



**Wir schaffen Wissen – heute für morgen**

# **REUSABLE PATIENT SAFETY SYSTEM FRAMEWORK FOR THE PROTON THERAPY CENTRE AT PSI**

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1. Introduction
2. Requirements of the project
3. Patient Safety System (PaSS) concept
4. System architecture
5. Verification and validation
6. Results: Improvements
7. Conclusion





## Proton Therapy at the Paul Scherrer Institut

### Patient treatment areas:

Gantry 1 (1996)

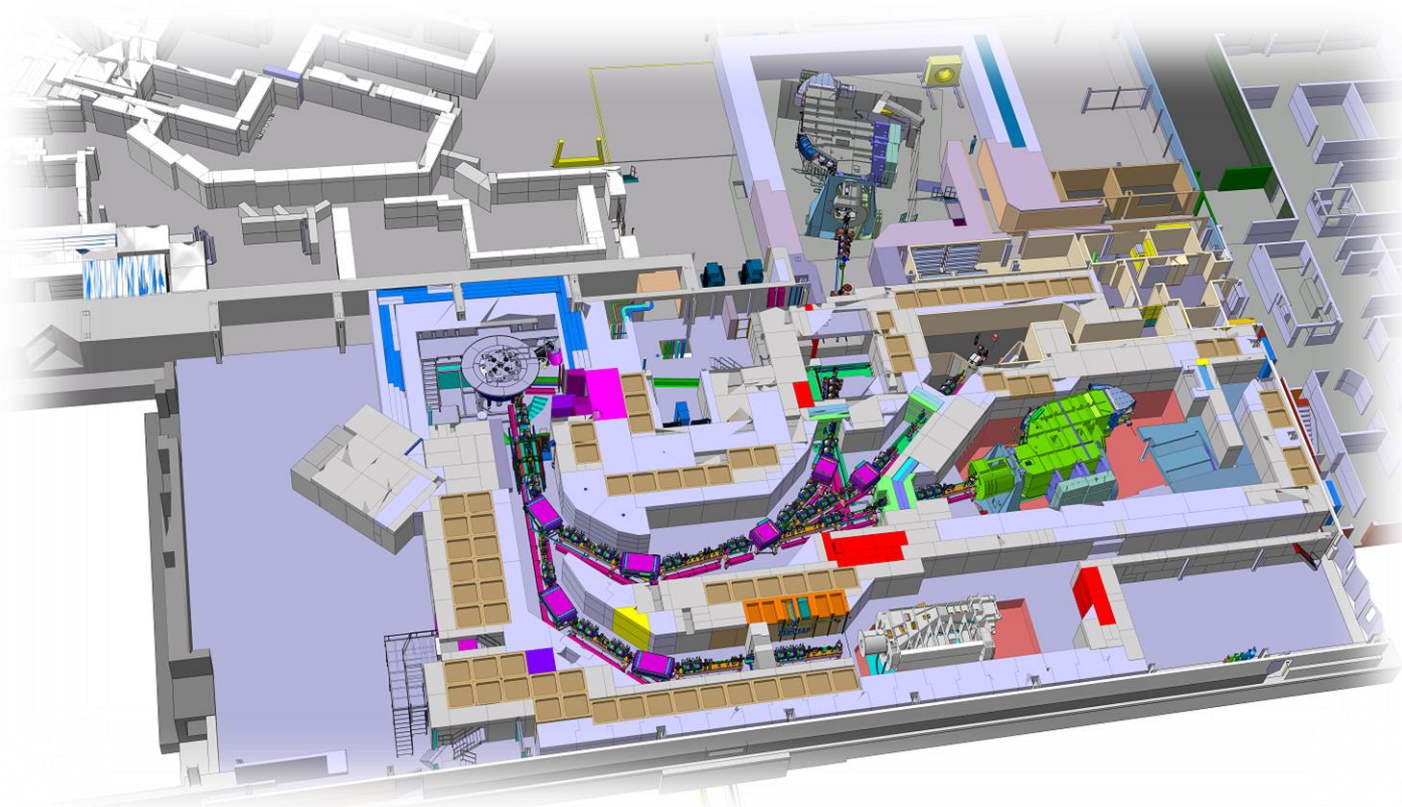
Optis 2 (2010)

Gantry 2 (2013)

