



Equipment Faults Detection Sequence

Bruno PUCCIO

Workshop on Machine Protection,
focusing on Linear Accelerator complexes

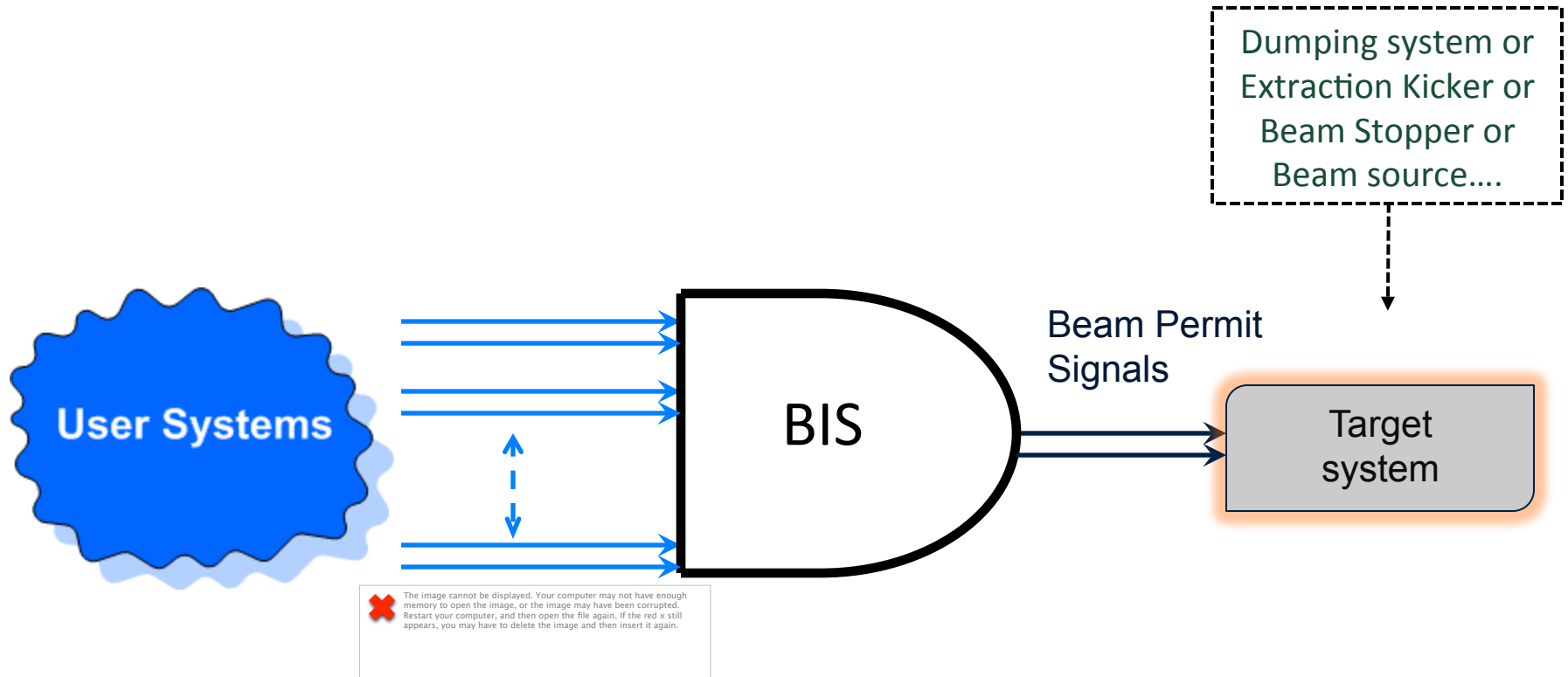
6-8 June 2012

With contributions of Benjamin Todd, Ivàn Romera & Markus Zerlauth

Outline

- ◆ Beam Interlock System overview
- ◆ BIS & Timing Sequences
- ◆ Post-Mortem system
- ◆ Summary

Beam Interlock System Function



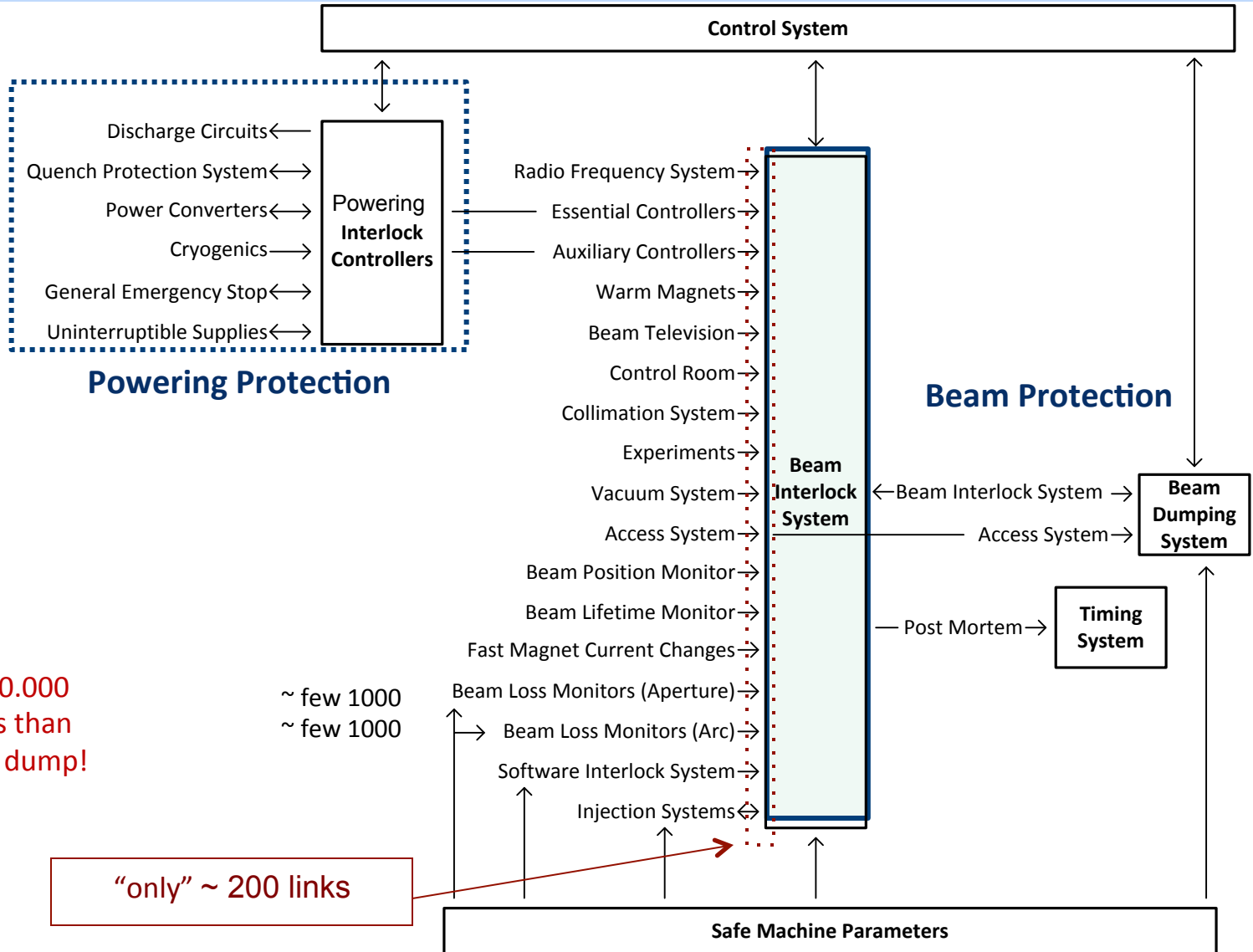
$\Sigma(\text{User Permit} = \text{"TRUE"}) \Rightarrow \text{Beam Operation is allowed}$

$\text{IF one User Permit} = \text{"FALSE"} \Rightarrow \text{Beam Operation is stopped}$

BIS = Core of LHC Machine Protection

Interlock conditions

- 24
- ~ 20000
- ~ 1800
- ~ 3500
- ~ few 100
- ~ few 100

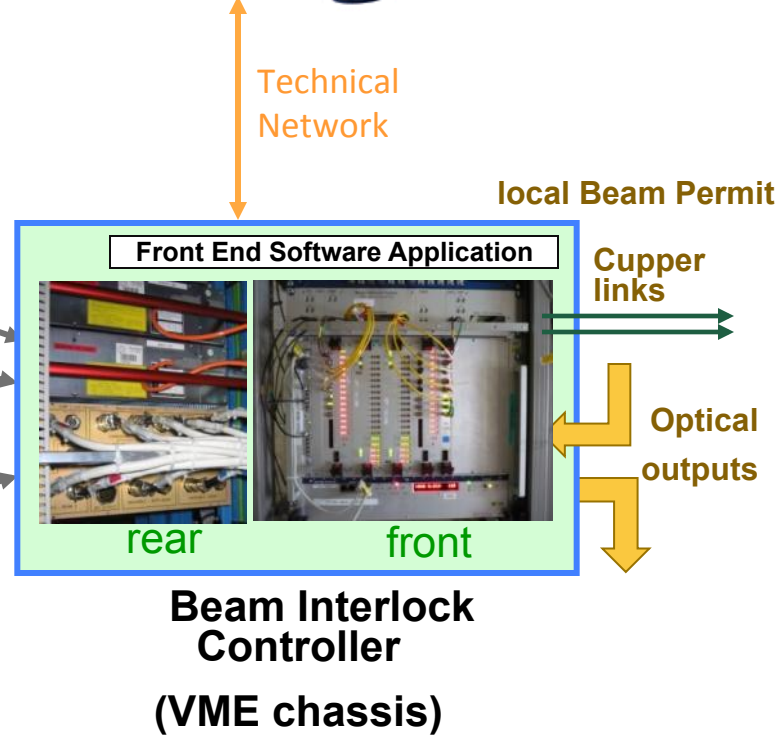
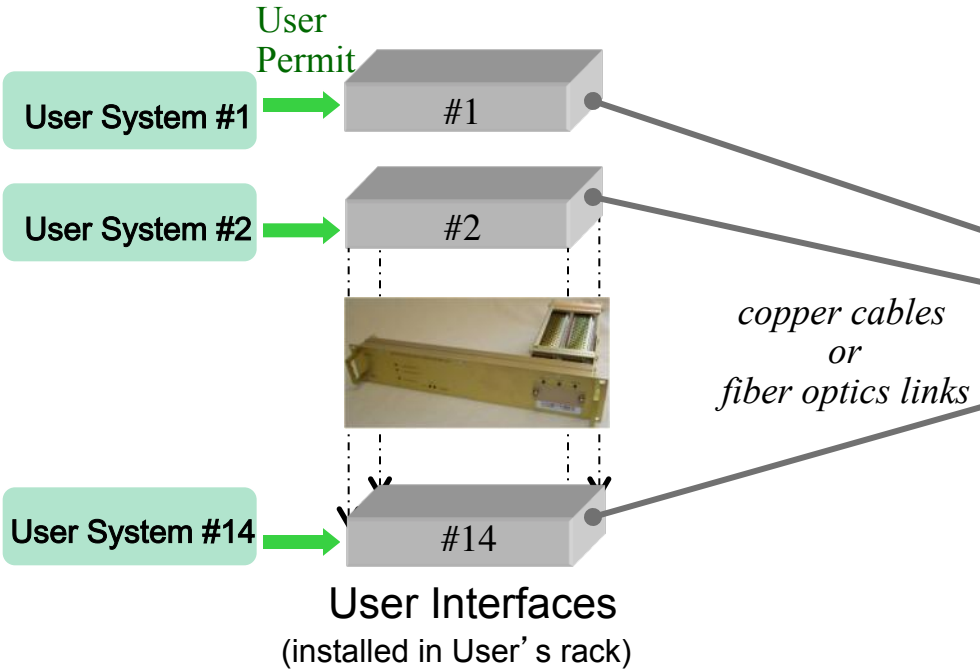
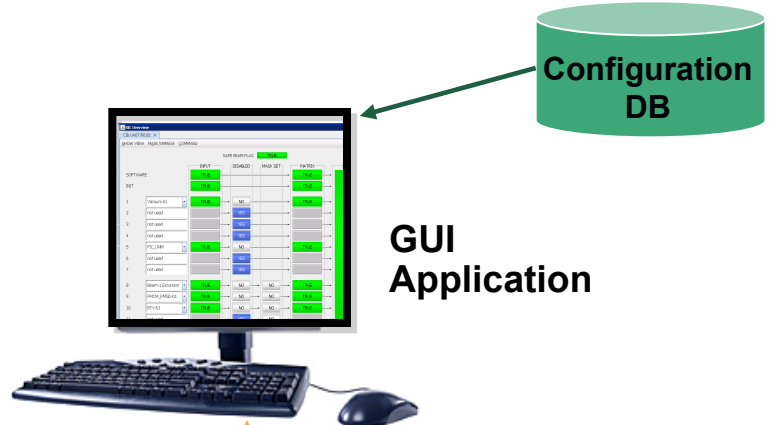


In total, several 10.000 interlock channels than can trigger a beam dump!

