MPS @ FLASH & XFEL

Machine Protection Experience at FLASH, lessons for XFEL

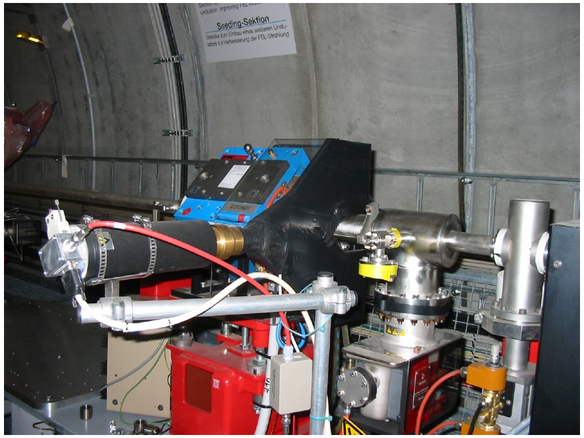
Martin Staack, 06.06.2012

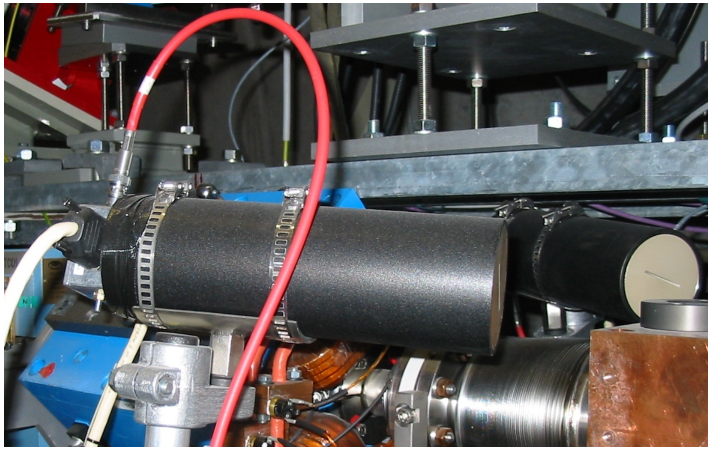
Requirements for the Machine protection System

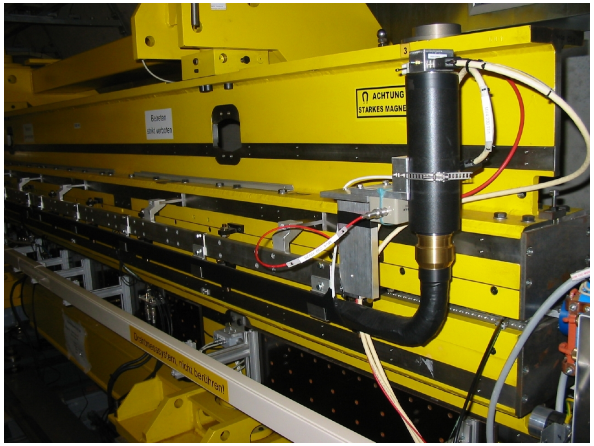
- Protect accelerator components from damage
- Facilitate easy handling of machine
- Impair machine operation only if necessary
- Limit activation of accelerator components to preserve functionality and maintainability
- Beam time will be high in demand, the goal should be to limit downtimes to their necessary extent
- MPS should be highly reliable and “user-friendly”
- MPS should be as simple and flexible as possible
- Incorporate good experience from FLASH MPS
- Personal safety is not covered by MPS → separate system

Beam loss detection at FLASH

- ~90 Photomultipliers distributed over the accelerator with different types of scintillators

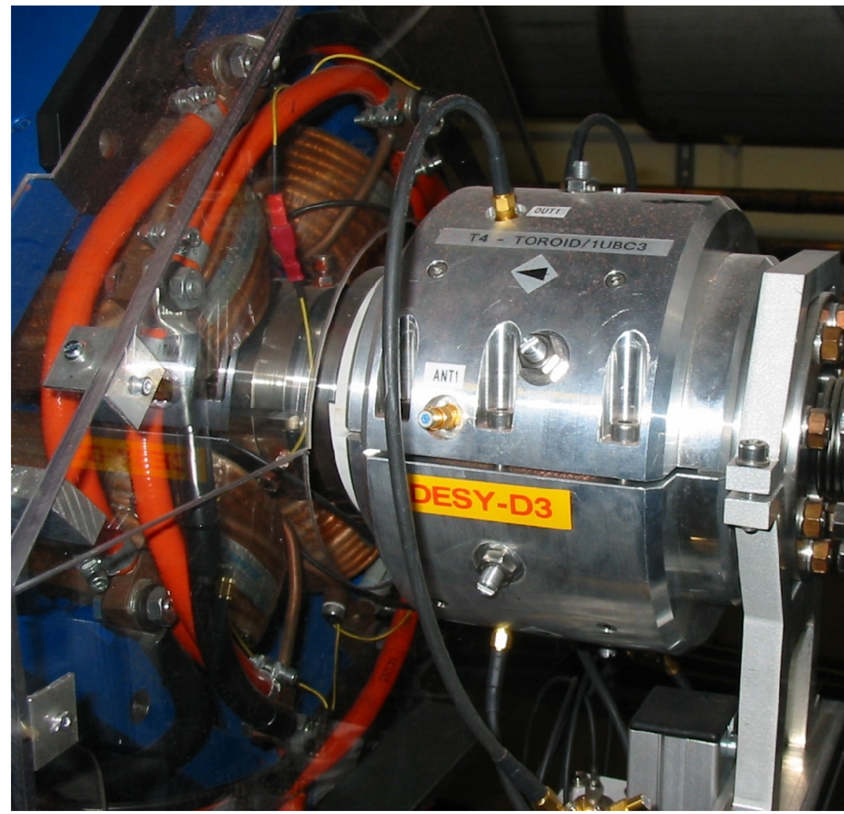






Beam loss detection at FLASH

- 4 pairs of toroids with electronics detect beam losses in the machine
- System complements beam loss detection by photomultipliers