New Gantry 3

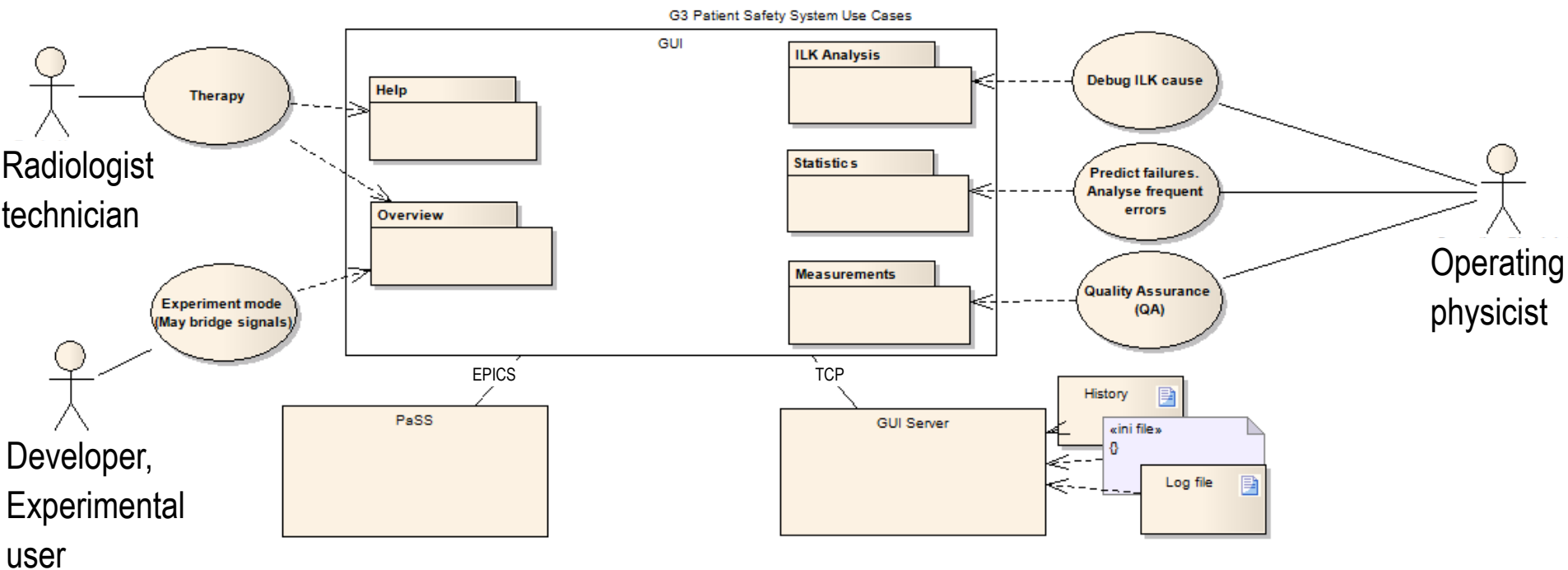
} Developed in house

⇒ Commercial from Varian Medical Systems



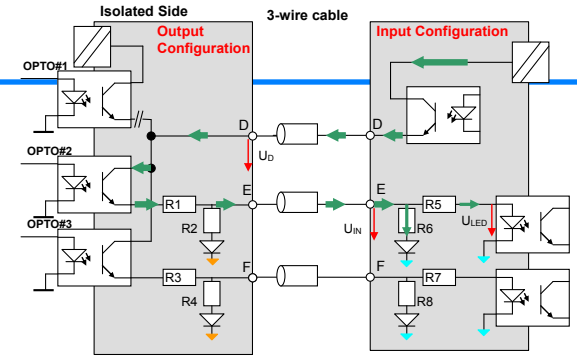
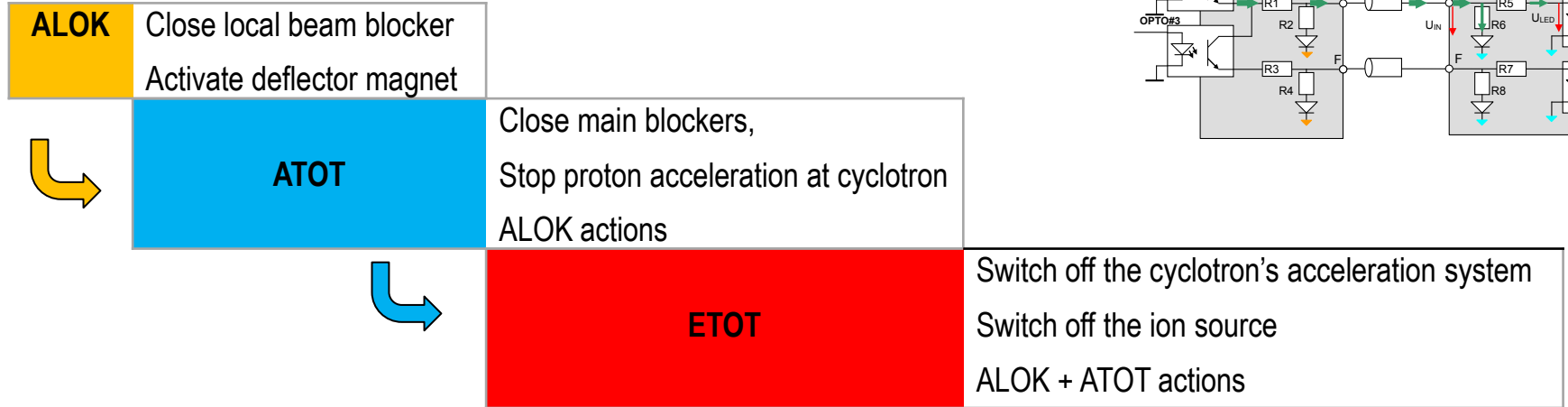
# Requirements of the new design