“only” ~ 200 links

BIS Overview

- Remote **User Interfaces** safely transmit Permit signals from connected systems to Controller
- Controller** acts as a concentrator
- collecting User Systems Permits
- generating local Beam Permit
- Controllers could be **daisy chained** (Tree architecture) or could share **Beam Permit Loops** (Ring architecture)



LHC Beam Permit Loops

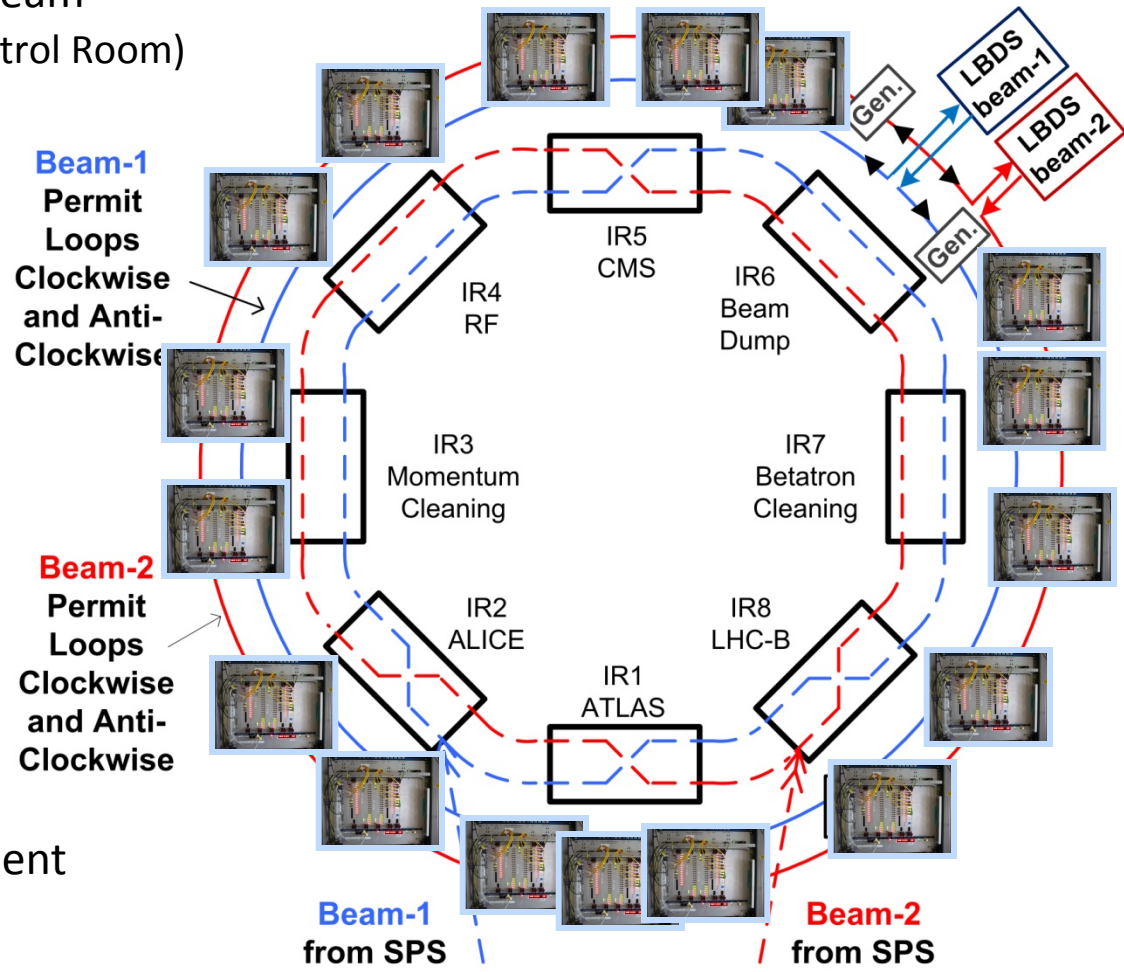
17 Beam Interlock Controllers per beam
(2 per Insertion Region (IR) + 1 near Control Room)

4 fibre-optic channels:
1 clockwise & 1 anticlockwise
for **each** beam

Square wave generated at IR6:
Signal can be **cut** and **monitored** by
any Controller

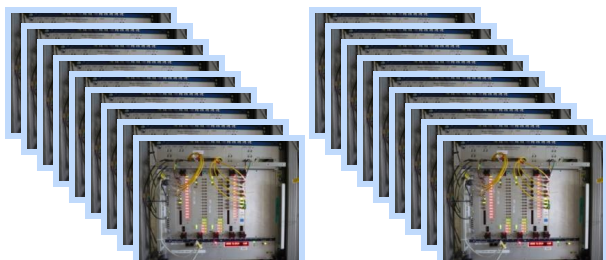
When any of the four signals are
absent at IR6, **BEAM DUMP!**

Beam-1 / Beam-2 loops are independent
but they can be linked (or unlinked)

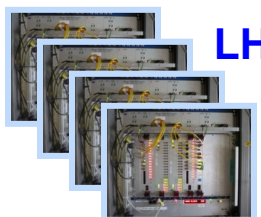


Beam Interlock Systems currently in Operation

50 Controllers in total
~ 370 connected systems



LHC ring
 (2 x 17 controllers)



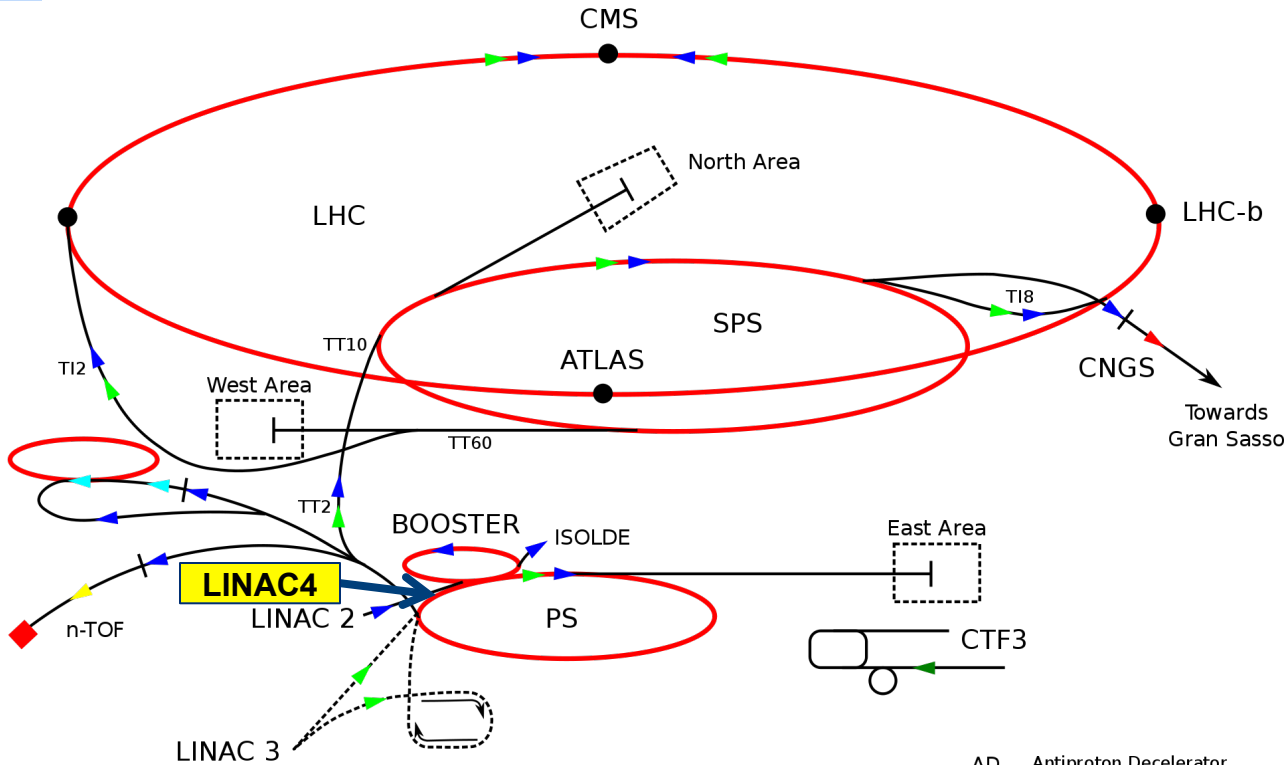
LHC Injection regions
 (4 c.)



SPS to LHC Transfer lines
 (14 c.)



SPS ring
 (since 2006)
 (6 c.)

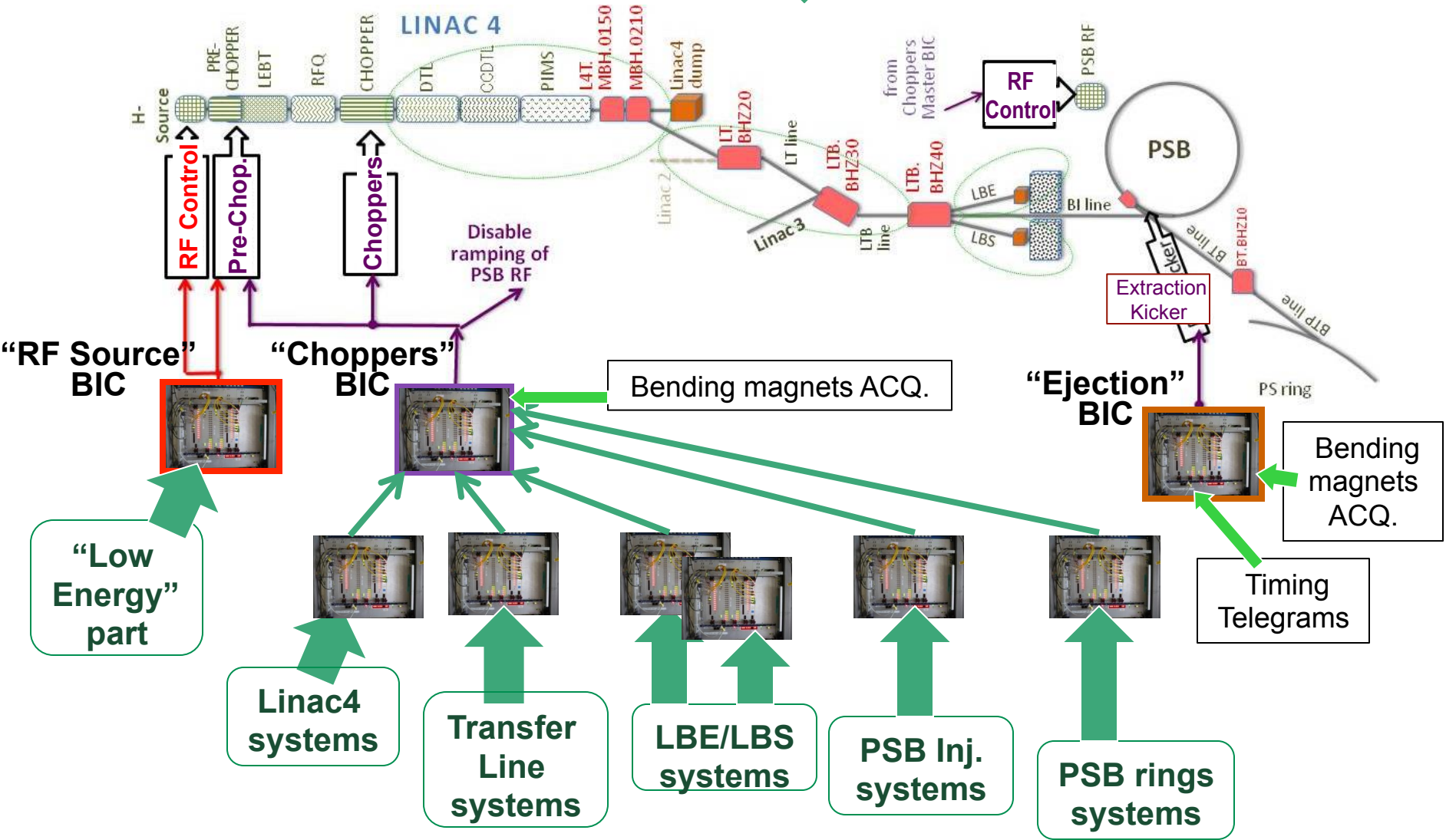


- ▶ protons
- ▶ antiprotons
- ▶ ions
- ▶ electrons
- ▶ neutrons
- ▶ neutrinos

- PS Proton Synchrotron
- SPS Super Proton Synchrotron
- LHC Large Hadron Collider
- AD Antiproton Decelerator
- n-TOF Neutron Time Of Flight
- CNGS CERN Neutrinos Gran Sasso
- CTF3 CLIC Test Facility 3

2013: BIS deployment to new Linac4 (and to Booster)

in using same Hw



Fail Safe concept:

Must go to fail safe state whatever the failure

Safe: (Safety Integrity Level 3 was used as a guideline).