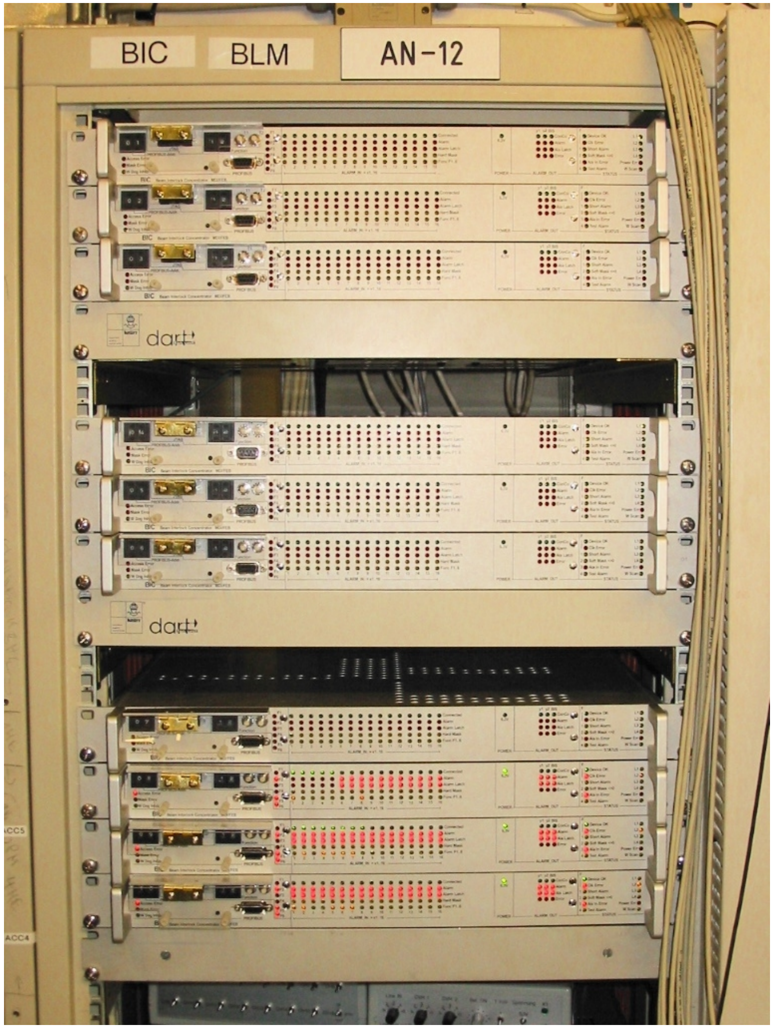


FLASH MPS: PLC based system

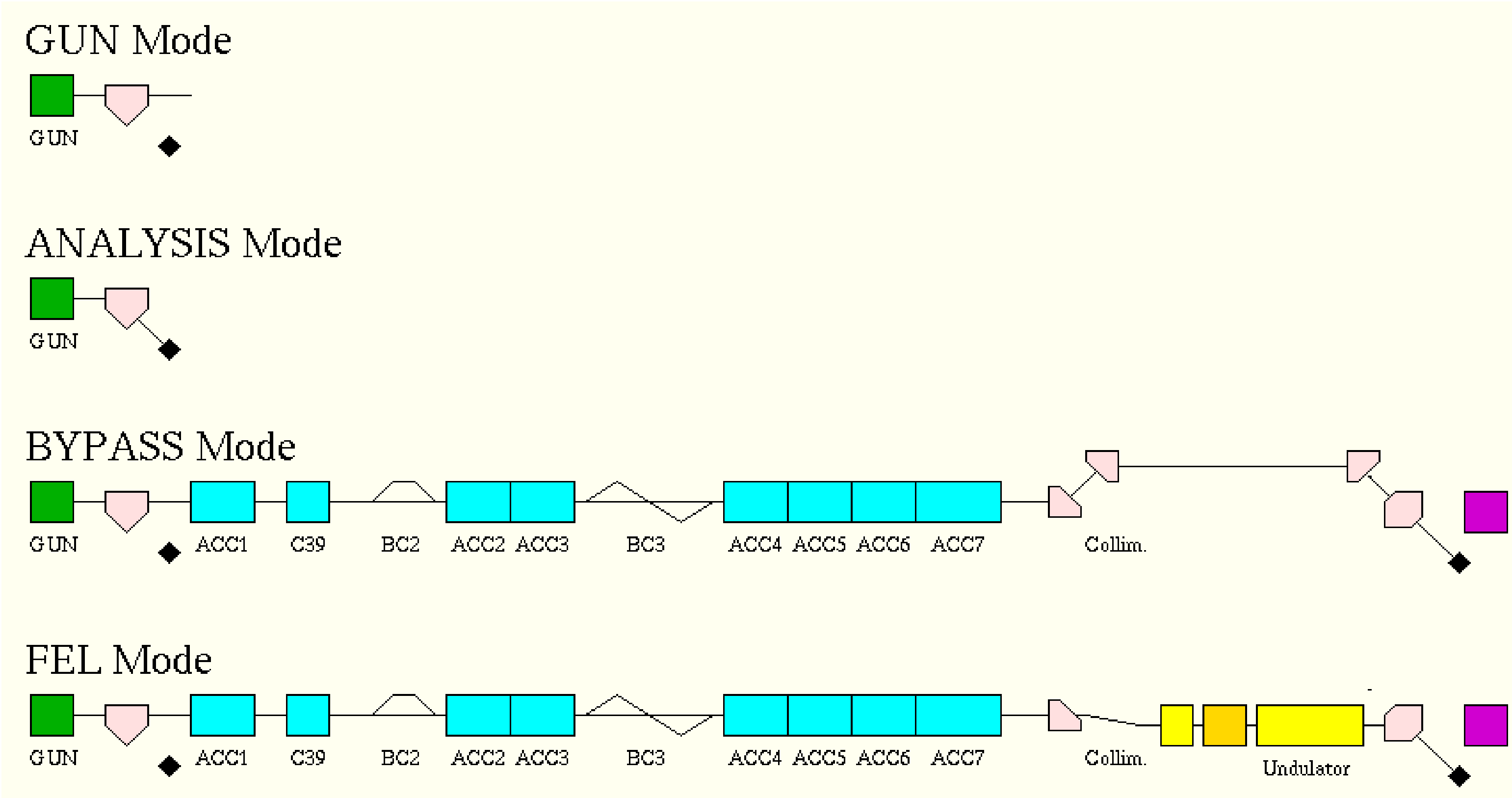
- PLC collects 300 signals
- Reaction time in range of ms
- Power supplies
- Screens, wirescanners
- Water flow and temperature
- Vacuum Valves
- Beam Loss Monitors
- Toroid Protection System
- Collimators
- Low Level RF status
- ...

FLASH MPS: Fast alarm signals

- Fast alarm collectors
- Directly connected to injector laser
- 90 Beam Los Monitors
- 16 Toroid protection channels
- Reaction time of 2 µs (cable)
- Modules are read out and controlled by PLC
- Input channels can be masked out

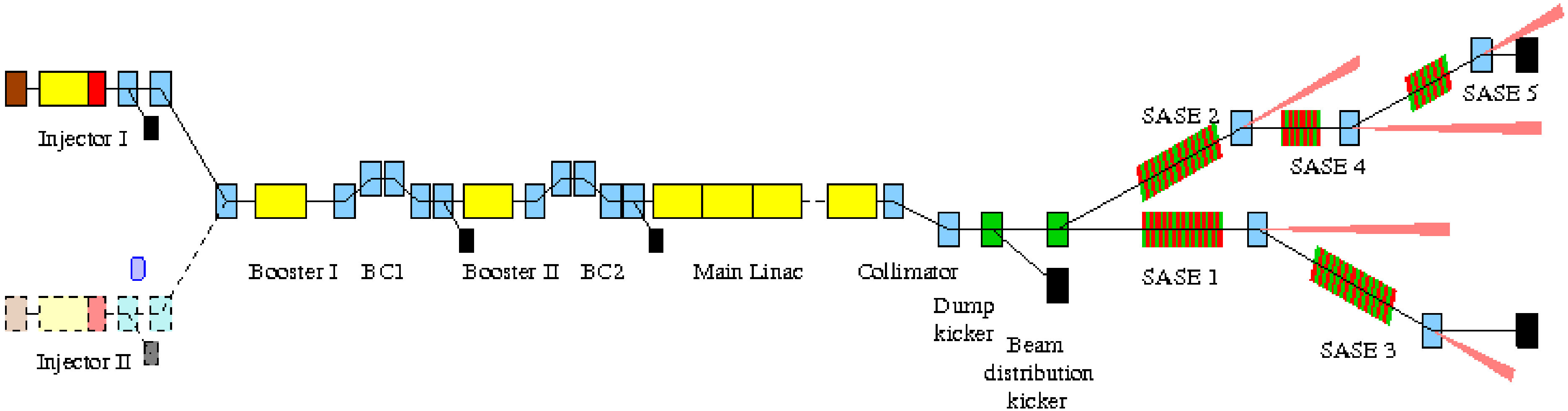


FLASH: Operation Modes



- MPS determines operation mode from machine settings
- Operators set magnets and vacuum valves, MPS reacts

XFEL Architecture



- 2 independant injectors
- Superconducting linac with 3 bunch compressors
- 3 Electron paths with beam dumps
- 5 Photon beamlines

