The LHC Beam Interlock System

Functional Specification

DRAFT
GENERATION AND DISTR[illegible]TION OF SAFE LHC PAR[illegible]TERS

To be replaced by the right one…

Abstract

For safe operation[illegible], several parameters must be generated and distributed around the LHC[illegible]gn reliability.
The beam [illegible] system and the injection kickers require a parameter proportional to the energ[illegible]e LHC ENERGY".
When a flag, [illegible]e "SAFE BEAM FLAG", is received by the interlock system, it will be possible to disable some of the interlocks. When the LHC is operating with beam parameters that exclude damage of equipment in case of uncontrolled beam loss, this flag is present.
For injection of high intensity beam from the SPS into the LHC, the BEAM PRESENCE FLAG must be set.

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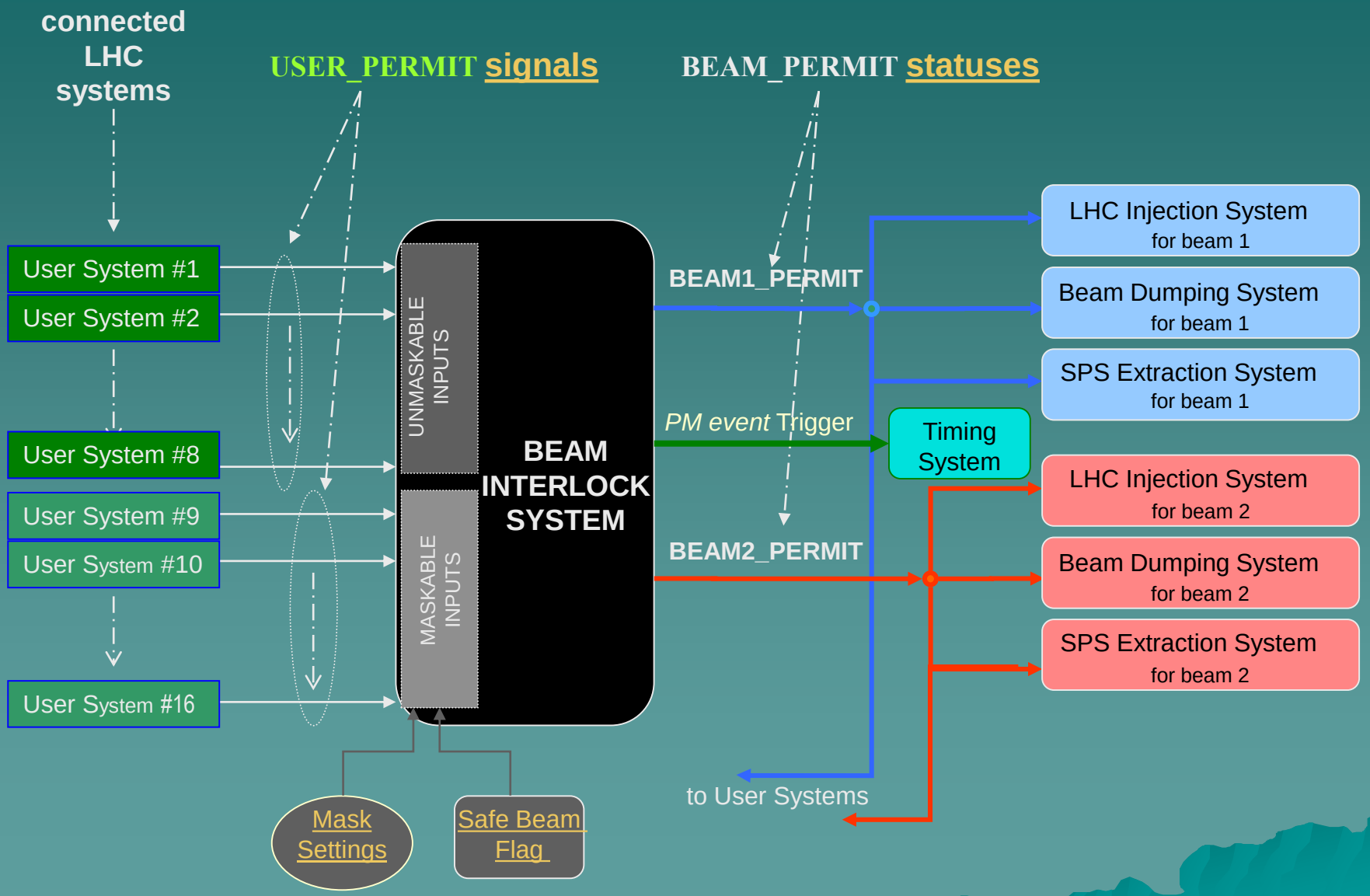
Aim and Objective

- One of the systems required to operate the LHC safely with beam.