Must react with a probability of unsafe failure of less than 10^{-7} per hour and, Beam abort less than 1% of missions due to internal failure (2 to 4 failures per year).

Reliable: (whole design studied using Military and Failure Modes Handbooks)

Results from the LHC analysis are:

P (false beam dump) per hour = 9.1×10^{-4}

P (missed beam dump) per hour = 3.3×10^{-9}

Available:

Uninterruptable Powering (UPS)

Redundant Power Supply for Controller (i.e. VME crate)

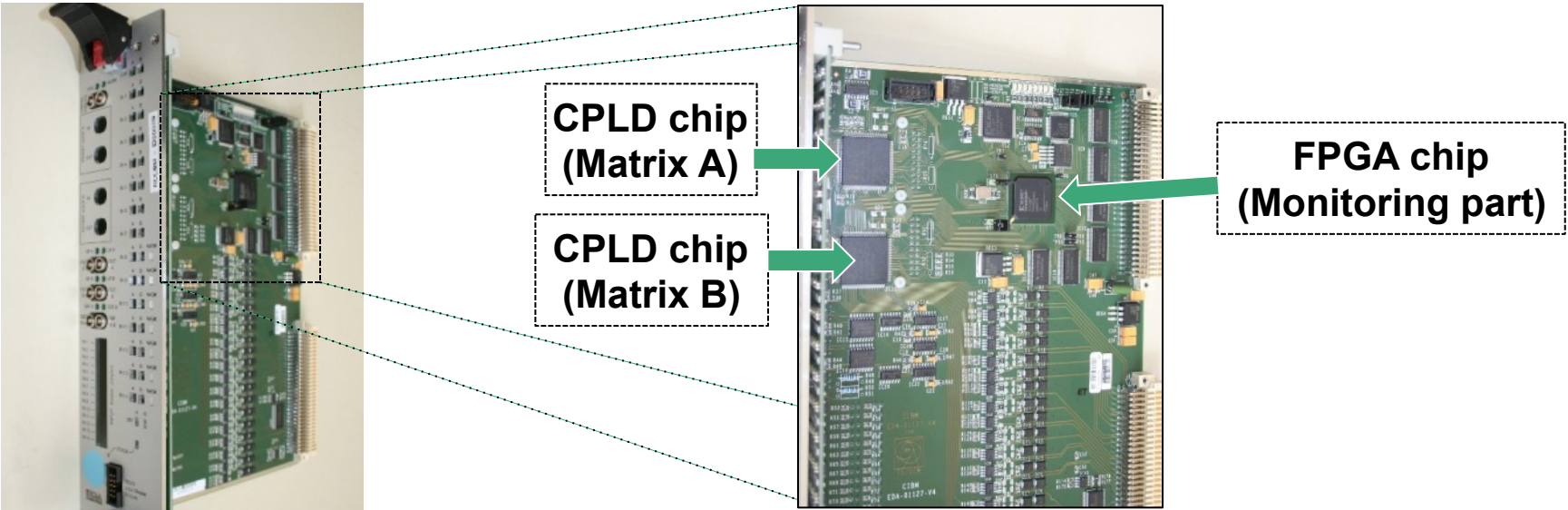
Redundant Power Supply for Remote User Interface

Critical process in Hardware:

- ◆ functionality into 2 redundant matrices
- ◆ VHDL code written by different engineers following same specification.

Critical / Non-Critical separation:

- ◆ Critical functionality always separated from non-critical.
- ◆ Monitoring elements fully independent of the two redundant safety channels.



Manager board

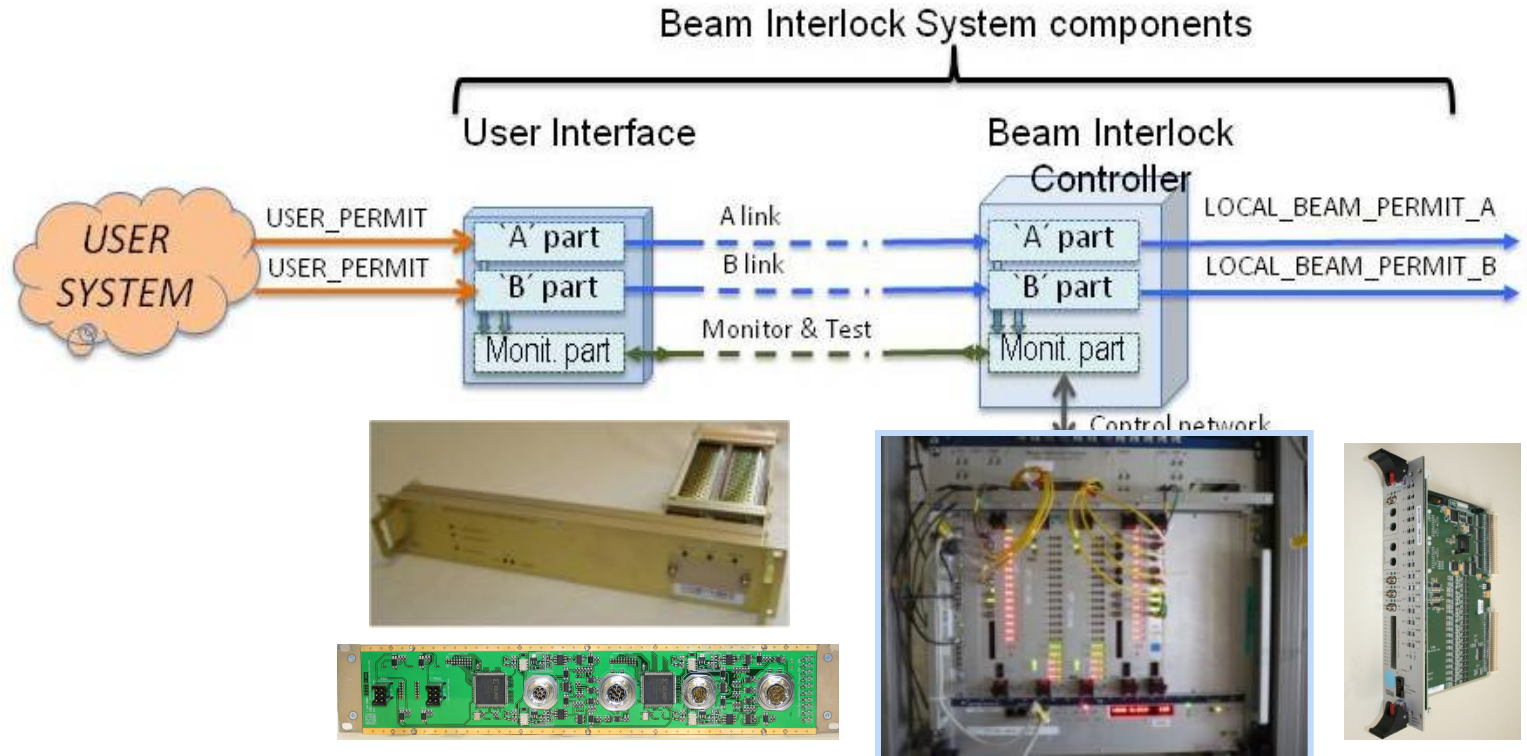
Used CPLD: 288 macro-cells & 6'400 equivalent gates

Used FPGA: 30'000 macro-cells & 1 million gates + all the built in RAM ,etc.

CPLD: Complex Programmable Logic Device FPGA: Field Programmable Gate Array

BIS Performance

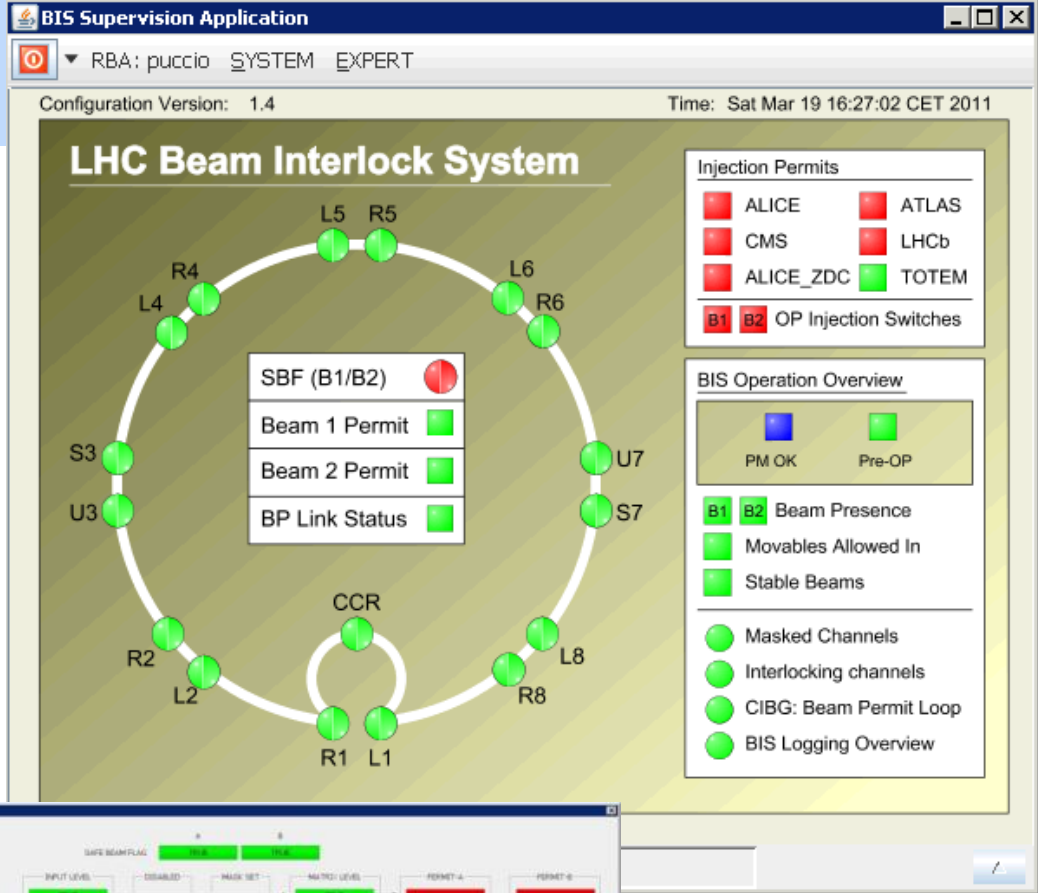
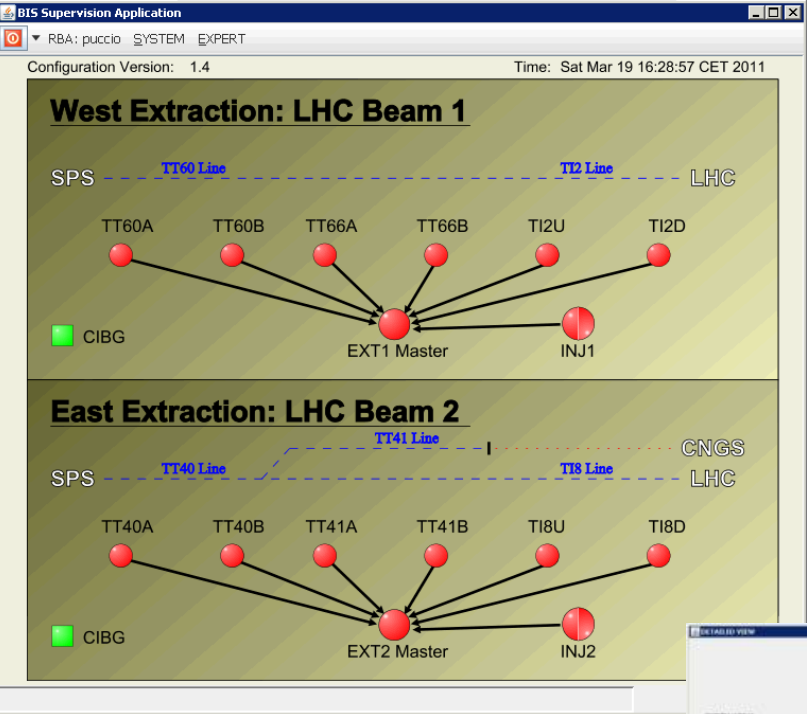
100% Online Test Coverage: Can be easily tested from end-to-end in a safe manner => recovered “good as new”