- Implement same safety functionality as in other areas. Most safety elements are centralised
- Interface Gantry 3 proprietary control system to the existing PSI infrastructure as part of PaSS
- Specifications not fully defined yet
- Expected lifespan 20 years
- Restricted time and manpower
- Use cases:





# Patient Safety System concept



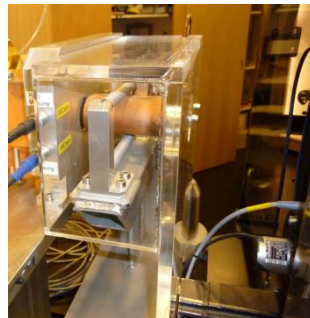
Cyclotron



Kicker magnet



Main beam blocker

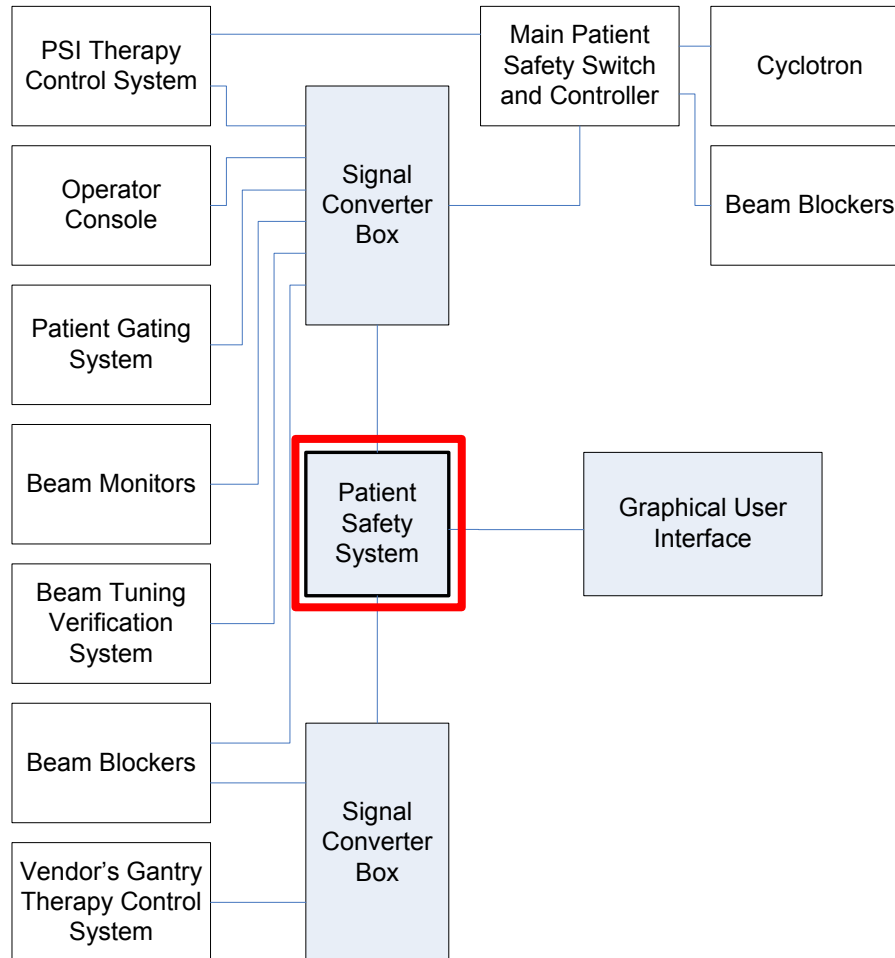


Fast beam blocker



Treatment gantry

# Patient Safety System overview



## IOC: IFC1210

COTS with PowerPC Dual core and user FPGA

VME bus

2 FMC Mezzanines

Boot from server, remote configuration, Linux OS

## Signal Converter Box

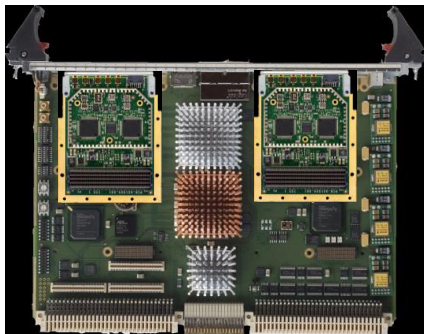
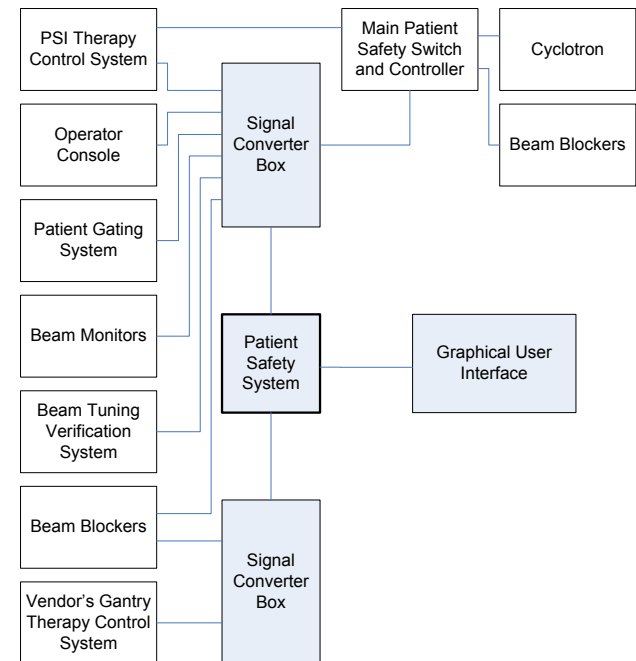
Specific design (Subcontracted)

Configurable Multiplexer

6 SFP for gigabit optical communication

10 plugin ports

**Plugins:** Optical, TTL, 3 wire logic, redundant 24v...



IFC1210



Signal Converter Box



Plugins



## Tosca Network on Chip (IOxOS)

### Shared resources:

Memory, DMA, Configurable clocks...

