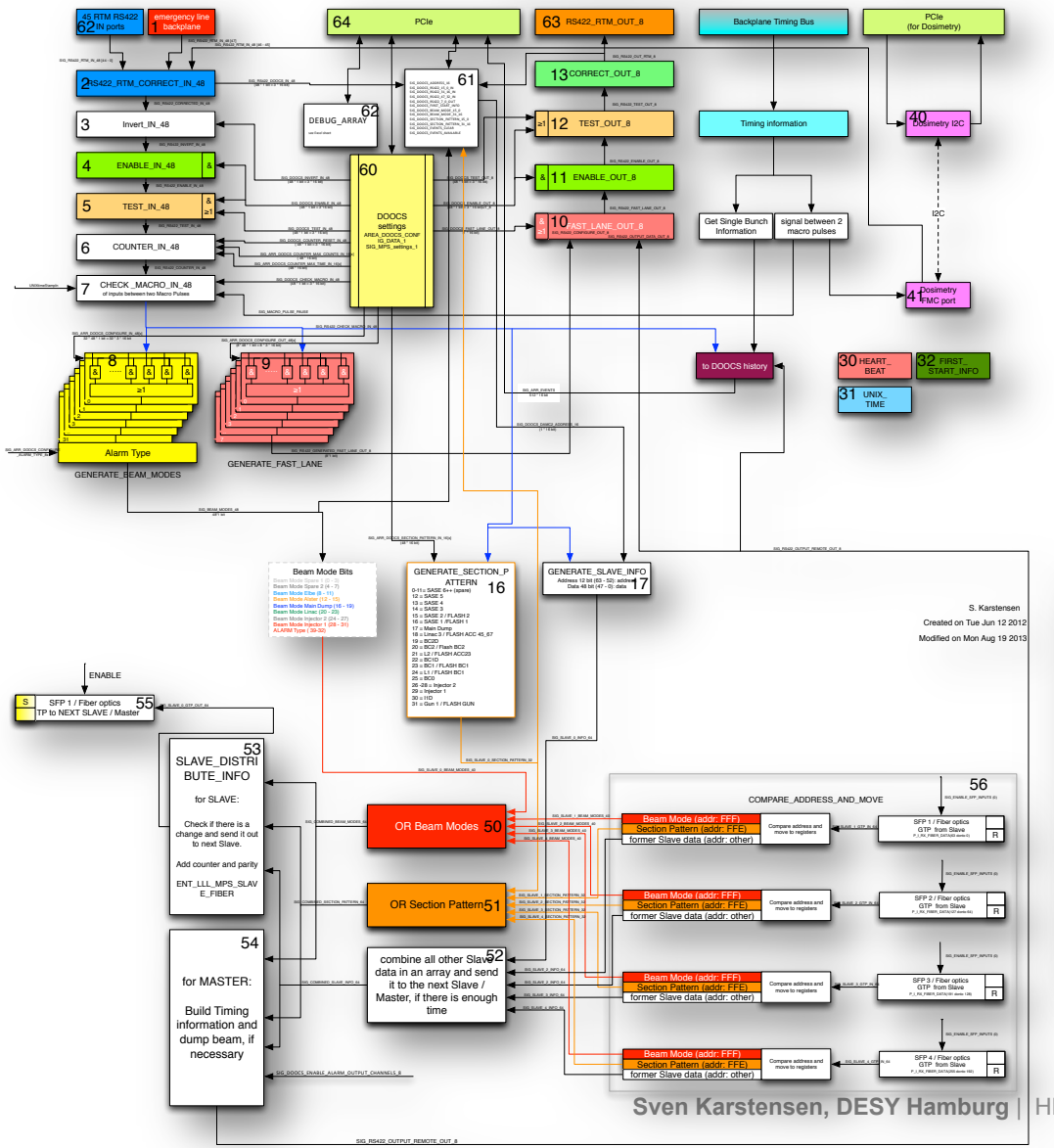
MPS DAMC2 overall features

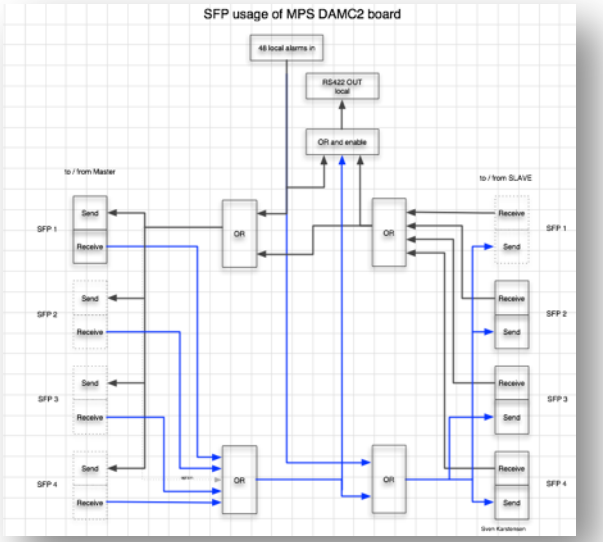
- Scalability
- same firmware in every DAMC2
- Every DAMC2 slave holds all information of all prior connected slaves (debugging)
- Every slave can be connected to the timing system
- Every slave can be hold one I2C driven FMC Dosimetry board
- **Configurable – NOT programmable**