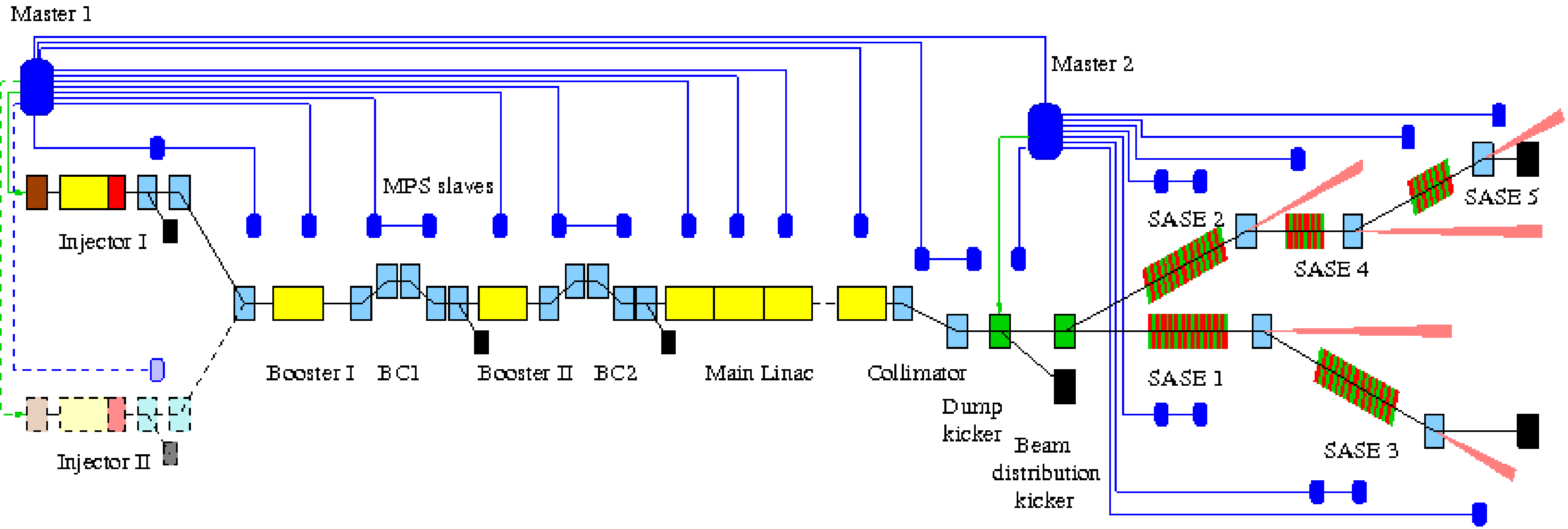
European XFEL

Reaction times

Beam loss location	Distance from Injector	Distance from Dump	# of lost bunches
Injector	0 m	-1970 m	0
BC1	160 m	-1810 m	7
BC2	360 m	-1610 m	15
Linac center	1040 m	-930 m	44
Linac End	1650 m	-320 m	69
Beam distribution	2010 m	40 m	2
Last undulator	3010 m	1040 m	44

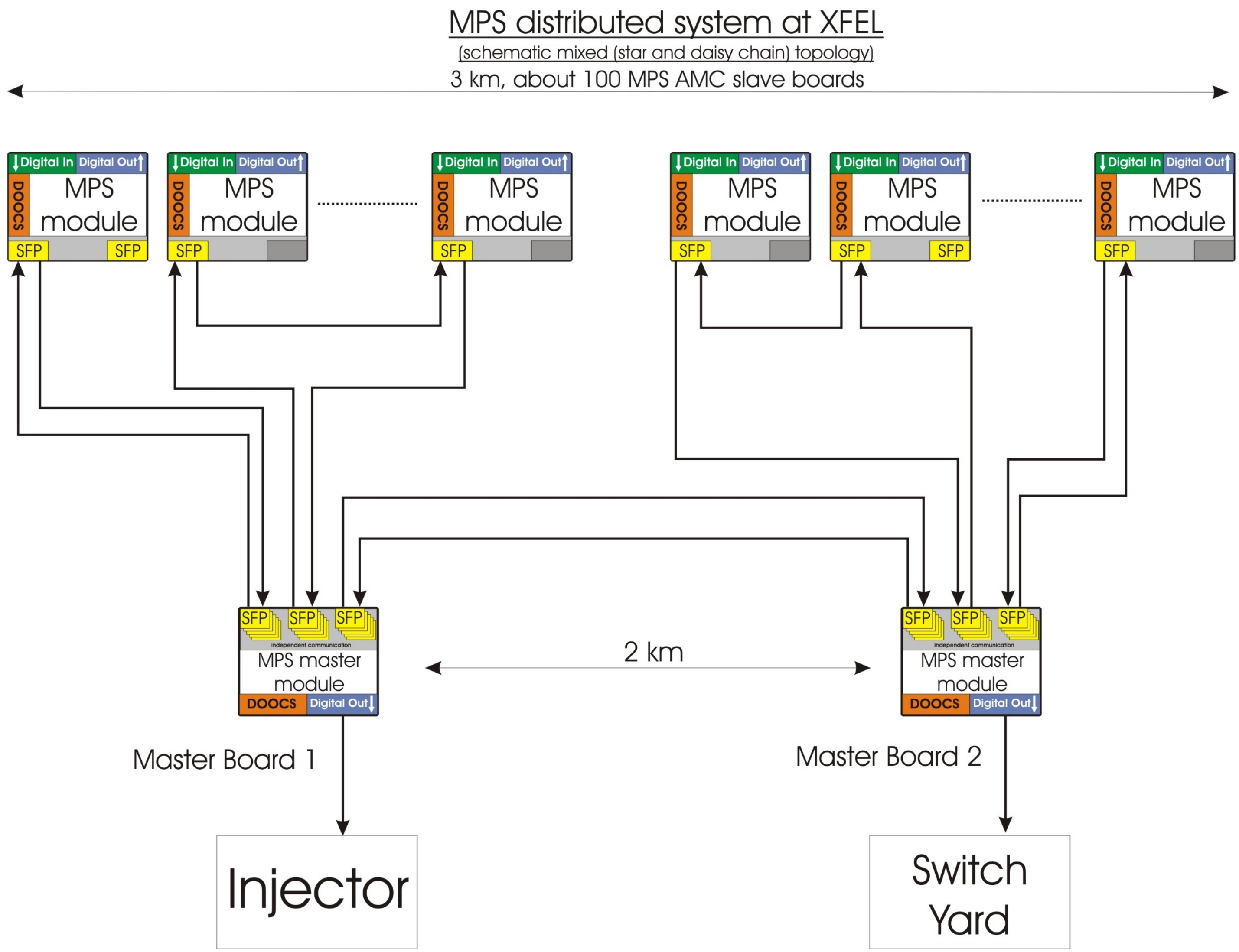
- ~50 bunches are in the accelerator
- Signal transport from dump to injector 20 μs
- ~50 bunches generated before laser is blocked
- Using beam dump kicker reduces the number of lost bunches in the SASE undulator sections

Machine Protection Architecture



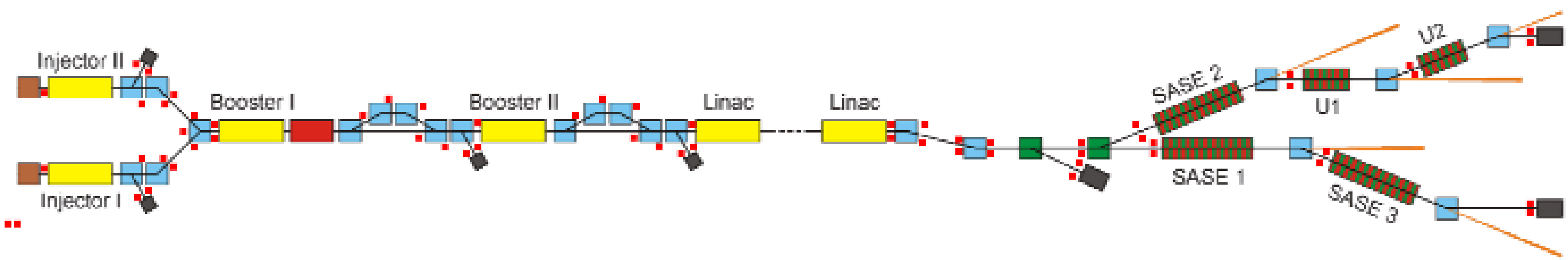
- Distributed System with µTCA modules
- MPS Master Modules at Gun and switch yard / dump kickers
- Optical fiber connections between MPS modules
- MPS can act on injector laser to stop production of electron beam
- MPS can dump beam if dump beam line signalizes readiness
- Defective input channels can be masked out