Fast: ~20 μ S reaction time from *User Permit* change detection to the corresponding *Local Beam Permit* change

Modular: (“Tree” or ”Ring” topology) & (daisy chain of BIC to BIC possible)

Control Room GUIs



ENABLED VIEW

	SAFE BEAM FLAG	A	B			
	INPUT LEVEL	DISABLED	MASK SET	MASK LEVEL	PERMIT-A	PERMIT-B
SOFTWAREA	TRUE			TRUE	FALSE	FALSE
SOFTWAREB	TRUE			TRUE		
INFA	TRUE			TRUE		
INFB	TRUE			TRUE		
1/A	Variable 01	FALSE	NO	FALSE		
1/B	PER LEAD	FALSE	NO	FALSE		
2/A	PER LEAD	FALSE	NO	FALSE		
2/B	PER LEAD	FALSE	NO	FALSE		
3/A	PER LEAD	FALSE	NO	FALSE		
3/B	PER LEAD	FALSE	NO	FALSE		
4/A	BLM_LPM	FALSE	NO	FALSE		
4/B	BLM_LPM	FALSE	NO	FALSE		
5/A	PEC_LPM	TRUE	NO	TRUE		
5/B	PEC_LPM	TRUE	NO	TRUE		
6/A	Variable 0300	FALSE	NO	FALSE		
6/B	Variable 0300	FALSE	NO	FALSE		
7/A	INJ	FALSE	NO	FALSE		
7/B	INJ	FALSE	NO	FALSE		
8/A	COLLIMPTOL	TRUE	NO	NO		
8/B	COLLIMPTOL	TRUE	NO	NO		
9/A	COLLIMPTOL	TRUE	NO	NO		
9/B	COLLIMPTOL	TRUE	NO	NO		
10/A	BTF01	FALSE	NO	FALSE		
10/B	BTF01	FALSE	NO	FALSE		
11/A	BLM_MON	FALSE	NO	FALSE		
11/B	BLM_MON	FALSE	NO	FALSE		
12/A	PEC_MON	FALSE	NO	FALSE		
12/B	PEC_MON	FALSE	NO	FALSE		
13/A	PER LEAD	FALSE	NO	FALSE		
13/B	PER LEAD	FALSE	NO	FALSE		
14/A	PER LEAD	FALSE	NO	FALSE		
14/B	PER LEAD	FALSE	NO	FALSE		

History Buffer

PERMIT	TIMESTAMP	DEVICE	DESCRIPTION
🚫🚫	2012-06-06 16:02:06.152292	CIB.BA6.TT60A	USER PERMIT: Ch 8(TT60 Converters currents): B T -> F
🚫🚫	2012-06-06 16:02:06.152291	CIB.BA6.TT60A	USER PERMIT: Ch 8(TT60 Converters currents): A T -> F
🚫🚫	2012-06-06 16:02:06.15228	CIB.BA6.TT60A	LOCAL PERMIT: B T -> F
🚫🚫	2012-06-06 16:02:06.15228	CIB.BA6.TT60A	LOCAL PERMIT: A T -> F
🟢🟢	2012-06-06 16:02:06.152278	CIB.BA6.TT60A	USER PERMIT: Ch 9(MSE/MST currents): B T -> F
🟢🟢	2012-06-06 16:02:06.152278	CIB.BA6.TT60A	USER PERMIT: Ch 9(MSE/MST currents): A T -> F
🟢🟢	2012-06-06 16:02:06.151002	CIB.BA6.TT60A	MARKER: 2 us
🟢🟢	2012-06-06 16:02:06.147781	CIB.BA6.TT60A	LOCAL PERMIT: B F -> T
🟢🟢	2012-06-06 16:02:06.147781	CIB.BA6.TT60A	LOCAL PERMIT: A F -> T
🚫🚫	2012-06-06 16:02:06.14778	CIB.BA6.TT60A	USER PERMIT: Ch 10(MBB current): B F -> T
🚫🚫	2012-06-06 16:02:06.14778	CIB.BA6.TT60A	USER PERMIT: Ch 9(MSE/MST currents): A F -> T
🚫🚫	2012-06-06 16:02:06.14773	CIB.BA6.TT60A	USER PERMIT: Ch 9(MSE/MST currents): B F -> T
🚫🚫	2012-06-06 16:02:06.14773	CIB.BA6.TT60A	USER PERMIT: Ch 9(MSE/MST currents): A F -> T
🚫🚫	2012-06-06 16:02:06.147724	CIB.BA6.TT60A	USER PERMIT: Ch 8(TT60 Converters currents): B F -> T
🚫🚫	2012-06-06 16:02:06.147724	CIB.BA6.TT60A	USER PERMIT: Ch 8(TT60 Converters currents): A F -> T
🚫🚫	2012-06-06 16:02:06.140292	CIB.BA6.TT60A	USER PERMIT: Ch 8(TT60 Converters currents): B T -> F
🚫🚫	2012-06-06 16:02:06.140291	CIB.BA6.TT60A	USER PERMIT: Ch 8(TT60 Converters currents): A T -> F
🚫🚫	2012-06-06 16:02:06.140278	CIB.BA6.TT60A	USER PERMIT: Ch 9(MSE/MST currents): B T -> F
🚫🚫	2012-06-06 16:02:06.140278	CIB.BA6.TT60A	USER PERMIT: Ch 9(MSE/MST currents): A T -> F
🚫🚫	2012-06-06 16:02:06.140231	CIB.BA6.TT60A	LOCAL PERMIT: B T -> F
🚫🚫	2012-06-06 16:02:06.140231	CIB.BA6.TT60A	LOCAL PERMIT: A T -> F
🟢🟢	2012-06-06 16:02:06.140229	CIB.BA6.TT60A	USER PERMIT: Ch 10(MBB current): A T -> F
🟢🟢	2012-06-06 16:02:06.140228	CIB.BA6.TT60A	USER PERMIT: Ch 10(MBB current): B T -> F
🟢🟢	2012-06-06 16:02:06.135737	CIB.BA6.TT60A	LOCAL PERMIT: B F -> T
🟢🟢	2012-06-06 16:02:06.135737	CIB.BA6.TT60A	LOCAL PERMIT: A F -> T
🚫🚫	2012-06-06 16:02:06.135736	CIB.BA6.TT60A	USER PERMIT: Ch 9(MSE/MST currents): B T -> F
🚫🚫	2012-06-06 16:02:06.135736	CIB.BA6.TT60A	USER PERMIT: Ch 9(MSE/MST currents): A T -> F
🚫🚫	2012-06-06 16:02:06.135734	CIB.BA6.TT60A	USER PERMIT: Ch 8(TT60 Converters currents): B F -> T
🚫🚫	2012-06-06 16:02:06.135734	CIB.BA6.TT60A	USER PERMIT: Ch 8(TT60 Converters currents): A F -> T
🚫🚫	2012-06-06 16:02:06.135703	CIB.BA6.TT60A	USER PERMIT: Ch 10(MBB current): B F -> T
🚫🚫	2012-06-06 16:02:06.135703	CIB.BA6.TT60A	USER PERMIT: Ch 10(MBB current): A F -> T
🚫🚫	2012-06-06 16:02:05.825663	CIB.BA6.TT60A	USER PERMIT: Ch 14(FMCM_MST6177M): B F -> T
🚫🚫	2012-06-06 16:02:05.825663	CIB.BA6.TT60A	USER PERMIT: Ch 14(FMCM_MST6177M): A F -> T
🚫🚫	2012-06-06 16:02:05.800256	CIB.BA6.TT60A	USER PERMIT: Ch 13(FMCM_MSE6183M): B F -> T
🚫🚫	2012-06-06 16:02:05.800256	CIB.BA6.TT60A	USER PERMIT: Ch 13(FMCM_MSE6183M): A F -> T
🚫🚫	2012-06-06 16:02:05.238001	CIB.BA6.TT60A	SAFE BEAM FLAG: B F -> T
🚫🚫	2012-06-06 16:02:05.238001	CIB.BA6.TT60A	SAFE BEAM FLAG: A F -> T
🚫🚫	2012-06-06 16:01:47.388	CIB.BA6.TT60A	SAFE BEAM FLAG: A T -> F

Equipment systems



User Interfaces

Technical network



Safety part

Mon. part

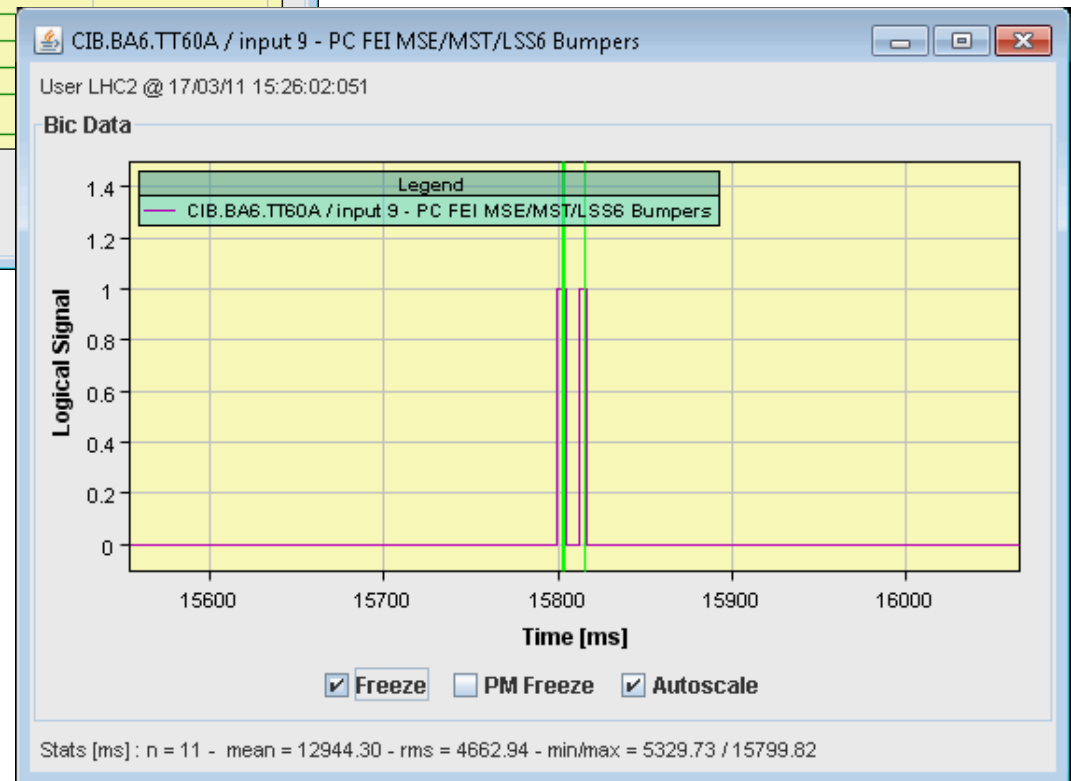
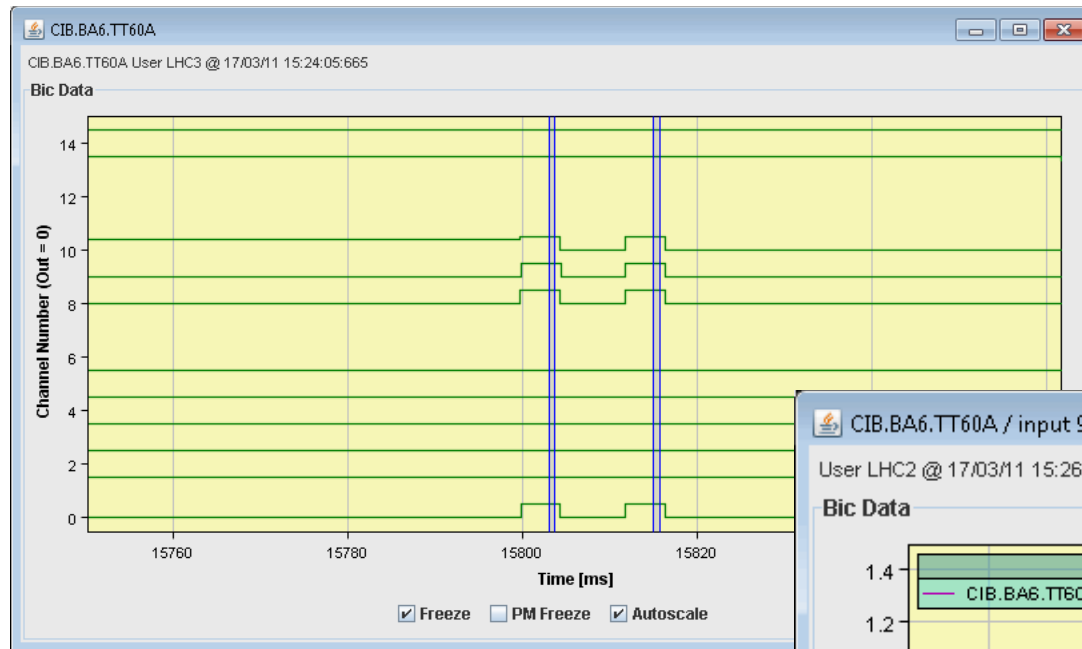