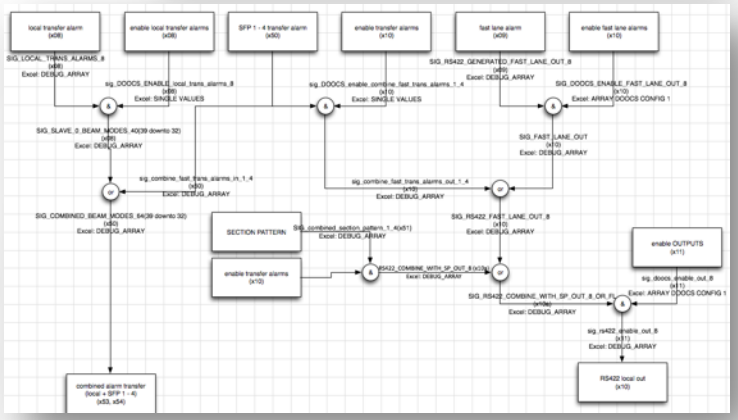


Digital Functionality inside FPGA

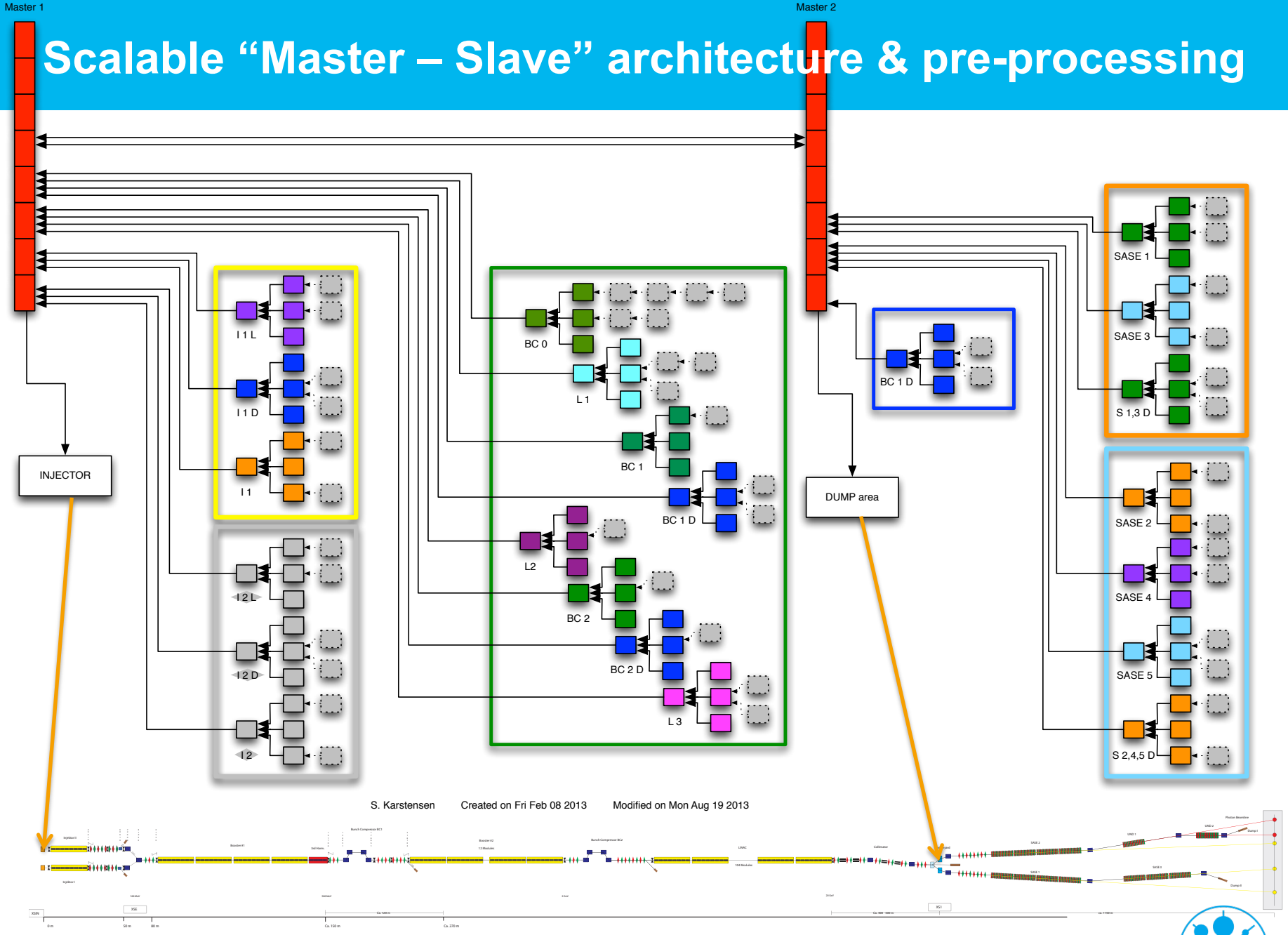
MPS SLAVE structure



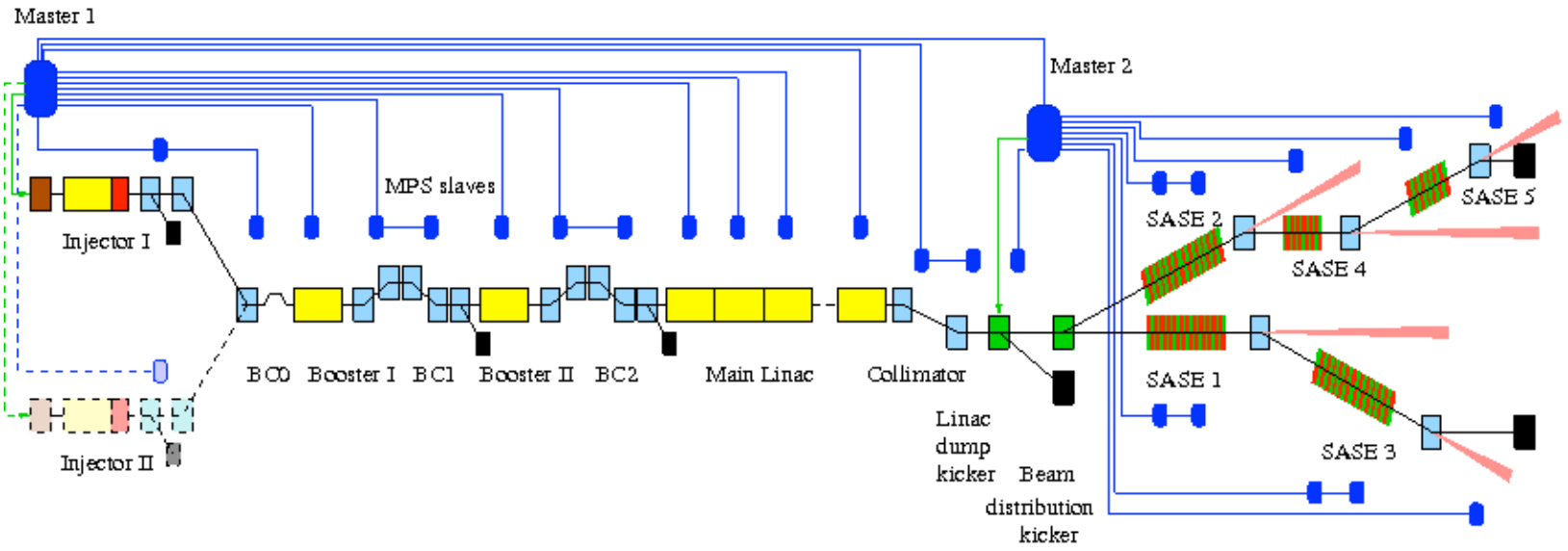




Scalable “Master – Slave” architecture & pre-processing

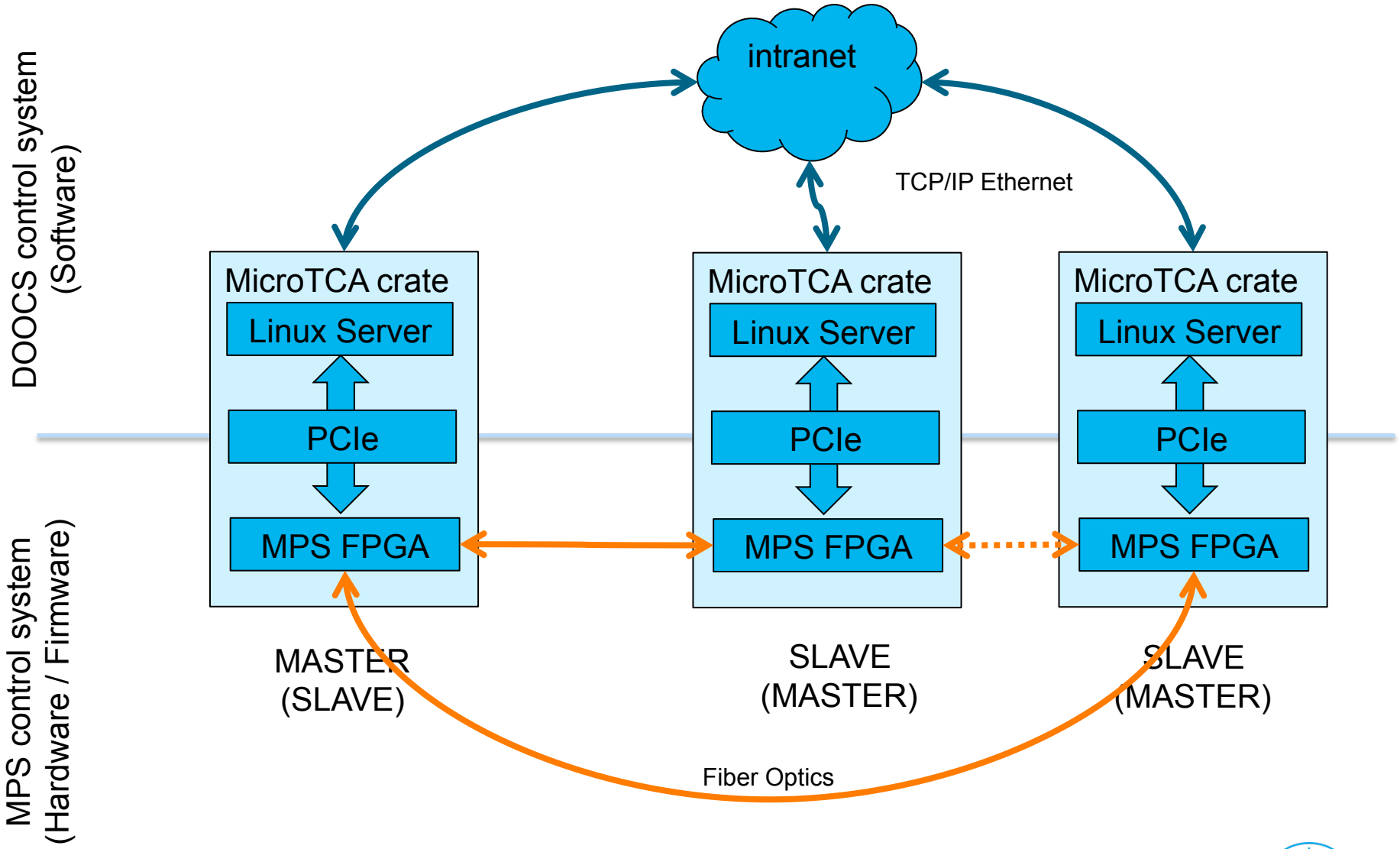


MPS Architecture in XFEL



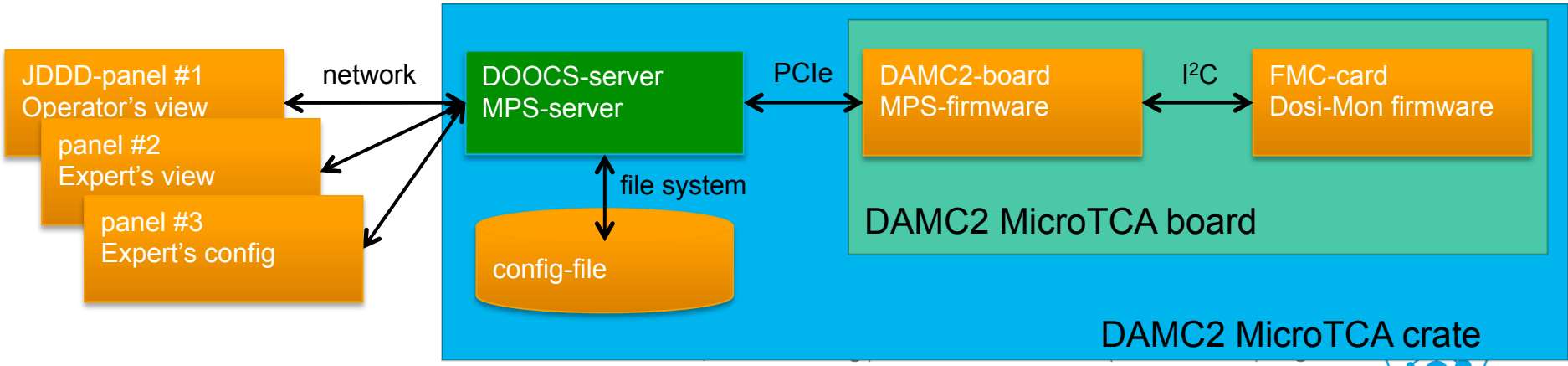
- The locations of ~120 MPS-boards were optimized according to short distances
  - to keep the signal-run times as short as possible to minimize the time frame an alarm situation has occurred and the beam has been effectively stopped
  - fiber optics for long-distance communication between MPS-boards
    - electrical potential free
    - robust against talk-over
    - fail-save due to the used protocol and its continuous communication
  - RS422 from interlock supplying systems and to the controlling actuators
    - robust due to differential, relatively-high voltage signals
    - fail-save because cable shunts or breaks result in error states