MPS topology

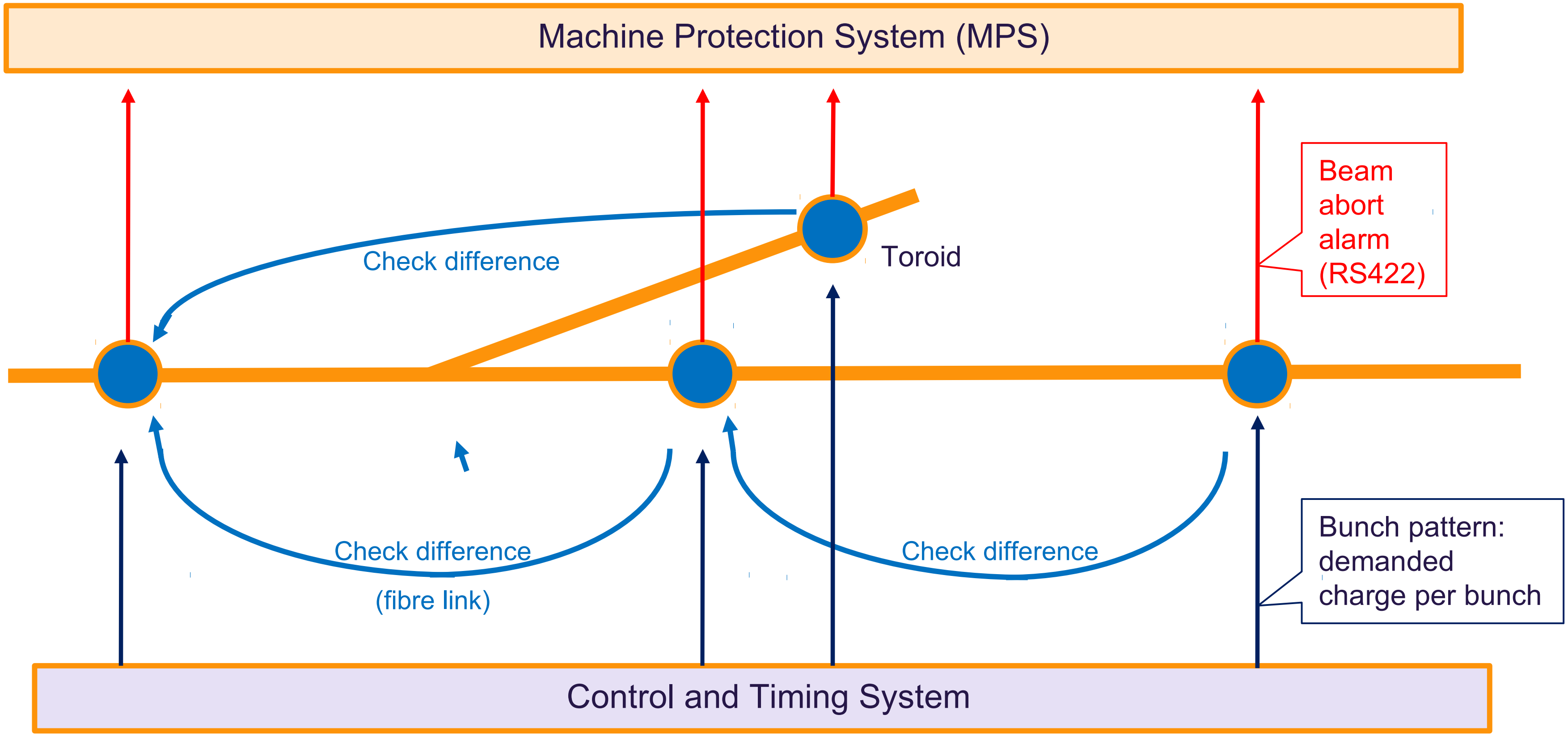


Beam Loss Monitors

- A distributed system of detectors to monitor secondary particles originating from lost beam electrons
- Signal above threshold leads to an alarm → MPS
- 2/3 of detectors in Undulator Areas



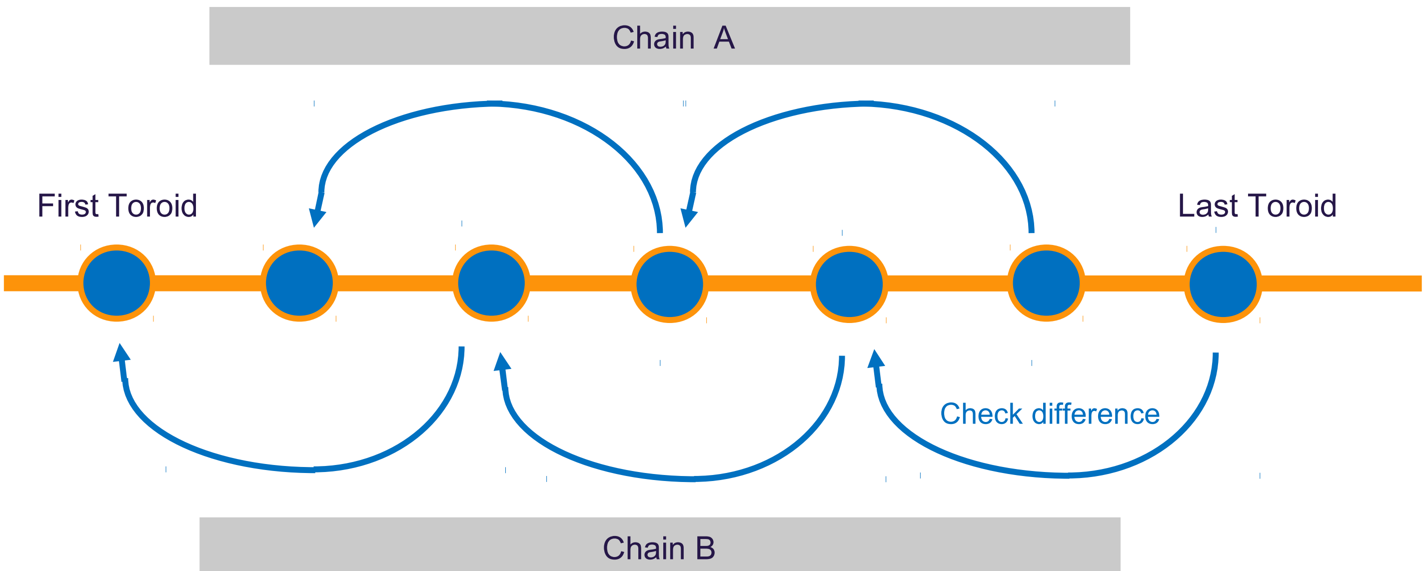
Toroid System: TPS principle



“Toroid Protection System“ (TPS) is one application of the Toroid system:

- Compare charge (bunch by bunch) of neighbored Toroids: abort beam if difference is too large
- Compare beam intensity with requirements from control system: abort beam if charge too high or too low (too low can mean beam loss at previous section)

Toroid system: Redundancy, Availability

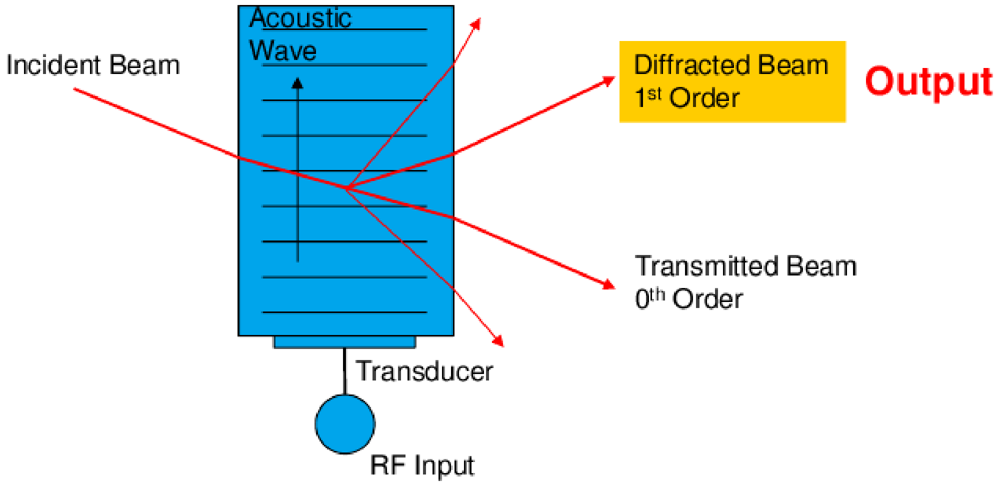


Redundancy for the TPS functionality is added by interleaved fibre chains.

If one Toroid fails (except the very first or very last device), the accelarator can still be operated with full TPS protection. This results in high availability.