Local Beam Permit

Beam Interlock Controller

🚫🚫	2012-06-06 16:02:06.15228	CIB.BA6.TT60A	LOCAL PERMIT: B T -> F
🚫🚫	2012-06-06 16:02:06.15228	CIB.BA6.TT60A	LOCAL PERMIT: A T -> F
🟢🟢	2012-06-06 16:02:06.152278	CIB.BA6.TT60A	USER PERMIT: Ch 9(MSE/MST currents): B T -> F
🟢🟢	2012-06-06 16:02:06.152278	CIB.BA6.TT60A	USER PERMIT: Ch 9(MSE/MST currents): A T -> F
🟢🟢	2012-06-06 16:02:06.151002	CIB.BA6.TT60A	MARKER: 2 us
🟢🟢	2012-06-06 16:02:06.147781	CIB.BA6.TT60A	LOCAL PERMIT: B F -> T
🟢🟢	2012-06-06 16:02:06.147781	CIB.BA6.TT60A	LOCAL PERMIT: A F -> T

Timing views extracted from history buffer

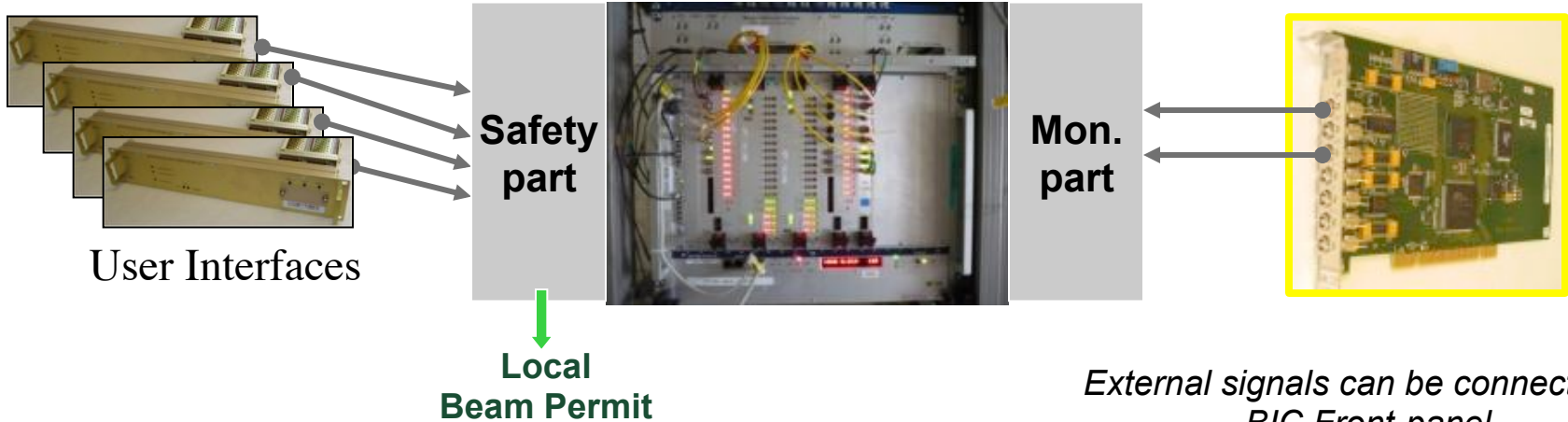


External signal(s) logged in history buffer

Equipment systems

Beam Interlock
Controller

Timing Receiver card

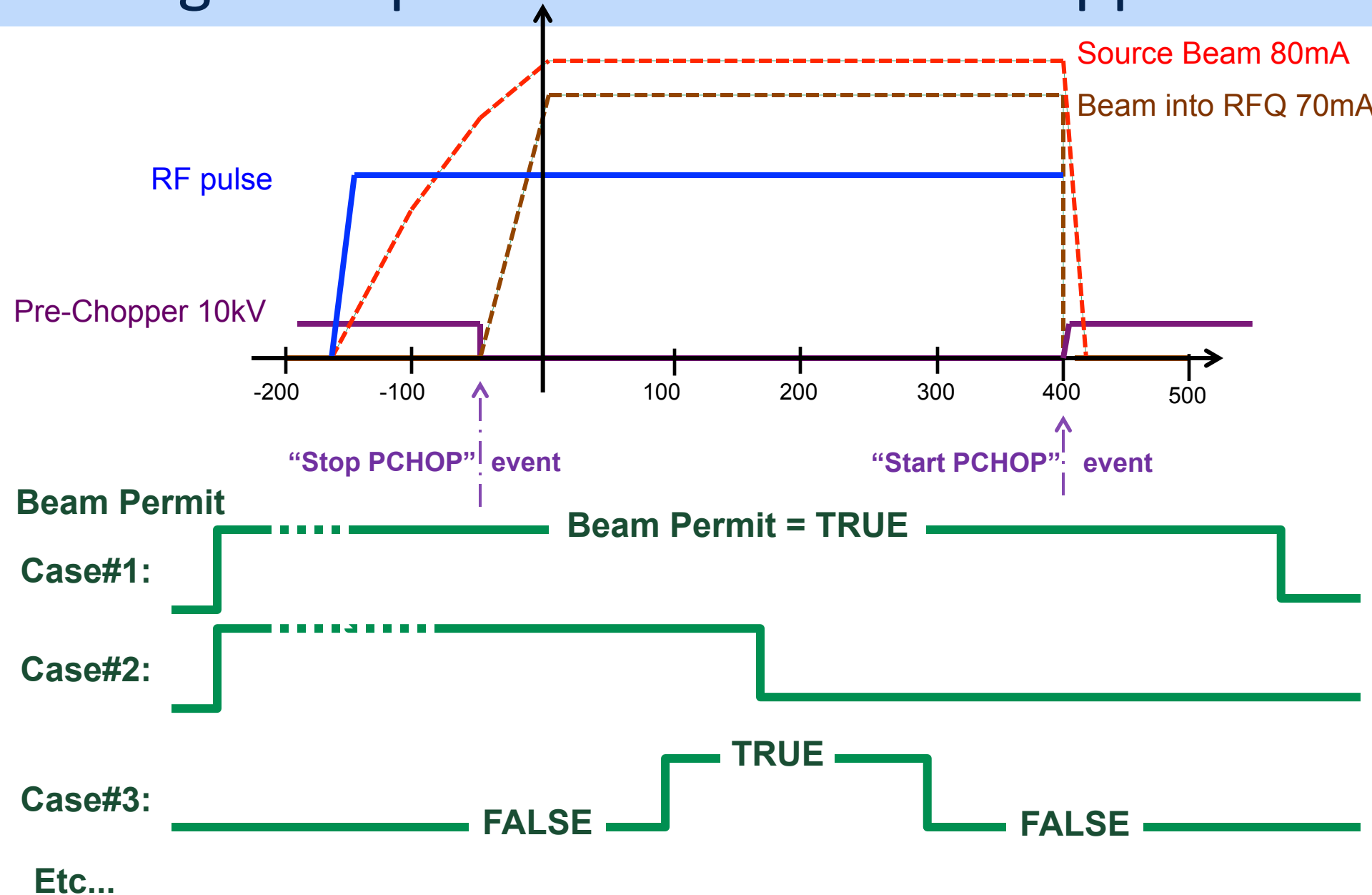


External signals can be connected to BIC Front-panel

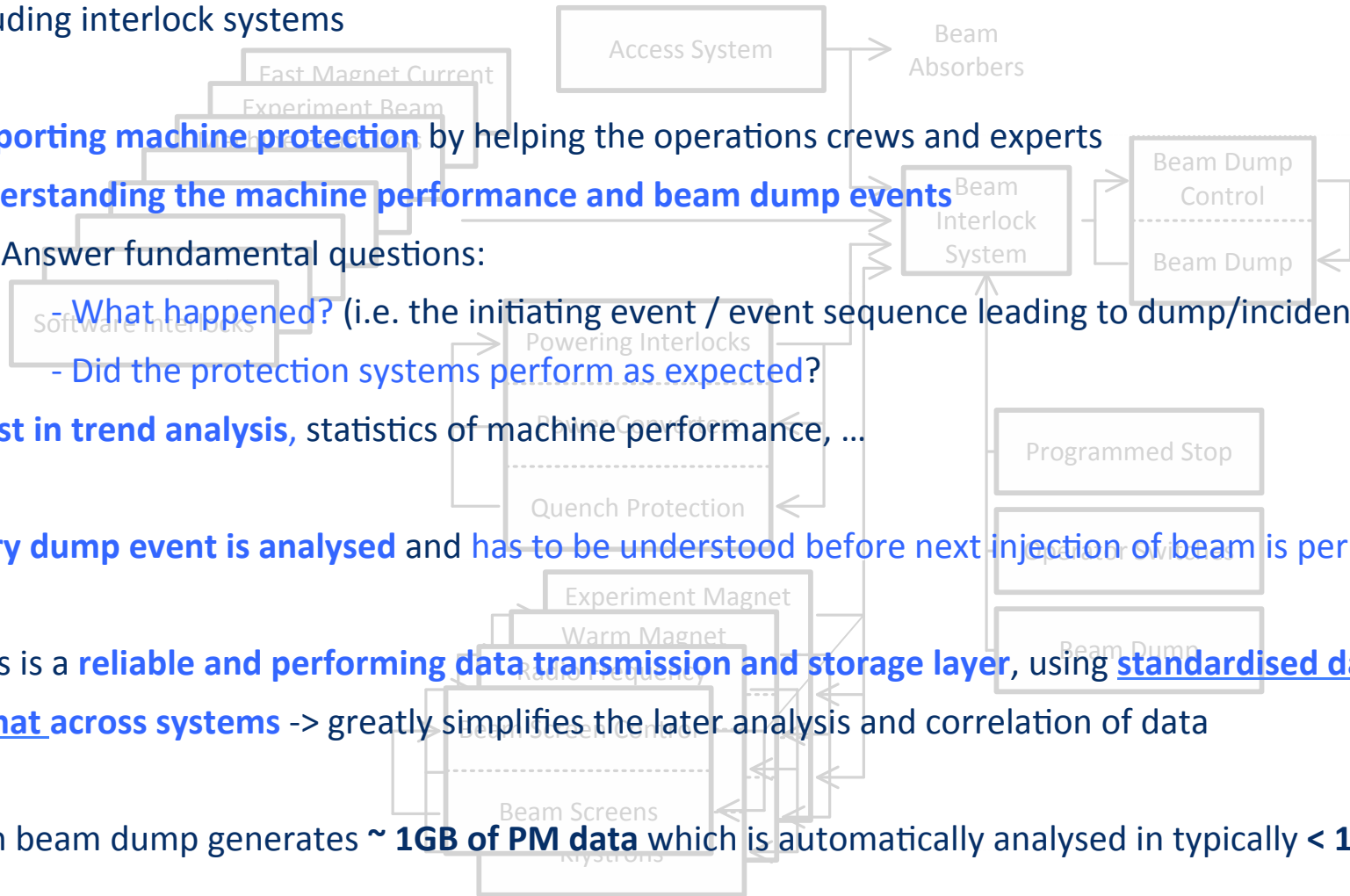
🚫🚫	2012-06-06 16:02:06.15228	CIB.BA6.TT60A	LOCAL PERMIT: B T -> F
🚫🟢	2012-06-06 16:02:06.15228	CIB.BA6.TT60A	LOCAL PERMIT: A T -> F
🟢🟢	2012-06-06 16:02:06.152278	CIB.BA6.TT60A	USER PERMIT: Ch 9(MSE/MST currents): B T -> F
🟢🟢	2012-06-06 16:02:06.152278	CIB.BA6.TT60A	USER PERMIT: Ch 9(MSE/MST currents): A T -> F
🟢🟢	2012-06-06 16:02:06.151002	CIB.BA6.TT60A	MARKER: ← SPS Extraction event
🟢🟢	2012-06-06 16:02:06.147781	CIB.BA6.TT60A	LOCAL PERMIT: B F -> T
🟢🟢	2012-06-06 16:02:06.147781	CIB.BA6.TT60A	LOCAL PERMIT: A F -> T