Control system and SAFETY structure

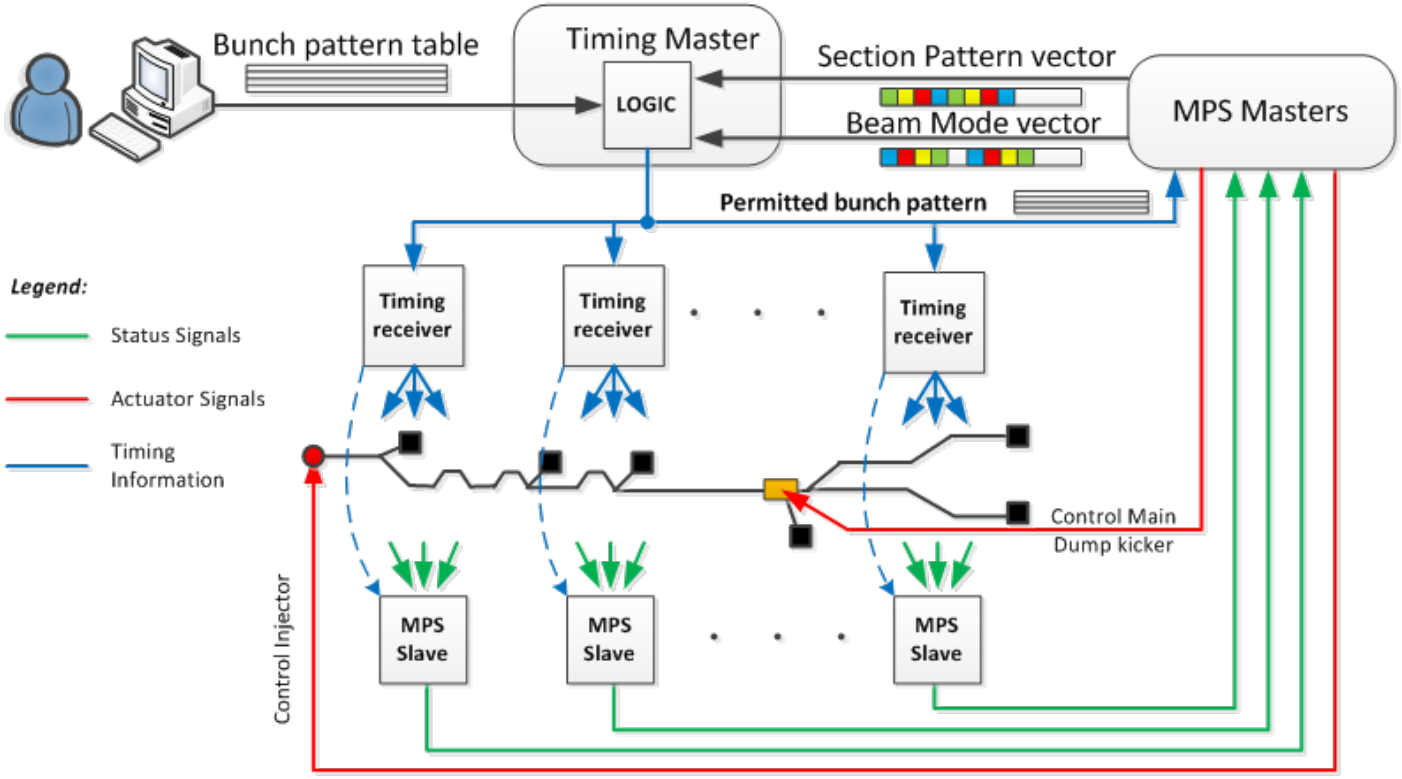


DOOCS control system – Server (Software) View

- Maintainability
  - **same server-software – Masters AND Slaves – but differently configured**
  - conformance between server software and FPGA firmware is checked
  - server-software supports hot-plugging of boards – auto-upload of static config
- JDDD-panels
  - for operators – graphical view to the first master only
  - for experts – graphical and textual views to all masters and slaves
- Synchronization / update times
  - JDDD-panels and MPS-server – widget-dependable between 1 and 10 Sec.
  - MPS-server to DAMC2-board – per macro pulse (10 Hz)
  - MPS-server to FMC-card via DAMC2 – per macro pulse (10 Hz)

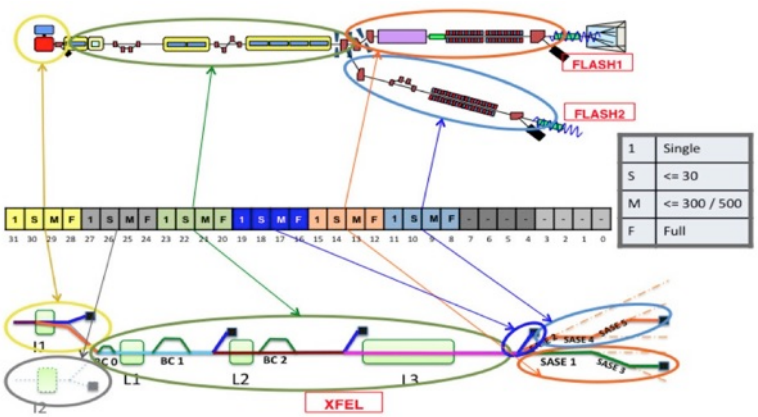


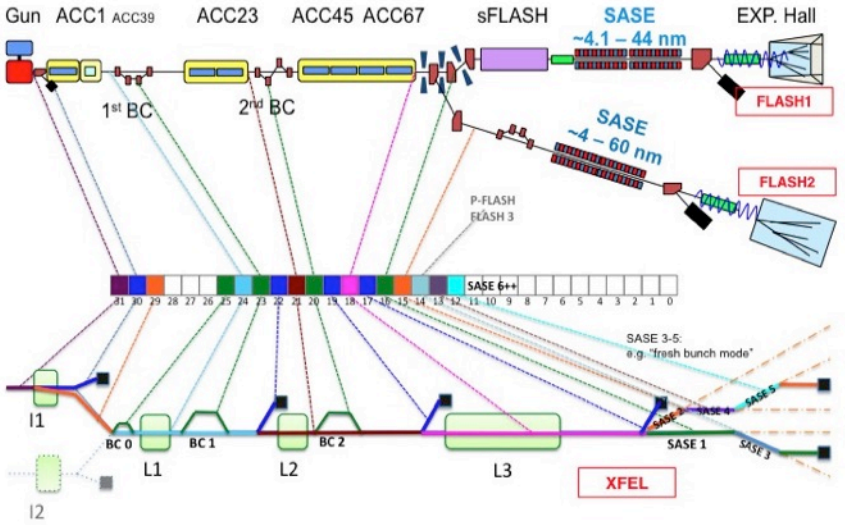
Timing System Integration



- The operator tells the Timing System the demanded beam parameters
- MPS detects the current machine state through its supplying (diagnostic) systems and tells the Timing System its beam vetoes in form of Section Pattern and Beam Modes vectors
  - MPS also have a master-slave architecture with a slaves to masters communication structure
- but MPS is also able to bypass the Timing System temporarily to directly control laser and kicker

Information and protocol structure





Beam Modes
> 1000

63-52						
Sec 63-58	Addr 57-52	51	50-48	47-40	39-32	31-0
FFF 12 (6+6)		P 1	CNT 3	spare 8 bit	ALARM Type 8 bit	BEAM Modes 32 bit

Section Pattern
only 1

63-52						
63-58	57-52	51	50-48	47-40	39-32	31-0
FFE 12 (6+6)		P 1	CNT 3	spare 8 bit	spare 8 bit	SECTION PATTERN 32 bit