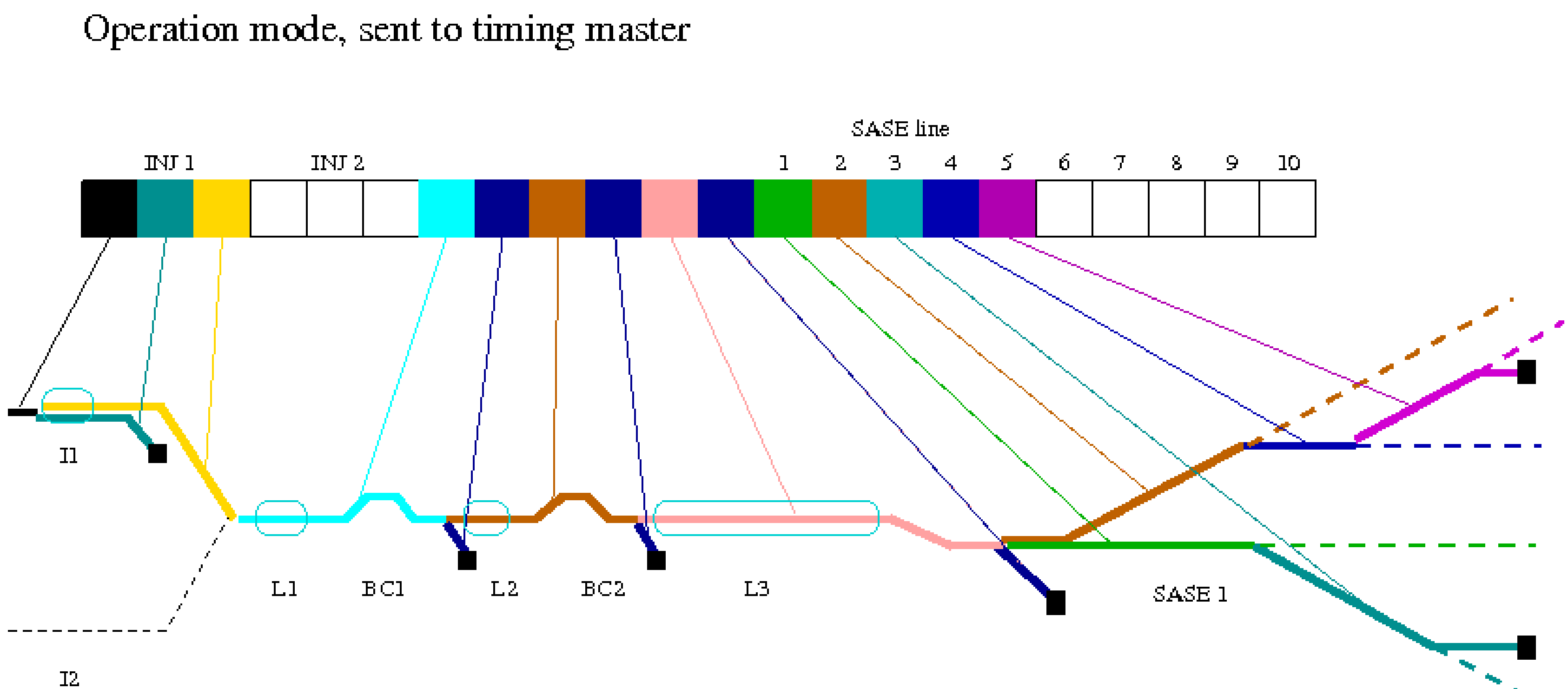
Stop beam with acousto-optical modulator

- Possible solution: cw pulse train conversion into UV, then definition of pulse trains with UV pulse picker → stable temperature of BBO crystal
  - Important: pulse picker must not show same effect as BBO crystal!
- Candidate for pulse picker: Acousto-Optic Modulator (AOM)
  - Principle: Diffraction of laser beam at acoustic wave



- Acousto-optical Modulator deflects laser beam
- Good method to stop beam in XFEL without affecting laser temperature stability

Operation Mode

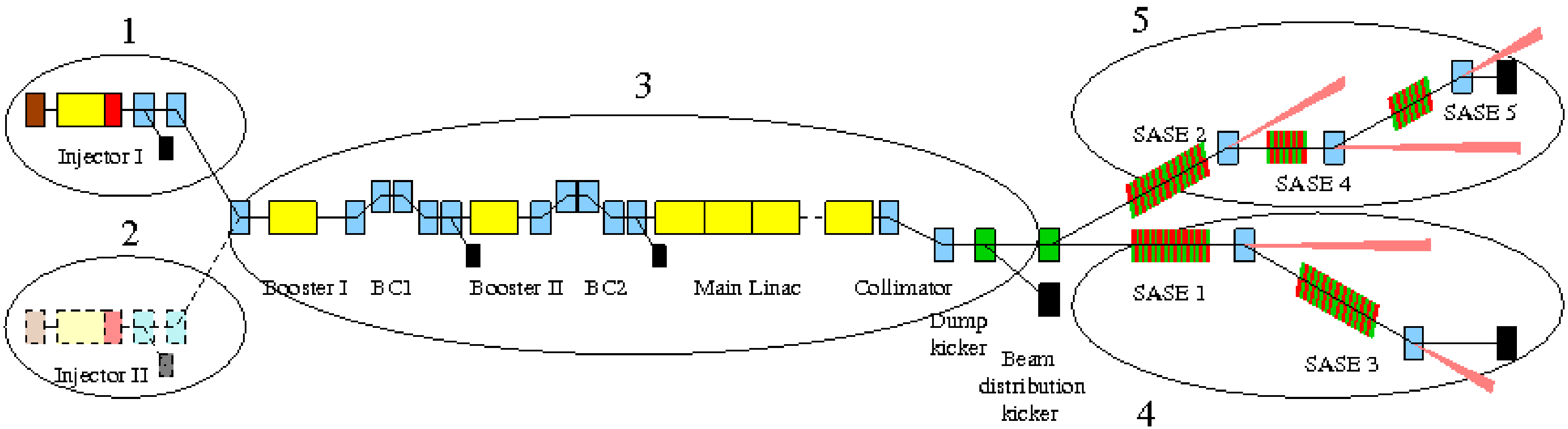


- Operation Mode is determined from magnet currents, vacuum valves and photon beamline status
- Operation Mode describes paths electrons can take
- Status is sent to Timing System

Beam Modes (1)

- MPS collects limitation signals from accelerator components
- BC beam dumps allow only few bunches
- Inserting screens into course of beam → limit to single bunch operation
- Experiments and photon beamlines have to inform MPS about limitations → how many bunches allowed?
- MPS can not calculate µJ into number of bunches
- MPS forwards this information to the timing system
- Timing system processes this information and distributes bunch patterns to injector lasers, LLRF, TPS, TDS, beam switch yard and other important systems

Beam Modes (2)



6: SASE 6 et al (future)

7: SASE 7 et al (future)

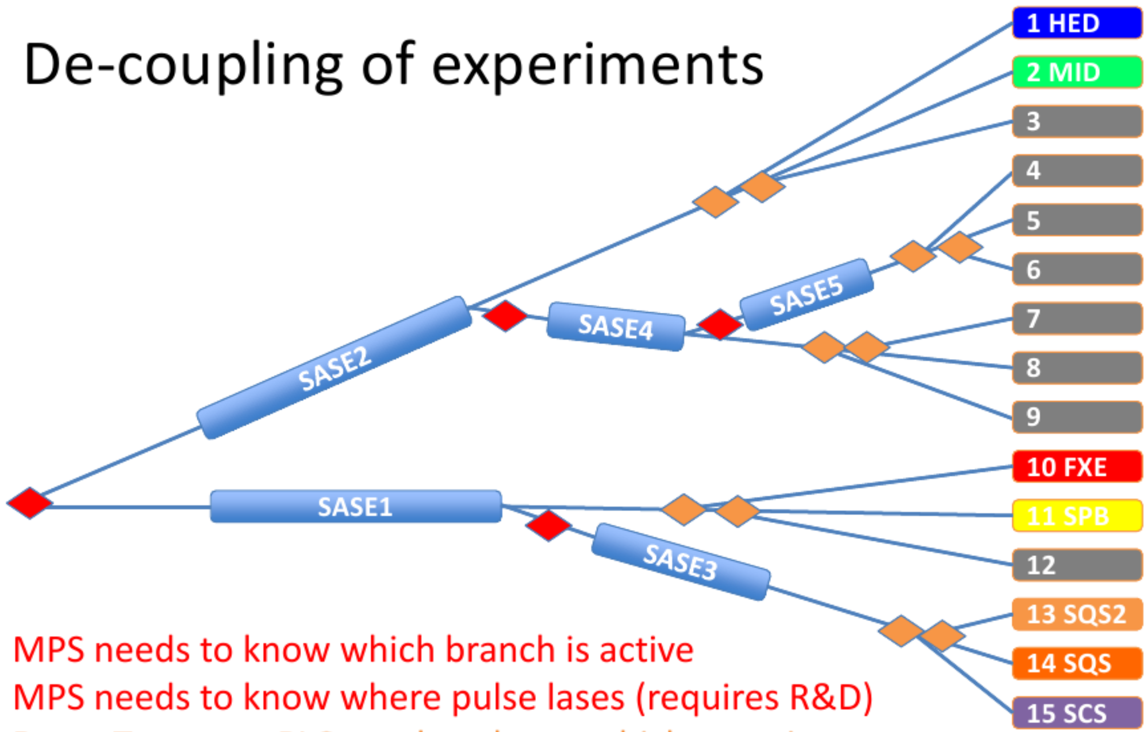
Beam mode (32 bit vector):