extracted from the SPS Extraction BIC's history buffer

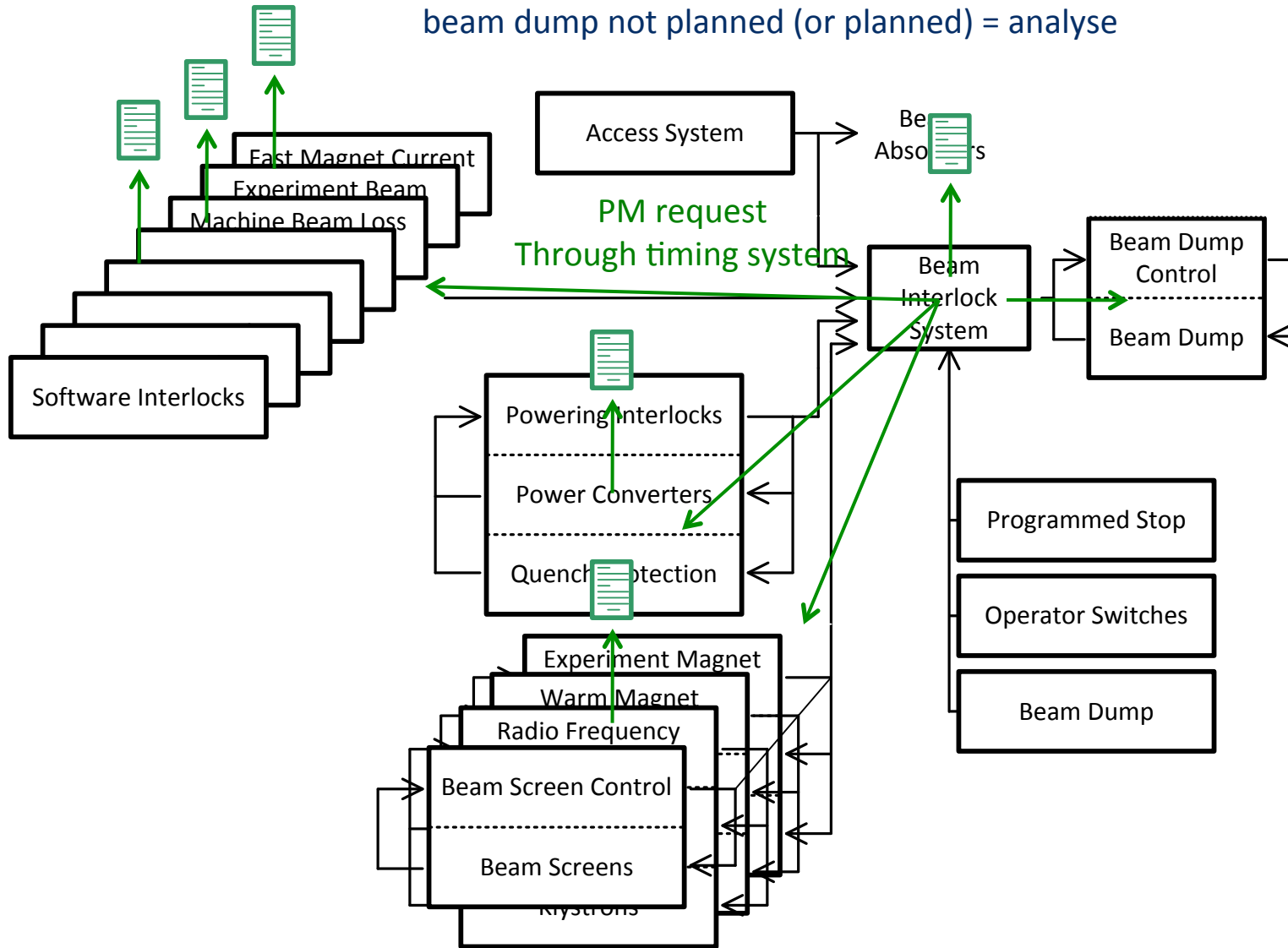
Timing example with Linac4 Pre-chopper



- Automated post-operational analysis** of transient data recordings from LHC equipment systems, including interlock systems
- Supporting machine protection** by helping the operations crews and experts
- Understanding the machine performance and beam dump events**
- and Answer fundamental questions:
 - What happened? (i.e. the initiating event / event sequence leading to dump/incident)
 - Did the protection systems perform as expected?
- Assist in trend analysis**, statistics of machine performance, ...
- Every dump event is analysed** and has to be understood before next injection of beam is permitted
- Basis is a **reliable and performing data transmission and storage layer**, using standardised data format across systems -> greatly simplifies the later analysis and correlation of data
- Each beam dump generates **~ 1GB of PM data** which is automatically analysed in typically **< 1 min**



beam dump not planned (or planned) = analyse



The screenshot displays the PM Server Architecture interface with the following sections:

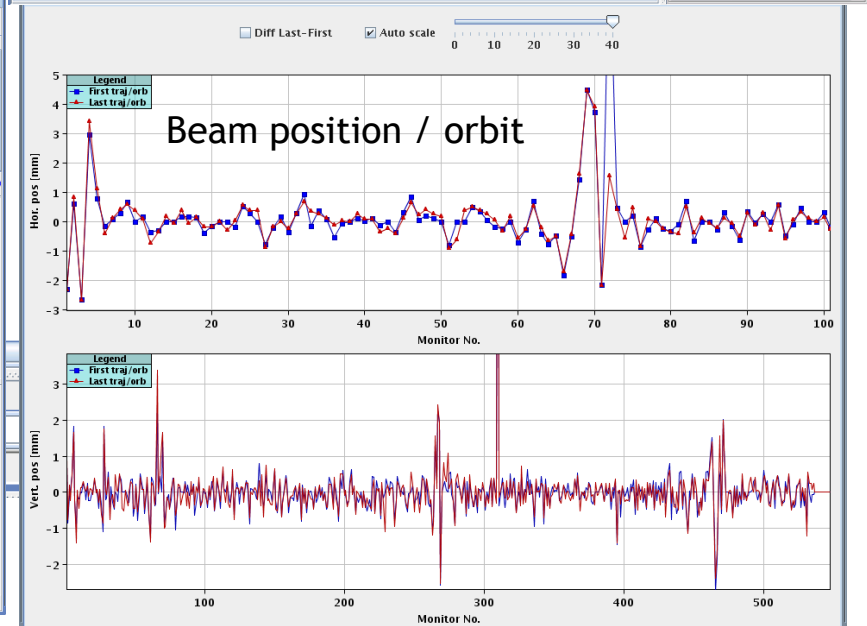
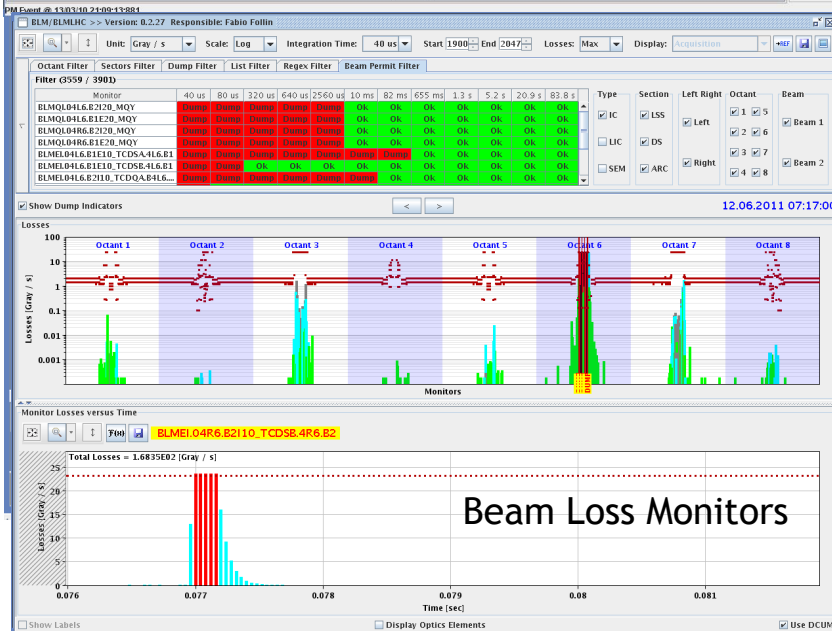
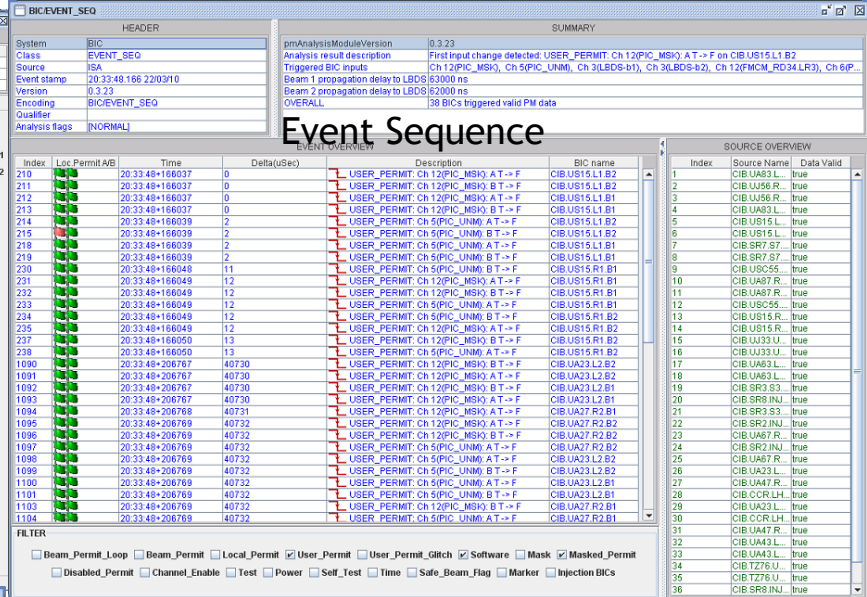
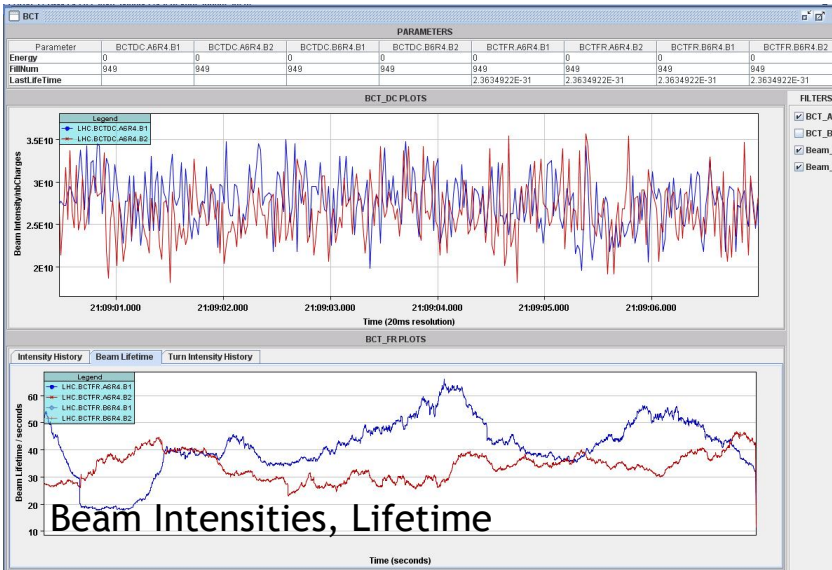
- Session confirmation** (selected): Shows event details for 2010.06.18 06:33:18 CEST, including Acc mode (BEAM SETUP), Beam mode (INJECTION PROBE BEAM), Energy (450120 [MeV]), and Intensity (0 [e^10 charges]).
- Machine protection features**: Lists various protection checks with status indicators (green checkmarks for OK, red X for error).