Fiber optics information / protocol

Configuration possibilities

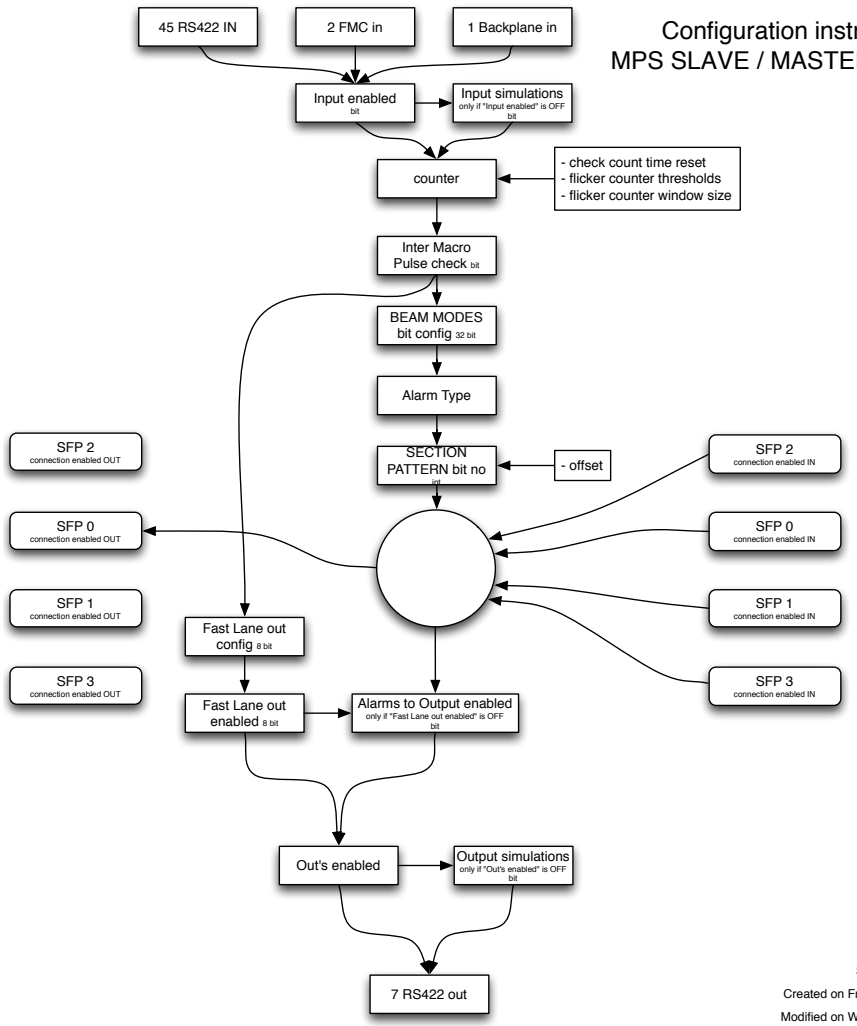
- Configuration for:
  - IN- and OUTput enabling
  - input signal bouncing filter settings
  - Fast Lane enable
  - Transfer Alarm
  - Beam Modes
  - Section Pattern
  - enable MPS-board communication
  - enable Timing System communication