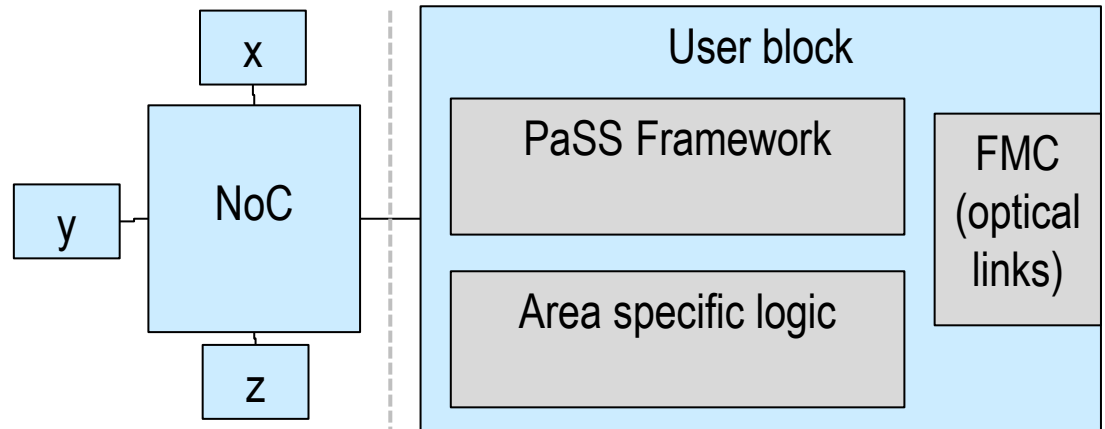
### User specific block

Optical links protocol

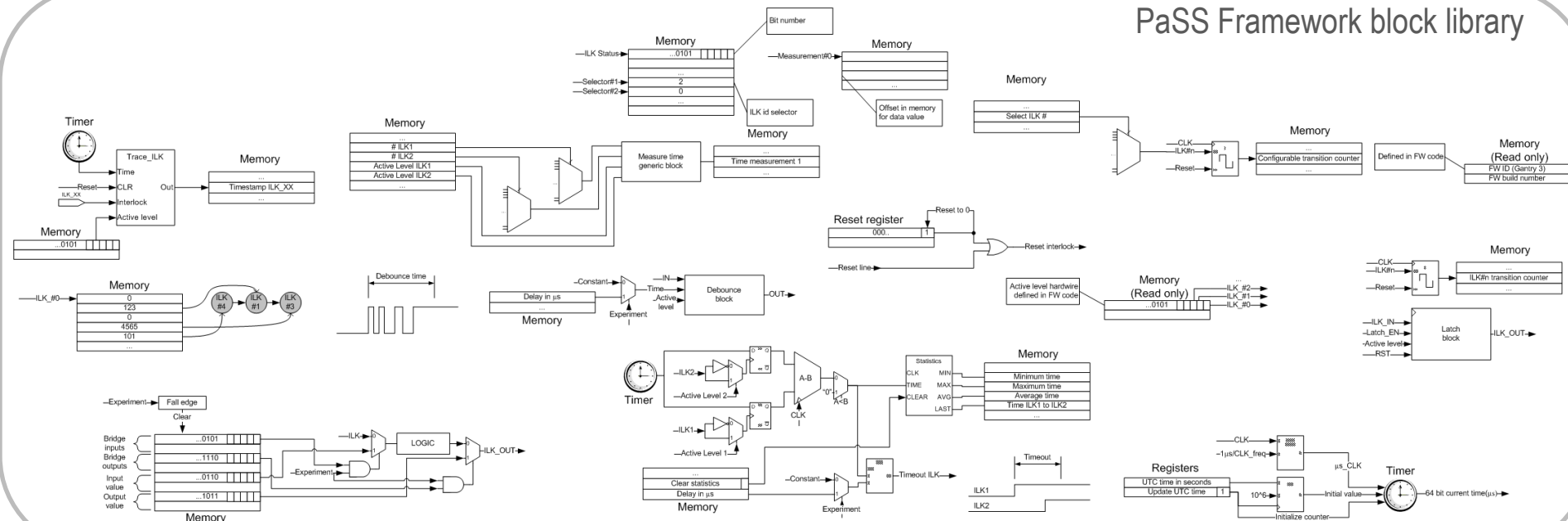
Generic framework

Gantry specific logic

All resources can be mapped to io memory



## PaSS Framework block library



**EPICS driver** maps FPGA resources to records

Interlock status

Control variables

Configurable measurements

**Java GUI** to access all records

User visualization

Operation and debug

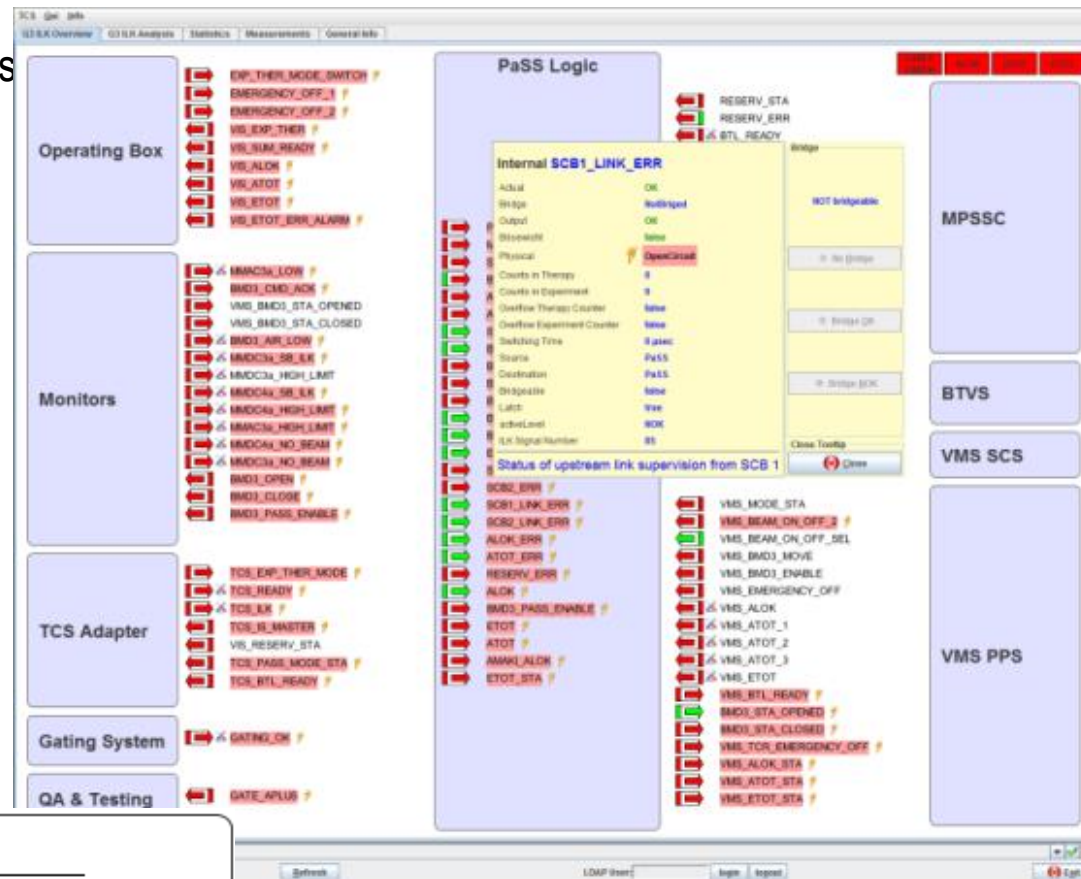
Visualize and log interlock events

Tools for QA

Statistics

Trends, defects, deterioration ...