BIC IPOC:	✓	FMCN ISA:	✓	PIC IPOC:	✓
XPOC B1:	✓	XPOC B2:	✗		
Safe for injection ?:	✓	PM Overall:	✓		
- Event sequence**: Details the event as a PROGRAMMED_DUMP, SINGLE_SYSTEM_DUMP, triggered by input changes in Ch 1 and Ch 3.
- Comments**: Includes a text area for session confirmation and buttons for Confirm, Discard, and Release SIS.
- Console**: Shows a log of system messages, including "Final analysis is finished" and "Ignoring IQC PM event".





Analysis of global events...



An example of event sequence

Event Timestamp: 12-JUN-11 07.17.00.656290 AM

Beam Energy: 3500040

Mps Expert Comment : Quench of RD2.L1 magnet

(+ due to suspected imbalance as well RQ4 some 17 sec. after the dump...

Dump clean.

The screenshot displays the BIC/EVENT_SEQ software interface. At the top, it shows the version (0.4.10) and the responsible person (Ivan Romero Romero). The interface is divided into several sections:

- HEADER:** Contains system information such as System (BIC), Class (EVENT_SEQ), Source (ISA), Event stamp (07:17:00.654 12/06/11), Version (0.4.10), Encoding (BIC/EVENT_SEQ), Qualifier, and Analysis flags ([NORMAL]).
- SUMMARY:** Provides a high-level overview of the event, including the pmAnalysisModuleVersion (0.4.10), Analysis result description (First USER_PERMIT change: Ch 12-PIC_MSK: A T -> F on CIB.US15.L1.B1), Triggered BIC inputs (Ch 12-PIC_MSK(L1.B1), Ch 5-PIC_UNM(L1.B1), Ch 12-PIC_MSK(L1.B2), Ch 5-PIC_UNM(L1.B2), Ch ...), Beam 1 propagation delay to LBDS (61000 ns), Beam 2 propagation delay to LBDS (64000 ns), and OVERALL status (38 BICs triggered valid PM data).
- EVENT OVERVIEW:** A table listing individual events with columns for Index, Loc.Permit A/B, Time, Delta(uSec), Description, and BIC name. The events are sorted by time, showing a sequence of USER_PERMIT changes for various BICs.
- SOURCE OVERVIEW:** A table listing the sources involved in the event, with columns for Index, Source Name, and Data Valid. It shows a list of BICs and their status.
- FILTER:** A section at the bottom with checkboxes to filter the event list based on various criteria like Beam_Permit_Loop, Beam_Permit, Local_Permit, User_Permit, etc.

Triggered BIS Inputs:

- Ch 12-PIC_MSK(L1.B1),
- Ch 5-PIC_UNM(L1.B1),
- Ch 12-PIC_MSK(L1.B2),
- Ch 5-PIC_UNM(L1.B2),
- Ch 5-PIC_UNM(R1.B2),
- Ch 5-PIC_UNM(R1.B1),
- Ch 12-PIC_MSK(R1.B2),
- Ch 12-PIC_MSK(R1.B1),
- Ch 4-BLM_UNM(L6.B2),
- Ch 4-BLM_UNM(L6.B1),
- Ch 11-BLM_MSK(L6.B2),
- Ch 11-BLM_MSK(L6.B1),
- Ch 8-BPMs L&R syst.'A' (R6.B2),
- Ch 8-BPMs L&R syst.'A' (R6.B1),
- Ch 10-BPMs L&R syst.'B' (L6.B1)
- Ch 10-BPMs L&R syst.'B' (L6.B2)
- Ch 3-LBDS-b2(R6.B2),
- Ch 3-LBDS-b1(L6.B1),
- Ch 4-Vacuum b1b2(R1.B2),
- Ch 4-Vacuum b1b2(R1.B1),
- Ch 1-Vacuum b2(L1.B2),
- Ch 1-Vacuum b1(L1.B1)

Summary

Beam Interlock System is by design: safe, reliable, fast, modular....

+ has embedded features for monitoring and testing interlock process,

Together with Timing system, Post-Mortem and GUI applications:

- Provide clear and useful information to Operation
- Minimize machine downtime

Thank you for your attention



Spare

BIS Feature

“Flexible”:

thanks to Input Masking

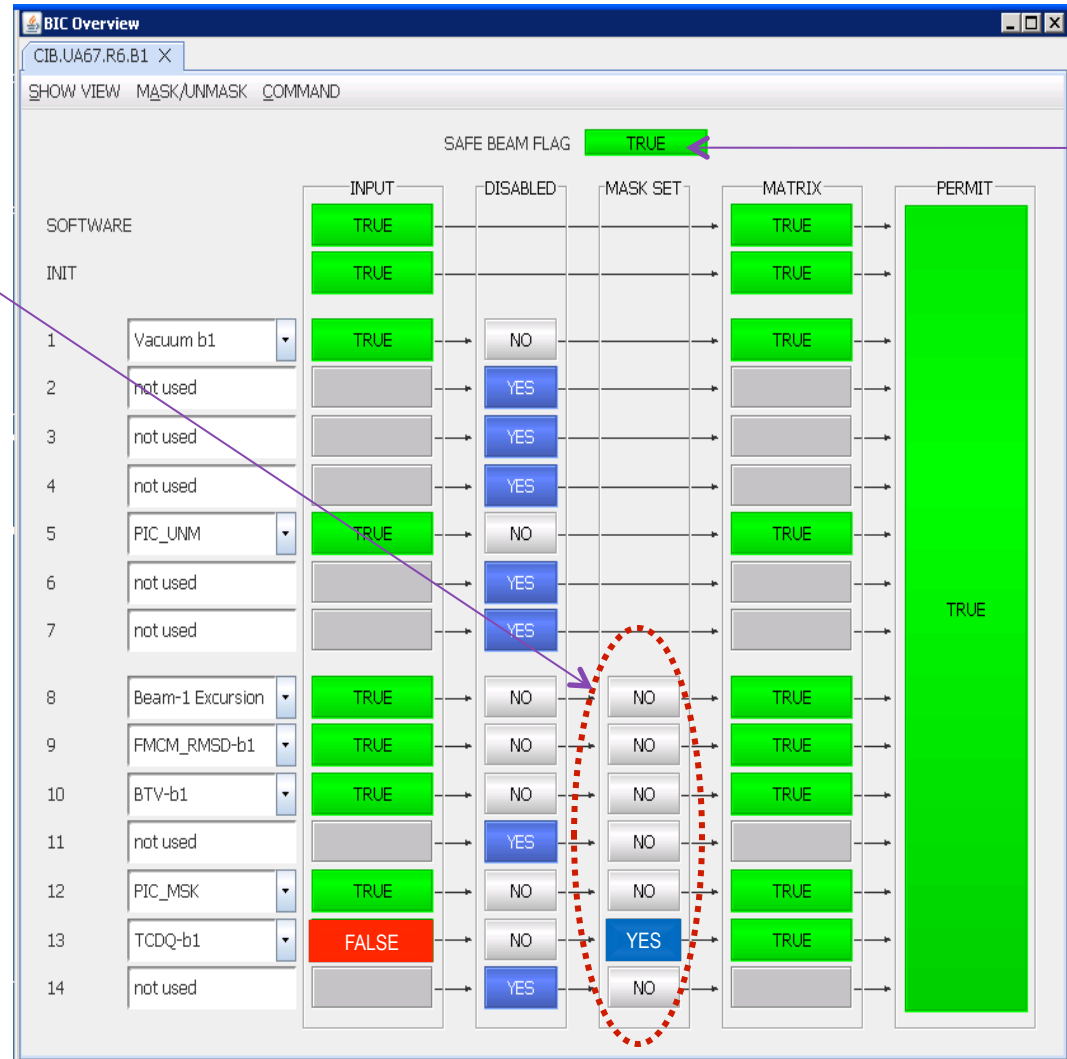
Within a fixed partition, half of *User Permit* signals could be remotely masked

Masking depends on an external condition:

the **Setup Beam Flag**

- generated by a separate & dedicated system (Safe Machine Parameters)
- distributed by Timing

Masking automatically removed when **Setup Beam Flag = FALSE**



BIS User Systems: LHC Vs. Linac4

version of 01.08.2009

		LHC ring																Σ	INJ.			
User systems		L1	R1	L2	R2	U3	S3	L4	R4	L5	R5	L6	R6	U7	S7	L8	R8	CCR	b1	b2	Abbrev.	
1	Collimation (Environmental Param.)		1 1	1 1	1 1	1 1				1 1	1 1	1 1		1 1		1 1	1 1	10 10	1	1	COLL_ENV	
2	Collimation (Motor positions)	1 1	1 1	1 1	1 1	1 1				1 1	1 1	1 1		1 1		1 1	1 1	11 11	1	1	COLL_MOT	
3	Vacuum system ("sector valves")	1 1		1 1	1 1	1 1		1 1	1 1	1 1		1 1	1 1	1 1		1 1	1 1	12 12			VAC	
	Vacuum system ("X valves")		1	1	1						1					1	1	6	1	1		
4	PIC for essential circuits	1	1	1	1	2		1	1	1	1	1	1	2		1	1	16			PIC_UNM	
	PIC for auxiliary circuits	1	1	1	1	2		1	1	1	1	1	1	2		1	1	16			PIC_MSK	
5	BLM at aperture limitations	1		1		1	1			1		1		1		1	1	8			BLM_UNM	
	BLM in arcs	1		1		1	1			1		1		1		1	1	8			BLM_MSK	
6	Fast Magnet current Change Monitors	1			2		3				1		1 1		3			10	1	1	FM_xxxx	
7	WIC (Warm Magnets Interlock)	1		1		1		1	1		1		1		1			1	1		WIC	
8	Screens			1		1 1			1 1			1 1	1 1					4	5		BTV	
9	RF & Transverse Damper							1 1	1 1									2	2		RF	
10	Beam excursion (BPM)												1 1					1	1		BPM	
11	LHC Beam Dumping System											1		1				1	1	1	1	LBDS
12	Beam Aperture Kicker						1 1											1	1		MKA	
13	Injection Kickers			1													1	1	1	1	MKI	
14	TCDQ											1 1						1	1		TCDQ	
15	LHC Access Safety System					1		1										1	3		LASS	
16	LHC Control Room (Operator Buttons)																	1	1	1	1	CCC
17	Programmed Beam Dump (via Timing)																	1	1		1	PROG
18	LHC Safe Machine Parameters																1 1	1	1		1	SMP
19	Fast Beam current Change Monitors								1 1									1	1			FBCM
20	ATLAS (Detector part)		1															1	1	1	1	ATL_DET
21	LHCF (Detector part)		1															1				LHCF_DET
22	ALICE (Detector part)				1													1	1	1	1	ALI_DET
23	CMS (Detector part)										1							1	1	1	1	CMS_DET
24	TOTEM (Detector part)										1							1	1	1	1	TOT_DET
25	LHCb (Detector part)																1	1	1	1	1	LHCB_DET
26	ATLAS (Magnets)		1															1				ATL_MAG
27	ALICE (Magnets)				1													1				ALI_MAG
28	CMS (Magnets)										1							1				CMS_MAG
29	LHCb (Magnets)																1 1	1	1			LHCB_MAG
30	ATLAS (movable devices)		1 1															1	1			ATL_MOV
31	TOTEM (movable devices)										1 1							1	1			TOT_MOV
32	LHCb (movable devices)																1	1				LHCB_MOV
33	ALICE-ZDC (movable device)																	0	0	1		ALI_ZDC
34	MSI Convertor Sum Fault																	0	0	1	1	MSI_SUM
User Systems		L1	R1	L2	R2	U3	S3	L4	R4	L5	R5	L6	R6	U7	S7	L8	R8	CCR				Abbrev.
Individual beam connections (Unmaskable) max = 3,3		1 1	1 1	1 1	2 1	1 1	0 0	1 1	1 1	1 1	1 1	2 1	1 2	1 1	0 0	1 1	1 1	1 1	50	51	14	13
Both beams connections (Unmaskable) max = 4		3	4	4	3	3	1	2	2	3	4	3	1	3	1	4	4	2	87	215	connections	
Individual beam connections (Maskable) max = 3,3																						