- QR-code database fill-in
  - locations, specifics

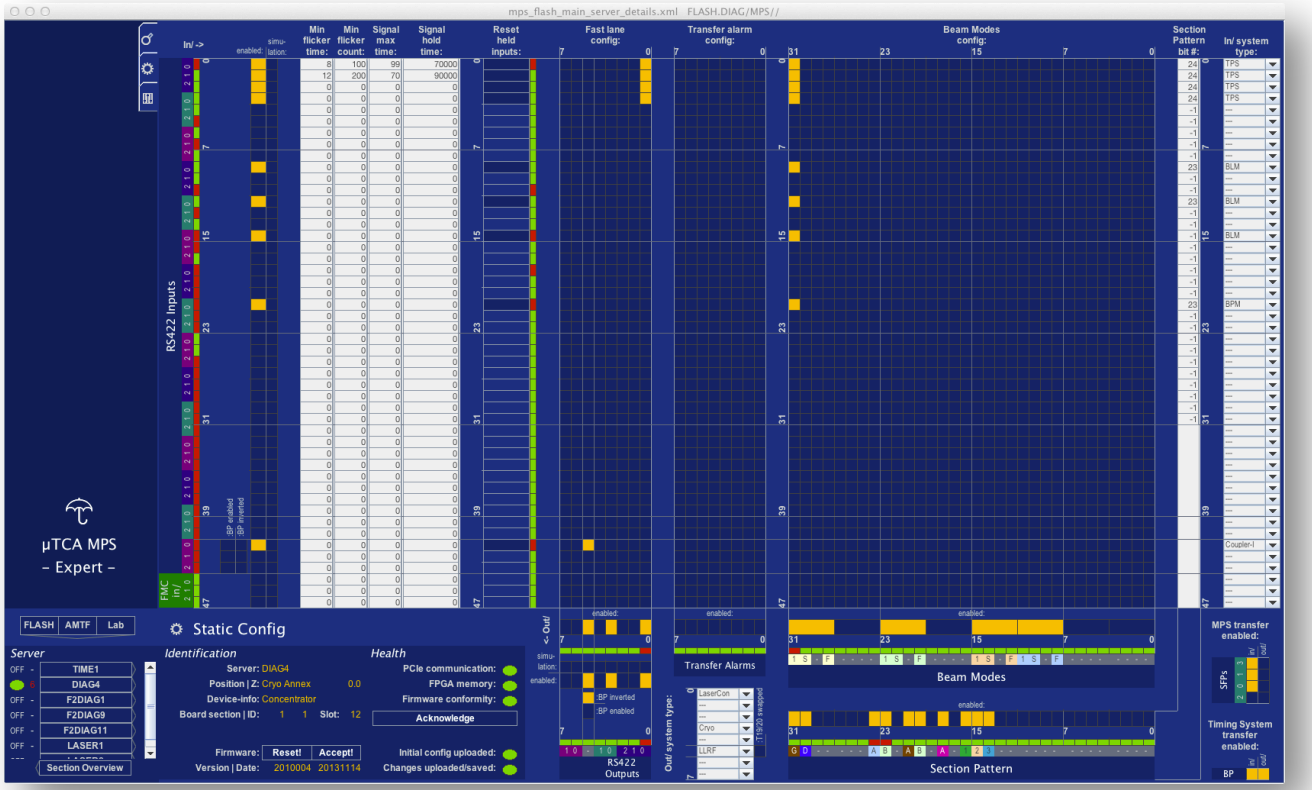
MCS4

DAMC2

1090



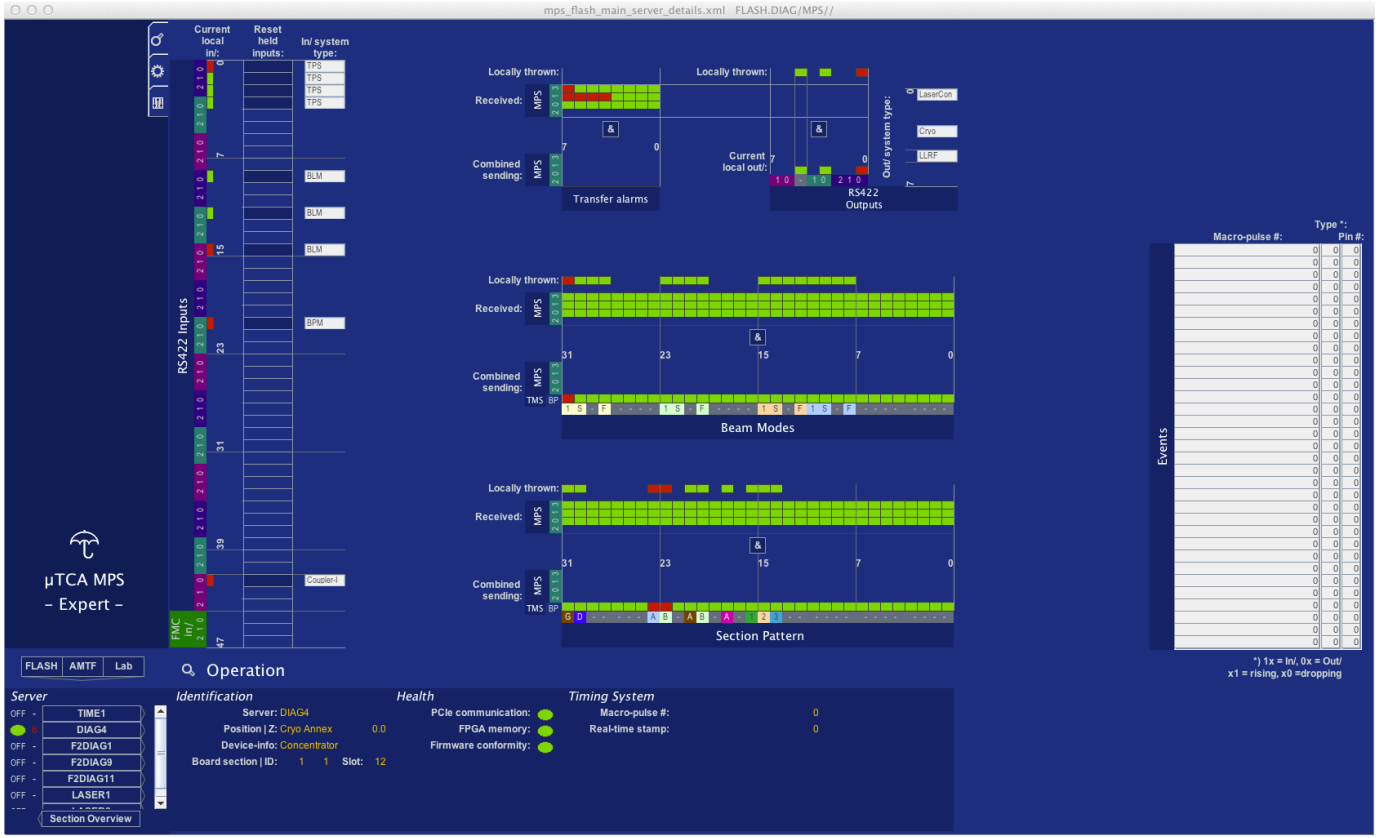
Expert's GUI – Configuration



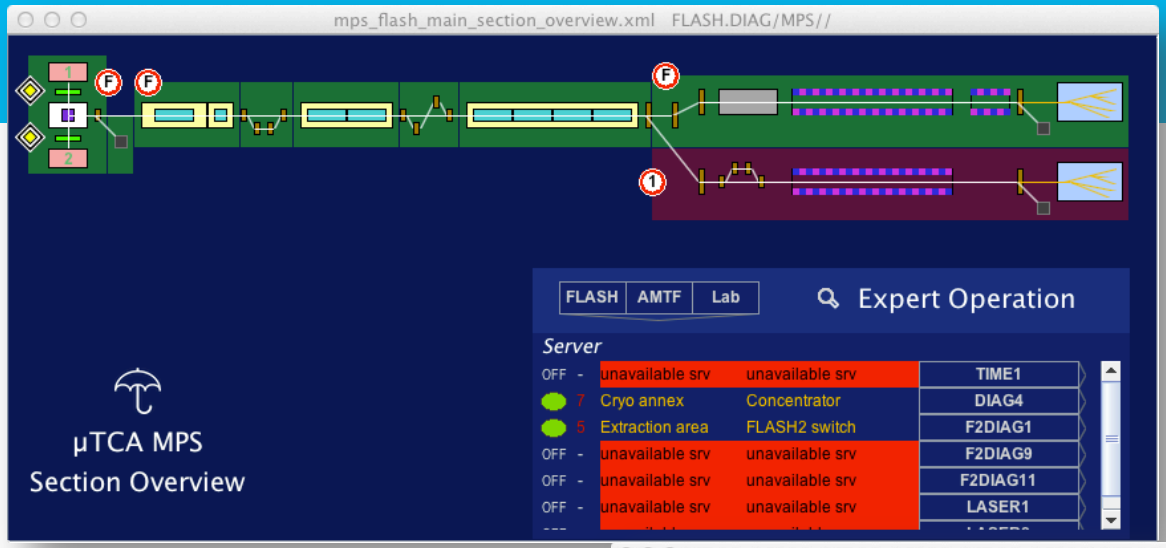
- MPS' alarm-response is highly configurable for each of the ~120 boards
  - Fast Lane path – locally routed interlocks
  - Transfer Alarms generation – transferred interlocks to other MPS boards
  - Beam Modes & Section Pattern generation – transferred limitations for the Timing System