1				2				3				4				5				6				7							
I1				I2				L				SASE 1				SASE 2				SASE 6				SASE 7				not used			
1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

- Single bunch → bit 1
- <= 30 bunches → bit 2
- < 300..1500 bunches → bit 3
- Full bunch train → bit 4

Beam Modes (3)

De-coupling of experiments



MPS needs to know which branch is active
MPS needs to know where pulse lases (requires R&D)
Beam Transport PLC needs to know which experiment active (max 10 Hz switching)

- 15 experiments in 5 SASE beamlines, 5 experiments with different beam requirements operated at the same time
- SASE 1 and SASE 3 get the same electron beam

Signals to MPS from accelerator

Devices	Inputs	Outputs
Cold Magnets	200	
PS Master	50	
Modulator	25	
Klystron	25	25
LLRF	25	50
Cryo / Vacuum	25	
Coupler interlock	120	120
OTR screens	160	
Wirescanner	80	20
Toroid protection	160	
BPM	120	
BLM	350	
Laser / Switchyard	20	20

and additional:

- Dump
- Watercooling
- Collimator temp
- …

- ~2000 alarm signals are collected, RS422 technology
- Coupler interlock: distribution of vacuum and cryo information

MPS modules in cold section

Section	Building	Room	Z [m]	ACC	Racktype	IT	IT	MPS	RTM	Patch	Timing	IN	OUT-B	OUT					
I1	XSE	UG04-02	0		DIAG		F	2	2		1	53			ContrSys WP28	1xBPM	BLM: 2x4	2xOTR: 11x4	
I1	XTIN		30	1	LLRF Master	HV	F	1	1		3	7	1	8	ContrSys WP28	PinDiode 1 Out	LLRF 1In/1Out	Coupler-Int 5In/6Out	
I1	XTIN		33	1	RF		F								Klystron 1In/1Out				
I1	XTIN		36	1	LLRF Slave		F	1	1		2	2	1	7	PinDiode 1 Out	LLRF 1In/1Out	Coupler-Int 2In/6Out		
I1	XTIN		47		DIAG		F	1	1		1	25			ContrSys WP28	1xBPM	BLM: 2x4	TPS: 4x4	
I1	XTL		100		DIAG		F	1	1		1	42			ContrSys WP28	2xBPM	OTR: 2x4	BLM: 4x4	TPS: 2x4
L1	XTL		117		PS / Vac		F			1					8xMagnet	GP & TSP			
L1	XTL		123	2	Cryo / Vac		F								Iso & Schieber	2xBPM	Kryogenik	2xCouplerMot	
L1	XTL		127	2	LLRF Master		F	1	1		1	1	1	1	PinDiode 1 Out	LLRF 1In/1Out			
L1	XTL		131	2	LLRF Master	HV	F+O	1	1		3	7	1	8	ContrSys WP28	PinDiode 1 Out	LLRF 1In/1Out	Coupler-Int 5In/6Out	
L1	XTL		138	2	RF		F								Klystron 1In/1Out				
L1	XTL		160	2	LLRF Slave		F	1	1		2	3	1	7	PinDiode 1 Out	LLRF 1In/1Out	Coupler-Int 2In/6Out		
L1	XTL		163	2	LLRF Slave		F	1	1		1	1	1	1	PinDiode 1 Out	LLRF 1In/1Out			
L1	XTL		167	2	Cryo / Vac		F								Cryo	Iso & Schieber			
B1	XTL		177		DIAG		F	1	1		1	14			ContrSys WP17	2xBPM	TPS: 1x4	BLM: 2x4	
B1	XTL		179		SDIAG		F								BAM1	EOD1			
B1	XTL		188		SDIAG										E-BPM	SRM			
B1	XTL		204		SDIAG		F				1				ContrSys WP18	BAM2	EOD2	IT/Patch	
B1	XTL		206		DIAG		F	1	1		1	26			ContrSys WP17	2xBPM	TPS: 1x4	BLM: 2x4	OTR: 3x4
B1	XTL		211		SDIAG		F								Pyro	TDS			
B1	XTL		213		Vacuum		F								GP & TSP	Iso & Shutter			
B1	XTL		216		DIAG		F	1	1		1	33		4	ContrSys WP17	1xBPM	WS:4x2In/1Out	BLM: 2x4	OTR: 4x4
B1	XTL		218		KICK	HV	F				1				ContrSys WP28	Kicker			
B1	XTL		221		DIAG		F	1	1		1	25		8	ContrSys WP17	1xBPM	WS: 8x2In/1Out	OTR: 2x4	
B1	XTL		223		DIAG		F								CRD				
L2	XTL		239	3	Cryo / DIAG		F	1	1		1	14			ContrSys WP17	2xBPM	TPS: 1x4	BLM: 2x4	Cryo
L2	XTL		244	3	Vacuum		F								GP & TSP				
L2	XTL		246	3	LLRF-Master	HV	F+O	1	1		3	7	1	8	ContrSys WP28	PinDiode 1 Out	LLRF 1In/1Out	Coupler-Int 5In/6Out	
L2	XTL		253	3	RF		F								Klystron 1In/1Out				
L2	XTL		276	3	LLFR-Slave		F	1	1		2	3	1	7	PinDiode 1 Out	LLRF 1In/1Out	Coupler-Int 2In/6Out		
L2	XTL		280	3	Spare														
L2	XTL		283	3	PS / Vac		F			1					8xMagnet	GP & TSP			
L2	XTL		294	4	LLRF-Master	HV	F	1	1		3	12	1	8	ContrSys WP28	PinDiode 1 Out	LLRF 1In/1Out	Coupler-Int 2In/6Out	
L2	XTL		302	4	RF		F								Klystron 1In/1Out				
L2	XTL		324	4	LLFR-Slave		F	1	1		2	11	1	7	PinDiode 1 Out	LLRF 1In/1Out	Coupler-Int 2In/6Out		
L2	XTL		331	4	PS		F			1					8xMagnet				
L2	XTL		334	4	PS		F			1					8xMagnet				
L2	XTL		342	5	LLRF-Master	HV	F	1	1		3	12	1	8	ContrSys WP28	PinDiode 1 Out	LLRF 1In/1Out	Coupler-Int 2In/6Out	
L2	XTL		350	5	RF		F								Klystron 1In/1Out				
L2	XTL		372	5	LLFR-Slave		F	1	1		2	3	1	7	PinDiode 1 Out	LLRF 1In/1Out	Coupler-Int 2In/6Out		
L2	XTL		379	5	Cryo / Vac		F								Cryo	Iso & Schieber			
B2	XTL		388		DIAG		F	1	1		1	14			ContrSys WP17	2xBPM	TPS: 1x4	BLM: 2x4	
B2	XTL		390		SDIAG		F								BAM1				