SIS
Source HV
Pre-chopper
L4 Beamstopper Out/Moving
L4 Beamstopper In
Chopper
L4 Low-Energy WD
No Inhibit (Operator)
L4 Low-Energy Vacuum Valves
AQN L4L.MQF3910
AQN L4L.MQD4010
AQN L4L.MQF4110

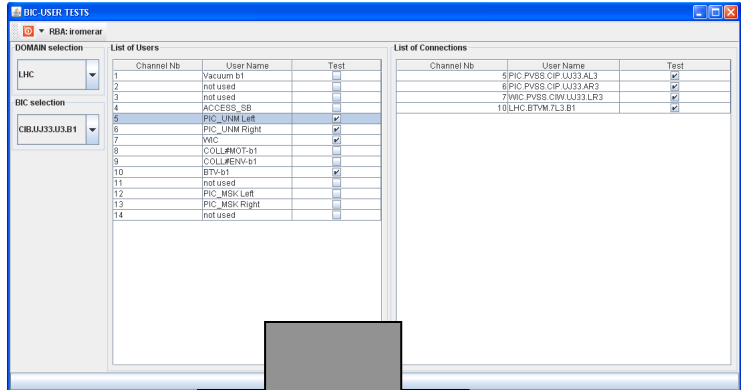
Low Energy part

SIS
Ex. Conditions (full pulse)
L4 RF
BLMs L4+TL (low loss)
BLMs L4+TL (high loss)
L4 WD before BHZ20 (high loss)
L4 WD before BHZ20 (low loss)
L4 Vacuum Valves + L4T.VVGS.0101

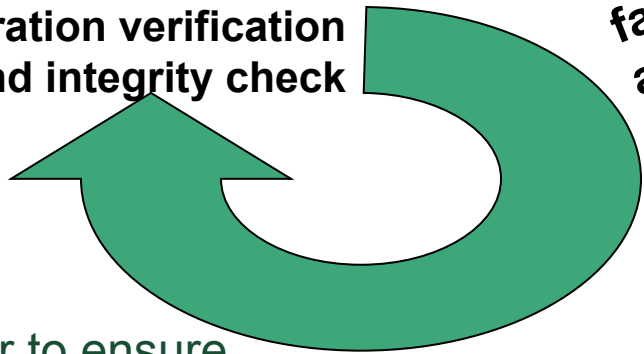
after Chopper

BIS: Operational Checks

Pre-Operation checks (launched by Beam Sequencer)



configuration verification and integrity check

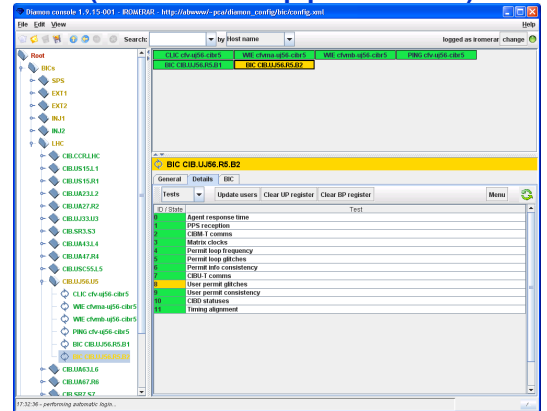


In order to ensure that safety is not compromised, the verification is carried out in three stages

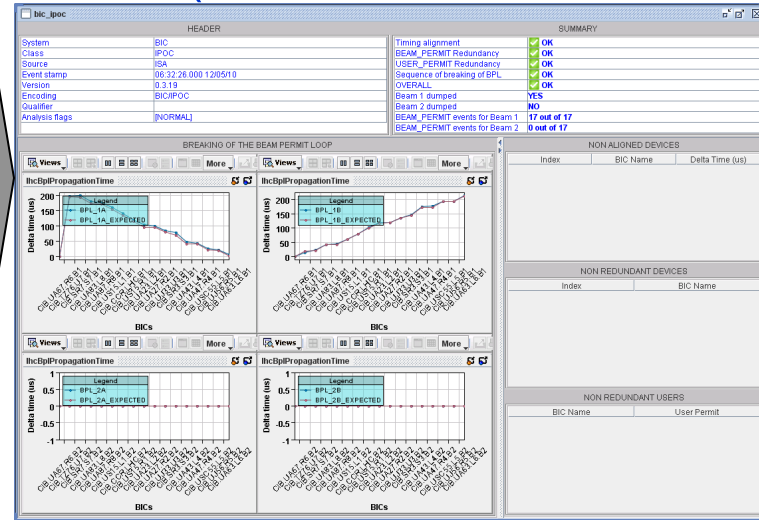
response analysis

fault diagnosis and monitoring

During Operation (DiaMon application)



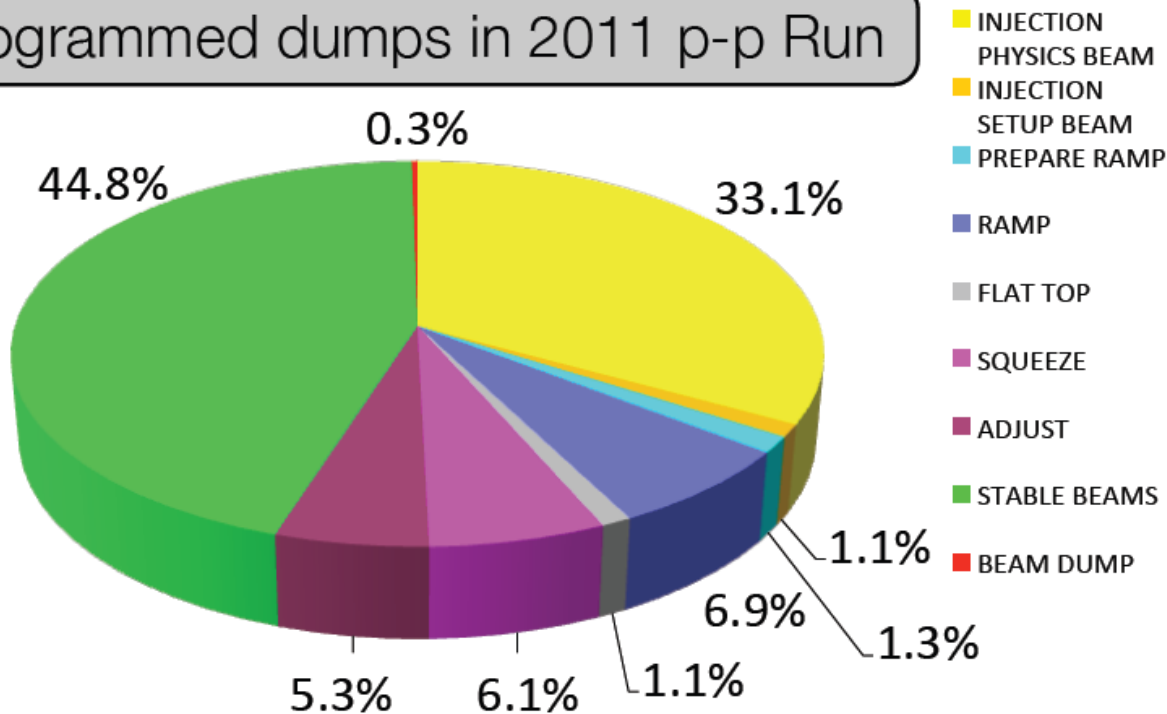
Post-Operation checks (included in Post Mortem analysis)



Beam Dumps in 2011 Proton Run

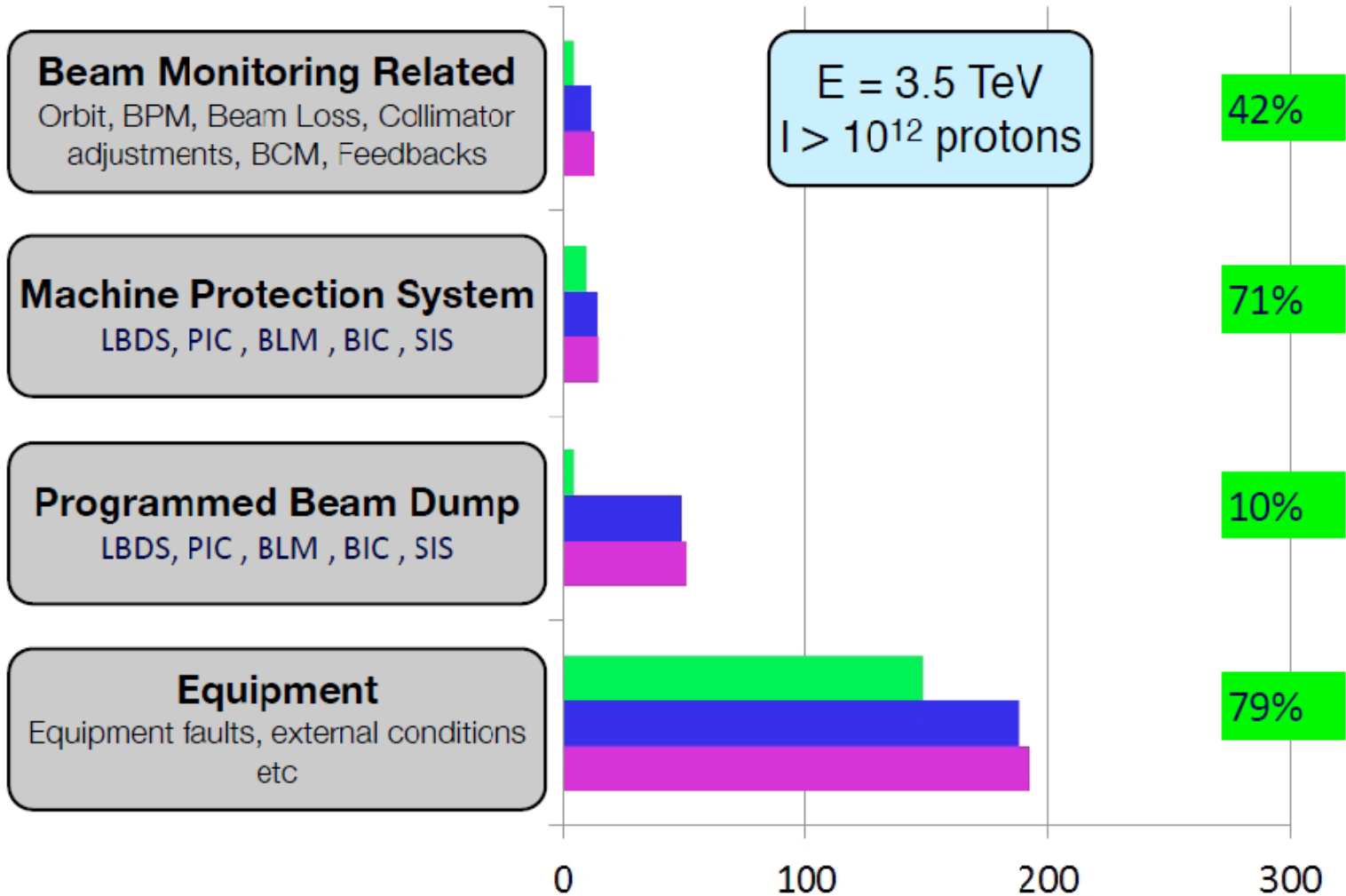
- Number of Beam Dumps in 2011 p-p Run: **482**
- Number of Non-Programmed Beam Dumps: **375 (78%)**
- Number of Non-Programmed Beam Dumps in Stable Beams: **168 (35%)**

Non-programmed dumps in 2011 p-p Run



2011 Proton Run: Beam Dump Causes

168 ■ STABLE BEAMS
 263 ■ MDs excluded
 272 ■ All beam dumps



Safe Machine Parameters Layout