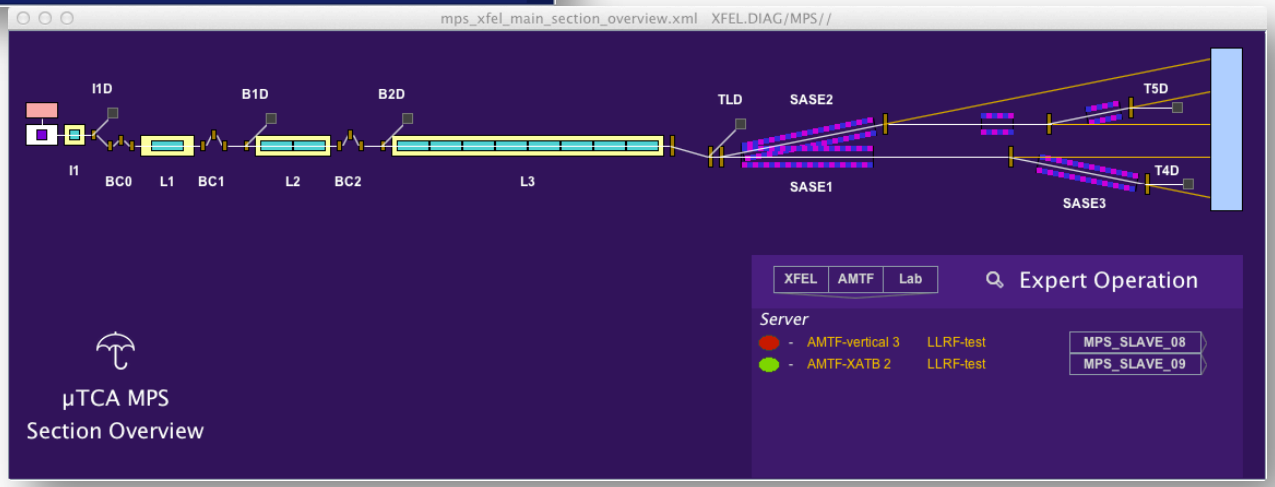
Expert's GUI – Operation

- Displays current state of every in-/output line, transferred alarms and transferred Beam Modes and Section Patterns, event history, health state …
- Provides one-click cross-system navigation – opens panel of connected in-/output system
- Enables an expert operator to reset intentionally held alarm signals



Operator's GUI



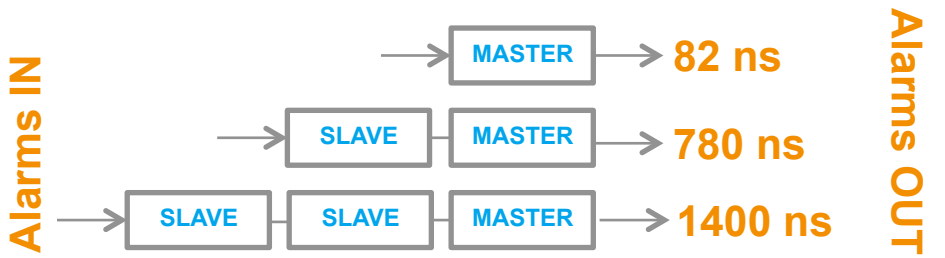


- Graphical representation
  - 'give way'-signs for current state of laser controller and linac dump kicker
  - 'speed limit'-signs for currently set beam limitations for 6 accelerator sections – the Beam Modes
  - 'red-green'-background for current availability of 17 different accelerator subsections – Section Pattern
  - list of MPS-servers with their current health state and the number of detected interlocks

Latencies

- Besides already travelling bunches
  - which cannot be stopped anymore by means of the laser or linac dump kicker
- Signal run-time to be added
  - worst case 1: from end of linac to laser controller via fiber optics ~10 µs
  - worst case 2: from last undulator to linac dump kicker via fiber optics ~2 µs
- Latency to be added
  - of signal converters and FPGA logic
  - of slave-master communication
- Power
  - max.: 20 GeV
  - 27.000 Flashes/s

Origin of an alarm	Distance from laser	Distance from dump kicker	# of already travelling bunches
Injector	0 m	-	0
BC1	160 m	-	7
BC2	360 m	-	15
Linac center	1040 m	-	44
Linac end	1650 m	-	69
Beam distribution	(2010 m)	40 m	2
Last undulator	(3010 m)	1040 m	44

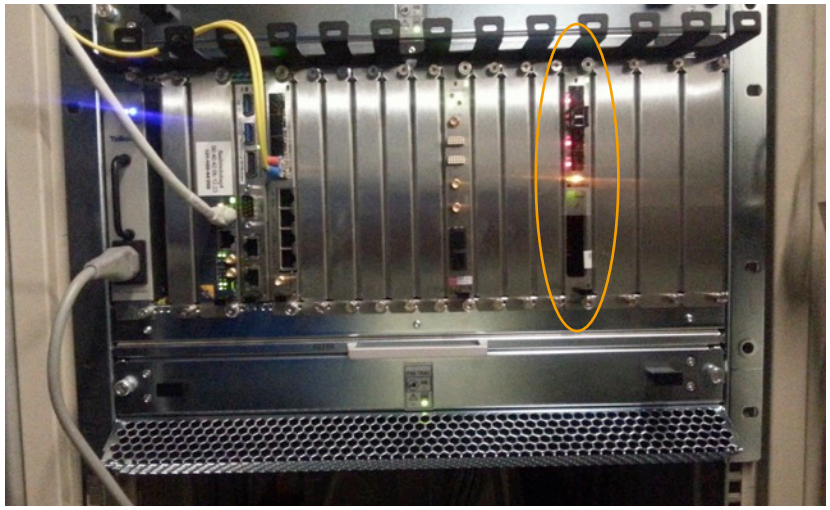


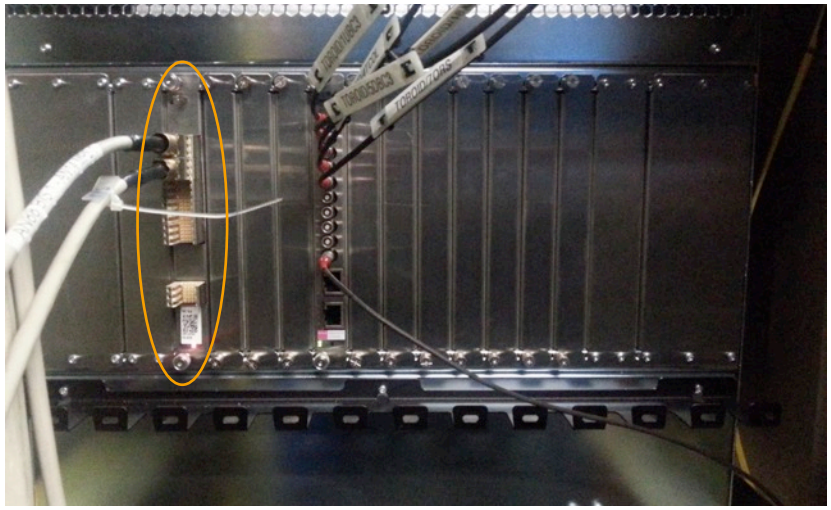
+Latency Fiber Optics: 5ns/m

Status (1./2)

- Hardware design is finished – 120+ DAMC2-boards are ordered
- Cables and plugs are chosen – 10 km RS422 cables in stock
- Requirements are frozen (CDR approved)
  - minor issues like inter-macro-pulse checks of subsystems can be added
- Interfaces are fully negotiated (CDR approved)
- Locations of board-installation are mostly planned
- Development of DAMC2-firmware is almost finished
  - cascading communication through multiple levels is under development
  - up-the-waterfall routing of Transfer Alarms is under development
- Development of front-end server software almost finished
  - cross-system navigation directly from reaction to cause is still under development
  - MPS-tab within the XFEL main task bar is still under development