Built-in measurements



**Trigger Signal**

61 - ATOT

**Trigger Active Level**

NOK

**Stopper Signal**

37 - ATOT STA

**Stopper Active Level**

NOK

**Timeout [µsec]**

250

**Set**

**Time Measurement 2**

Trigger

Stopper

Timeout

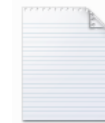
OK

0 µsec	Last
0 µsec	Minimum
0 µsec	Maximum
0 µsec	Average

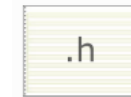
**Clear**

# Configuration file generator

EPICS configuration template



C memory definition



Xml GUI configuration



Framework package

Memory block

Optical communication decoder



INTERLOCK DEFINITION									
Index	Id name	Type	Bridgeable	Latch	Active Level	Description	Category		
1	GS_US_OK	IN	no	no	NOK	Pos. serial I&E	PMSC		
2	GS_US_RESERVED_STA	IN	no	no	NOK	Master/slave reservation status for GS area from MPSC	PMSC		
3	GS_US_RESERVED_ACK	IN	no	yes	NOK	Status signal: master/slave reservation at MPSC. Signal is common for all areas	PMSC		
4	GS_US_VMS_READY_STA	IN	no	no	NOK	Mode status signal from VPS system	VMS VPS		
5	GS_US_OP_THIR_MODE_SWITCH	IN	no	no	NOK	Mode status signal from Operator switch key	TCS Adapter		
6	GS_US_BTYS_READY	IN	no	no	NOK	Ready status of BTYS	BTYS		
7	GS_US_TCS_READY	IN	no	no	NOK	Ready status of TCS-Adapter	TCS Adapter		
8	GS_US_MMICHA_LOW	IN	no	no	NOK	Low current threshold supervision of MMICHA	Monitors		
9	GS_US_BTYS_READY	IN	no	no	NOK	Ready status of BTYS	PMSC		
10	GS_US_VMS_BEAM_ON_OFF_1	IN	no	no	NOK	Redundant 2 control signal to switch AMMI ON/OFF. Beam ON requires rising edge	VMS TCS		
11	GS_US_VMS_BEAM_ON_OFF_2	IN	no	no	NOK	Redundant 2 control signal to switch AMMI ON/OFF. Beam ON requires rising edge	VMS VPS		
12	GS_US_VMS_BEAM_ON_OFF_SEL	IN	no	no	NOK	Selection signal to switch AMMI ON/OFF to choose beam	VMS VPS		
13	GS_US_AMMI_STA	IN	no	no	OK	Status signal from AMMI magnet field supervision element	PMSC		
14	GS_US_VMS_MOVE	IN	no	no	NOK	BM03 enable signal from VMS VPS system	VMS VPS		
15	GS_US_VMS_MOVE_ENABLE	IN	no	no	NOK	BM03 enable signal from VMS VPS system	VMS VPS		
16	GS_US_BM03_CMD_ACK	IN	no	no	NOK	BM03 command acknowledgement response to BM03_ZASS_ENABLE	Monitors		
17	GS_US_VMS_BM03_STA_OPENED	IN	no	no	NOK	Status signal of BM03 open position and switches	Monitors		
18	GS_US_VMS_BM03_STA_CLOSED	IN	no	no	NOK	Status signal of BM03 close position and switches	Monitors		
19	GS_US_EMERGENCY_OFF_1	IN	no	yes	NOK	Status of emergency OFF button at operating box	Operating Box		
20	GS_US_EMERGENCY_OFF_2	IN	no	no	NOK	Status of emergency OFF button at operating box	Operating Box		
21	GS_US_VMS_EMERGENCY_OFF	IN	no	no	NOK	Emergency OFF signal from VMS VPS system	VMS VPS		
22	GS_US_BTYS_OK	IN	no	no	NOK	Interlock status of BTYS system	TCS Adapter		
23	GS_US_TCS_OK	IN	no	no	NOK	Interlock status of TCS-Adapter	Monitors		
24	GS_US_BM03_AIR_LOW	IN	no	yes	NOK	Status of BM03 air pressure supervision	Monitors		
25	GS_US_AMMI_ERR	IN	no	no	NOK	Status of AMMI supervision within MPSC	PMSC		
26	GS_US_MPSC_ATOT	IN	no	no	NOK	Status of MPSC ATOT interlock generation. In case of an MPSC ATOT BM03 has to be closed	PMSC		
27	GS_US_VMS_ACK	IN	no	no	NOK	Input from VMS VPS to generate ACK	VMS VPS		
28	GS_US_MMICHA_SE_UK	IN	no	yes	NOK	IC-DSE electronics status of MMICHA and Monitor IV	Monitors		
29	GS_US_MMICHA_HIGH_LIMIT	IN	no	yes	NOK	Max. beam current limit supervision at MMICHA to prevent monitor saturation	Monitors		
30	GS_US_MMICHA_SE_UK	IN	no	yes	NOK	IC-DSE electronics status of MMICHA and Monitor IV	VMS VPS		
31	GS_US_MMICHA_HIGH_LIMIT	IN	no	yes	NOK	Max. beam current limit supervision at MMICHA to prevent monitor saturation	Monitors		
32	GS_US_MMICHA_HIGH_LIMIT	IN	no	yes	NOK	Max. beam current limit supervision at MMICHA to prevent monitor saturation	Monitors		
33	GS_US_MMICHA_NO_BEAM	IN	no	no	NOK	No beam status of MMICHA	Monitors		