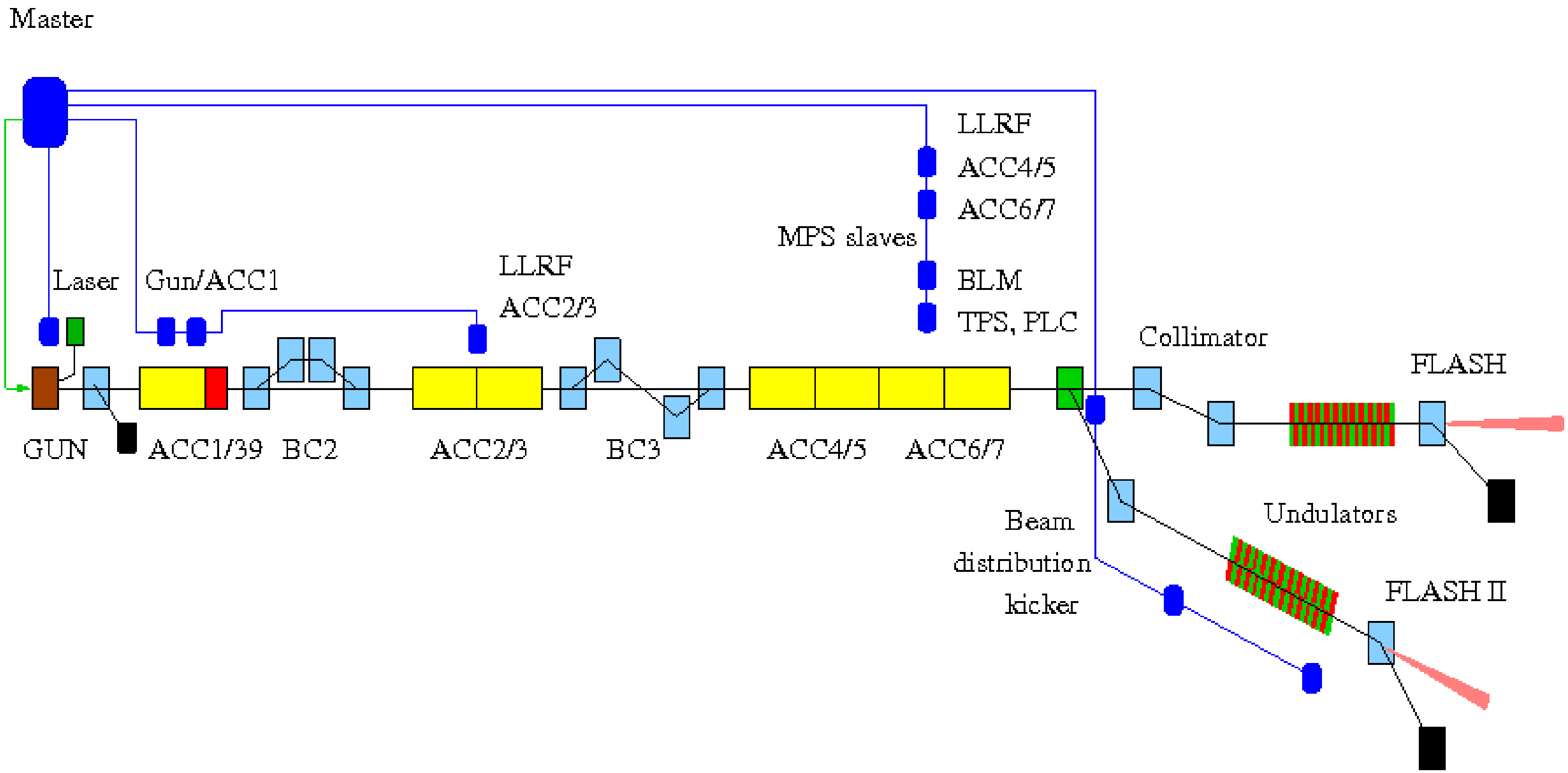
- MPS modules modules in LLRF Master and Slave Racks

MPS in undulator sections

SASE2	XTD1		2217		Rack														
SASE2	XTD1		2223		DIAG			1	1		1	17			ContrSys WP17	1xBPM	BLM: 4x4		
SASE2	XTD1		2229		Vacuum														
SASE2	XTD1		2235		DIAG										MBU BPM				
SASE2	XTD1		2242		IT		F								Patch				
SASE2	XTD1		2248		DIAG										MBU BPM				
SASE2	XTD1		2254		Vacuum														
SASE2	XTD1		2260		DIAG										MBU BPM				
SASE2	XTD1		2266		Rack														
SASE2	XTD1		2272		DIAG			1	1		1	17			ContrSys WP17	1xBPM	BLM: 4x4		
SASE2	XTD1		2278		Vacuum														
SASE2	XTD1		2284		DIAG										MBU BPM				
SASE2	XTD1		2290		Rack														
SASE2	XTD1		2296		DIAG										MBU BPM				
SASE2	XTD1		2303		Vacuum														
SASE2	XTD1		2309		DIAG										MBU BPM				
SASE2	XTD1		2315		IT		F								Patch				
SASE2	XTD1		2321		DIAG			1	1		1	17			ContrSys WP17	1xBPM	BLM: 4x4		
SASE2	XTD1		2327		Vacuum														
SASE2	XTD1		2333		DIAG										MBU BPM				
SASE2	XTD1		2339		Rack														
SASE2	XTD1		2345		DIAG										MBU BPM				
SASE2	XTD1		2351		Vacuum														

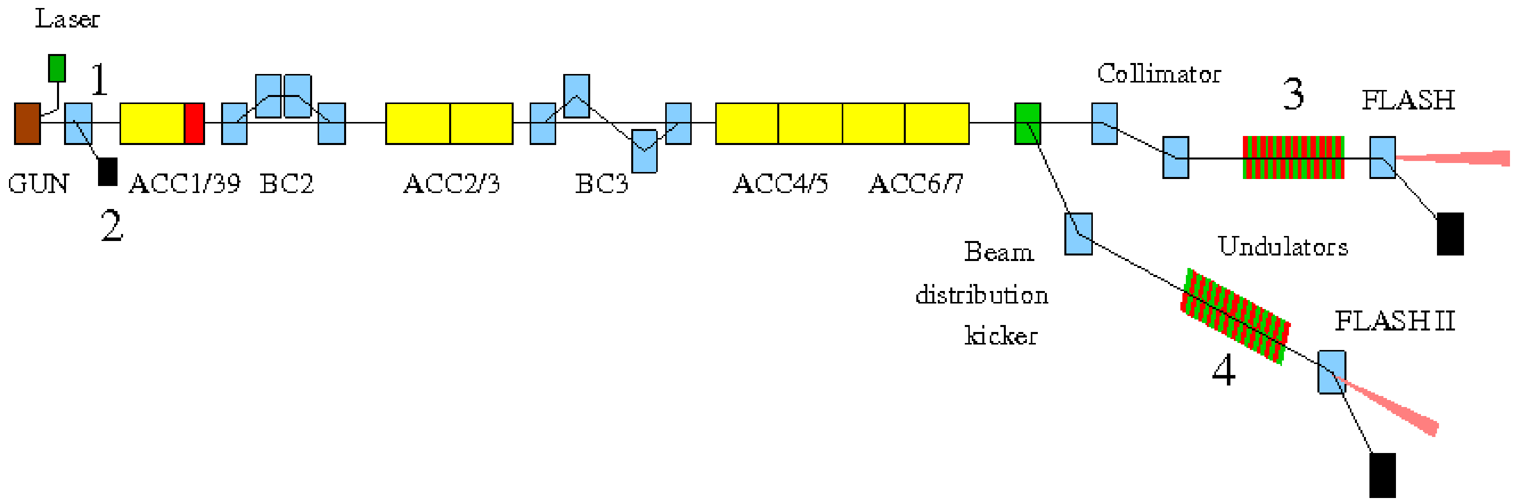
- SASE undulator section: MPS modules are hosted by diagnostic crates with BLM, TPS and BPM electronics