Status (2./2)



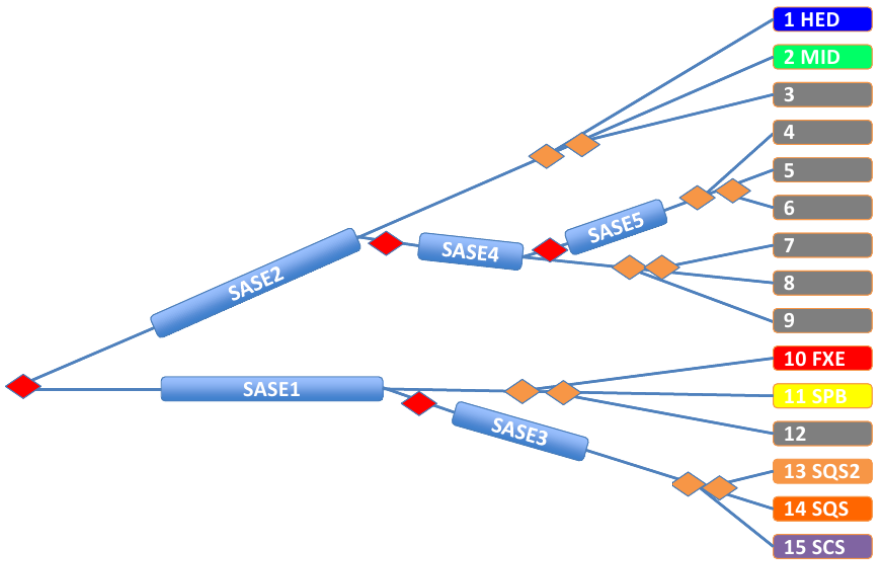


- Already successful operational installations (to be grown quickly)
  - 2 board at the 7th basement of the XFEL tunnel – for **XFEL gun test**
  - 5 boards at the injector hutch, cryo annex and extraction area of **FLASH2**
  - 5 boards at 3 test-stands in the **AMTF-hall** for LLRF tests

Thank you for your attention!

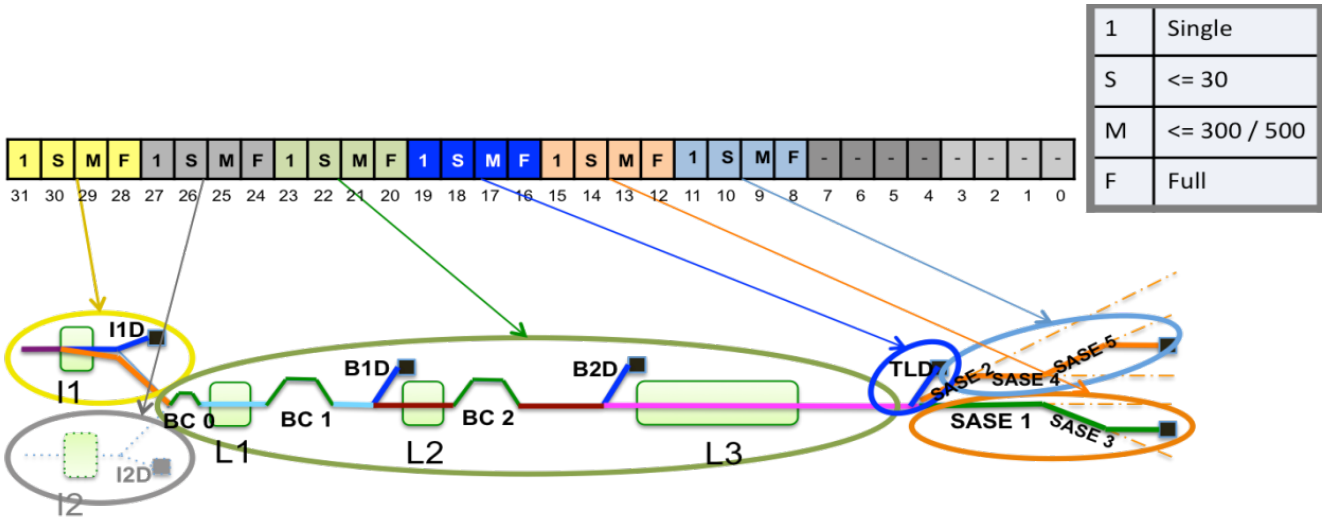
Questions and comments are welcome

MPS to Equipment Protection System Cooperation



- MPS receives a few interlocks from Equipment Protection System of the photon beamline
- MPS tells the Timing System the appropriate limits
  - the amount of bunches (Beam Modes) for two major different SASE-lines (Alster & Elbe)
  - the availability (Section Pattern) of all five SASE-lines
- Timing System controls the Distribution Kicker accordingly
- MPS triggers the Linac Dump Kicker in case of asynchronous beam stop

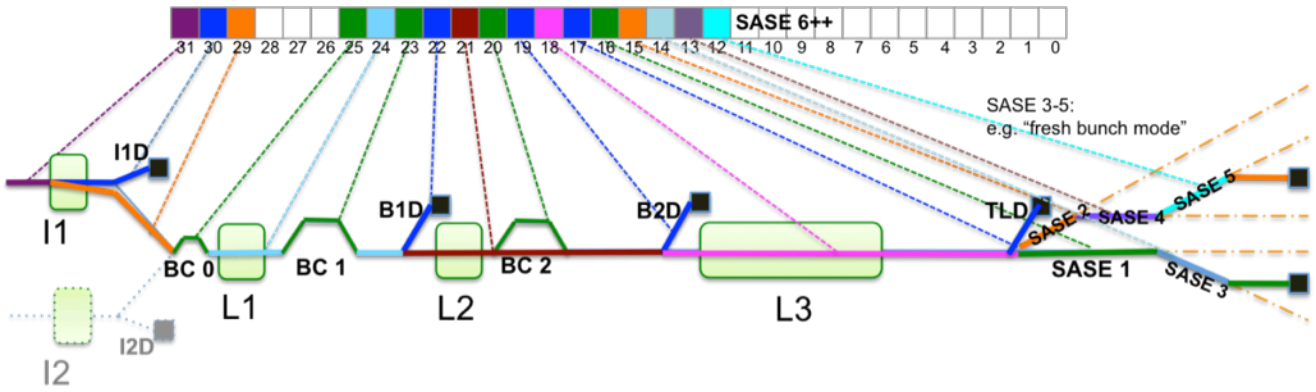
MPS to Timing System Cooperation



1	Single
S	<= 30
M	<= 300 / 500
F	Full

Beam Modes

- amount of bunches allowed in the corresponding accelerator sections



Section Pattern

- beam permissions in the corresponding accelerator subsections