34	GS_US_VMS_ATOT_1	IN	no	yes	NOK	ATOT signal from VMS VPS system	VMS VPS		
35	GS_US_VMS_ATOT_2	IN	no	yes	NOK	ATOT signal from VMS VPS system	VMS VPS		
36	GS_US_VMS_ATOT_3	IN	no	yes	NOK	ATOT signal from VMS VPS system	VMS VPS		
37	GS_US_ATOT_STA	IN	no	no	NOK	ATOT signal from MPSC system	PMSC		
38	GS_US_MMICHA_NO_BEAM	IN	no	no	NOK	No beam status of MMICHA	Monitors		
39	GS_US_VMS_ATOT	IN	no	yes	NOK	ATOT signal from VMS VPS system	VMS VPS		
40	GS_US_MPSC_ATOT	IN	no	no	NOK	ATOT signal from MPSC system	PMSC		
41	GS_US_ATOT_ERR	IN	no	no	NOK	ATOT error signal from MPSC system	PMSC		
42	GS_US_ATOT_ERR	IN	no	no	NOK	ATOT error signal from MPSC system	PMSC		
43	GS_US_ATOT_ERR	IN	no	no	NOK	ATOT error signal from MPSC system	PMSC		
44	GS_US_ATOT_ERR	IN	no	no	NOK	ATOT error signal from MPSC system	PMSC		
45	GS_US_ATOT_ERR	IN	no	no	NOK	ATOT error signal from MPSC system	PMSC		
46	GS_US_ATOT_ERR	IN	no	no	NOK	ATOT error signal from MPSC system	PMSC		
47	GS_US_ATOT_ERR	IN	no	no	NOK	ATOT error signal from MPSC system	PMSC		
48	GS_US_TCS_AIR_MASTER	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
49	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
50	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
51	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
52	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
53	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
54	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
55	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
56	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
57	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
58	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
59	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
60	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
61	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
62	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
63	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
64	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
65	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
66	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
67	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
68	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
69	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
70	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
71	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
72	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
73	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
74	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
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76	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
77	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
78	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
79	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
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81	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
82	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
83	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
84	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
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86	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
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92	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
93	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
94	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
95	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
96	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
97	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
98	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
99	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		
100	GS_US_VPS_RESERVED_STA	OUT	no	no	NOK	Status feedback to TCS-Adapter	TCS Adapter		