XFEL MPS will be tested at FLASH II

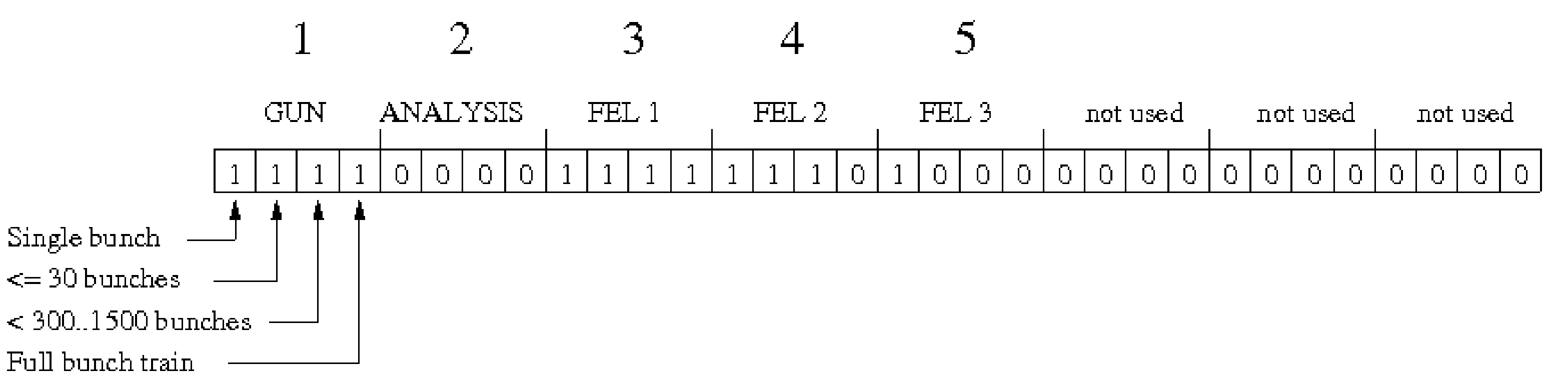


- XFEL MPS modules take care of new beam line and LLRF, Laser
- XFEL MPS will be master of the system
- 2 years before XFEL startup we will gain experience at FLASH II

Beam Modes for FLASH II

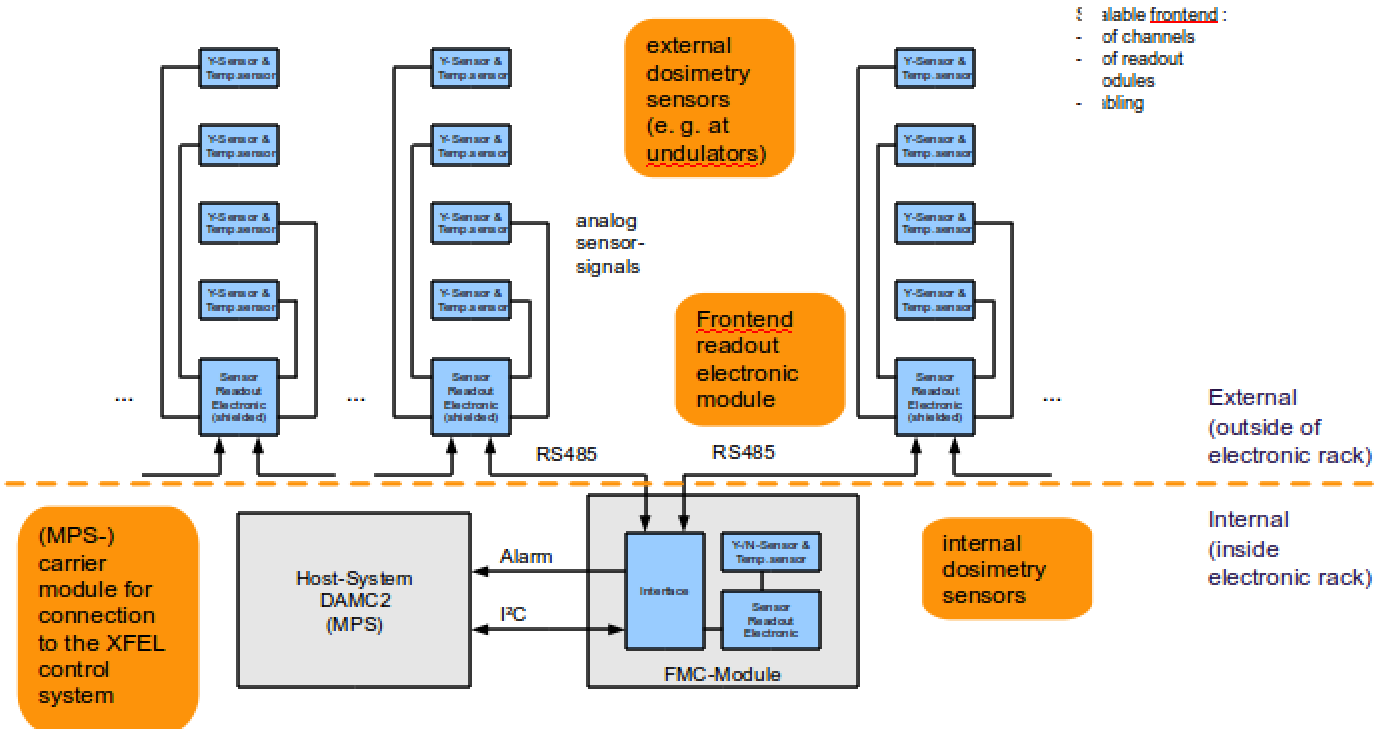


Beam mode (32 bit vector):



- Beam Modes similar to XFEL → only 1 system to be maintained

Radiation monitoring



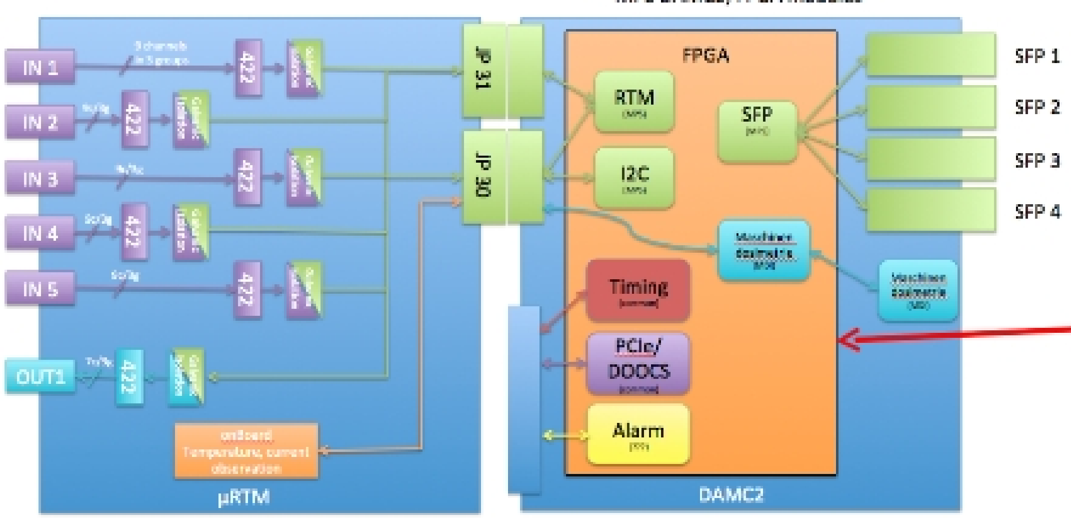
Frontend module connections and cabling

- Radiation monitoring hosted by MPS module
- Detection inside Racks and external in XFEL tunnel
- Alarm generation via MPS

Hardware status and schedule

- Production of first series of DAMC02 board has started
- MPS Rear Transition Module goes into production mid of May
- Tests at FLASH in 2012, installation and commissioning in 2013
- Installation at XFEL injector in 2013, commissioning in 2014
- Installation in XFEL tunnel and experimental hall in 2014
- Commissioning and start of operation in 2015

MPS DAMC2, FPGA modules



European XFEL

Summary

- MPS for XFEL is a distributed system
- FLASH MPS is a centralized system
- Simple and flexible structure of logic has proven
- Automatic detection of operation and beam modes
- Remote configuration and masking of defective channels
- XFEL MPS will be used for FLASH after upgrade, we will gain experience before applying MPS to XFEL
- MPS at FLASH did not appear in failure statistics
- Same philosophy, different technology
- FLASH converted from a Test Facility to a User Facility
- We learned a lot from High Current Runs for ILC
- Important subsystems have to be “inhouse developments”

Thank you for your attention!