PACKAGE DEFINITIONS	
Memory_word_size	32
Interlock_size	64
INTERLOCK METRICS	
GS_US_Beam_Angle	8
GS_First_VPS_1	GS_US_RESERVED_STA
GS_Second_VPS_1	GS_US_RESERVED_STA
GS_First_VPS_2	GS_US_RESERVED_STA
GS_Second_VPS_2	GS_US_RESERVED_STA
GS_First_VPS_3	GS_US_RESERVED_STA
GS_Second_VPS_3	GS_US_RESERVED_STA
GS_First_VPS_4	GS_US_RESERVED_STA
GS_Second_VPS_4	GS_US_RESERVED_STA
GS_First_VPS_5	GS_US_RESERVED_STA
GS_Second_VPS_5	GS_US_RESERVED_STA
GS_First_VPS_6	GS_US_RESERVED_STA
GS_Second_VPS_6	GS_US_RESERVED_STA
GS_First_VPS_7	GS_US_RESERVED_STA
GS_Second_VPS_7	GS_US_RESERVED_STA
GS_First_VPS_8	GS_US_RESERVED_STA
GS_Second_VPS_8	GS_US_RESERVED_STA
GS_First_VPS_9	GS_US_RESERVED_STA
GS_Second_VPS_9	GS_US_RESERVED_STA
GS_First_VPS_10	GS_US_RESERVED_STA
GS_Second_VPS_10	GS_US_RESERVED_STA
GS_First_VPS_11	GS_US_RESERVED_STA
GS_Second_VPS_11	GS_US_RESERVED_STA
GS_First_VPS_12	GS_US_RESERVED_STA
GS_Second_VPS_12	GS_US_RESERVED_STA
GS_First_VPS_13	GS_US_RESERVED_STA
GS_Second_VPS_13	GS_US_RESERVED_STA
GS_First_VPS_14	GS_US_RESERVED_STA
GS_Second_VPS_14	GS_US_RESERVED_STA
GS_First_VPS_15	GS_US_RESERVED_STA
GS_Second_VPS_15	GS_US_RESERVED_STA
GS_First_VPS_16	GS_US_RESERVED_STA
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GS_Second_VPS_25	GS_US_RESERVED_STA
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GS_Second_VPS_26	GS_US_RESERVED_STA
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GS_First_VPS_32	GS_US_RESERVED_STA
GS_Second_VPS_32	GS_US_RESERVED_STA
GS_First_VPS_33	GS_US_RESERVED_STA
GS_Second_VPS_33	GS_US_RESERVED_STA
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GS_Second_VPS_38	GS_US_RESERVED_STA
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GS_First_VPS_43	GS_US_RESERVED_STA
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GS_Second_VPS_45	GS_US_RESERVED_STA
GS_First_VPS_46	GS_US_RESERVED_STA
GS_Second_VPS_46	GS_US_RESERVED_STA
GS_First_VPS_47	GS_US_RESERVED_STA
GS_Second_VPS_47	GS_US_RESERVED_STA
GS_First_VPS_48	GS_US_RESERVED_STA
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GS_First_VPS_50	GS_US_RESERVED_STA
GS_Second_VPS_50	GS_US_RESERVED_STA
GS_First_VPS_51	GS_US_RESERVED_STA
GS_Second_VPS_51	GS_US_RESERVED_STA
GS_First_VPS_52	GS_US_RESERVED_STA
GS_Second_VPS_52	GS_US_RESERVED_STA
GS_First_VPS_53	GS_US_RESERVED_STA
GS_Second_VPS_53	GS_US_RESERVED_STA
GS_First_VPS_54	GS_US_RESERVED_STA
GS_Second_VPS_54	GS_US_RESERVED_STA
GS_First_VPS_55	GS_US_RESERVED_STA
GS_Second_VPS_55	GS_US_RESERVED_STA
GS_First_VPS_56	GS_US_RESERVED_STA
GS_Second_VPS_56	GS_US_RESERVED_STA
GS_First_VPS_57	GS_US_RESERVED_STA
GS_Second_VPS_57	GS_US_RESERVED_STA
GS_First_VPS_58	GS_US_RESERVED_STA
GS_Second_VPS_58	GS_US_RESERVED_STA
GS_First_VPS_59	GS_US_RESERVED_STA
GS_Second_VPS_59	GS_US_RESERVED_STA
GS_First_VPS_60	GS_US_RESERVED_STA
GS_Second_VPS_60	GS_US_RESERVED_STA
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GS_Second_VPS_64	GS_US_RESERVED_STA
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GS_Second_VPS_235	GS_US_RESERVED_STA
GS_First_VPS_236	GS_US_RESERVED_STA
GS_Second_VPS_236	GS_US_RESERVED_STA



There is no official procedure to get a license to do proton therapy in Switzerland

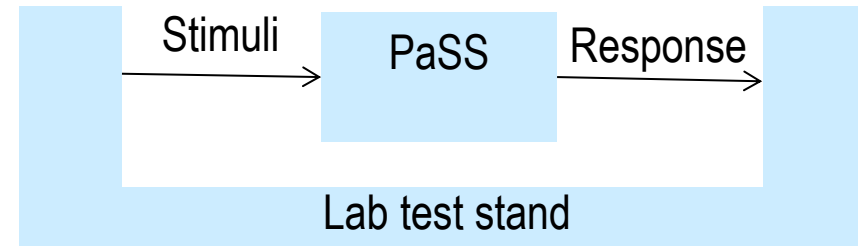
What worked in the past for us:

## Preparation

Risk analysis	}	Developed by different people
Design specification		
PaSS Implementation		
Test specification		

## Unit test in the lab

- Firmware simulation with Modelsim
- Extensive test with LabVIEW generated stimuli



## Integration test in the therapy area, full QA

- Test all functions
- Test all final elements
- Generate errors and monitor PaSS response

## Functional PaSS with EPICS GUI in time for gantry integration

### Extra functionality built in:

Improve work tools for physicist for error debugging:

Deterministic time tracking of interlock events

GUI describes detailed status, source, destination and properties of all signals

Reduce time needed for Quality Assurance

Built-in measurement of response time of safety elements

Many statistics available

### Development time

Comparison with the development in 2009 of the Optis PaSS (Similar system, some assumptions made)

G3 IOC + SCB FW	Optis PaSS FW	
165 man days	310 man days	~40% less

- A reusable, modular Patient Safety System was built to integrate a new commercial gantry in the existing infrastructure of the Center for Proton Therapy at PSI.
  - Reusing technology: sophisticated solution, highly customised, with restricted manpower and time.
  - Separation into generic and gantry specific: Fast deployment in other facilities, with only small adaptations being needed.
- GUI extensive information and deterministic log of interlock events can reduce the physicist's response time when called by radiographer technicians
- Including built-in debug, visibility and measurement elements make possible automating some QA tasks and to predict failures by ageing and deterioration of several components.