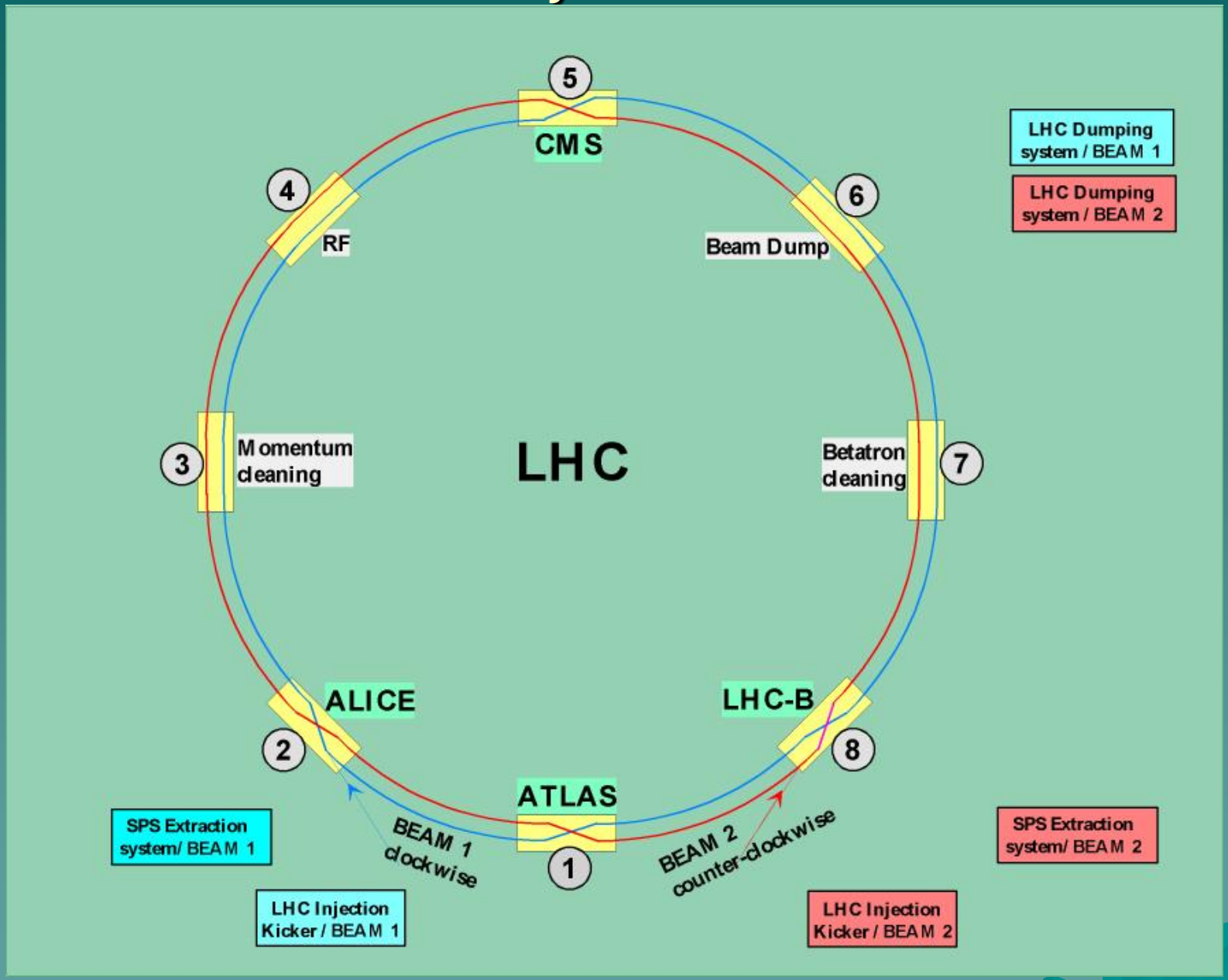
- Two roles:
  1) Permit injection when all LHC systems (connected to it) are ready for beam.
  2) (with circulating beam) Transmit any beam dump request from connected user systems to LBDS.

- Additional objectives:
  - Protect the beam
    - Faulty trigger signals should be avoided.
  - Provide the evidence
    - For multiple alarms: identify the initial failure.
    - Give time sequence of Beam Dump requests
  - Assist the operation of the machine
    - System Status and diagnostics for failures presented clearly to Operator
    - Give correct diagnostic messages to the operator.

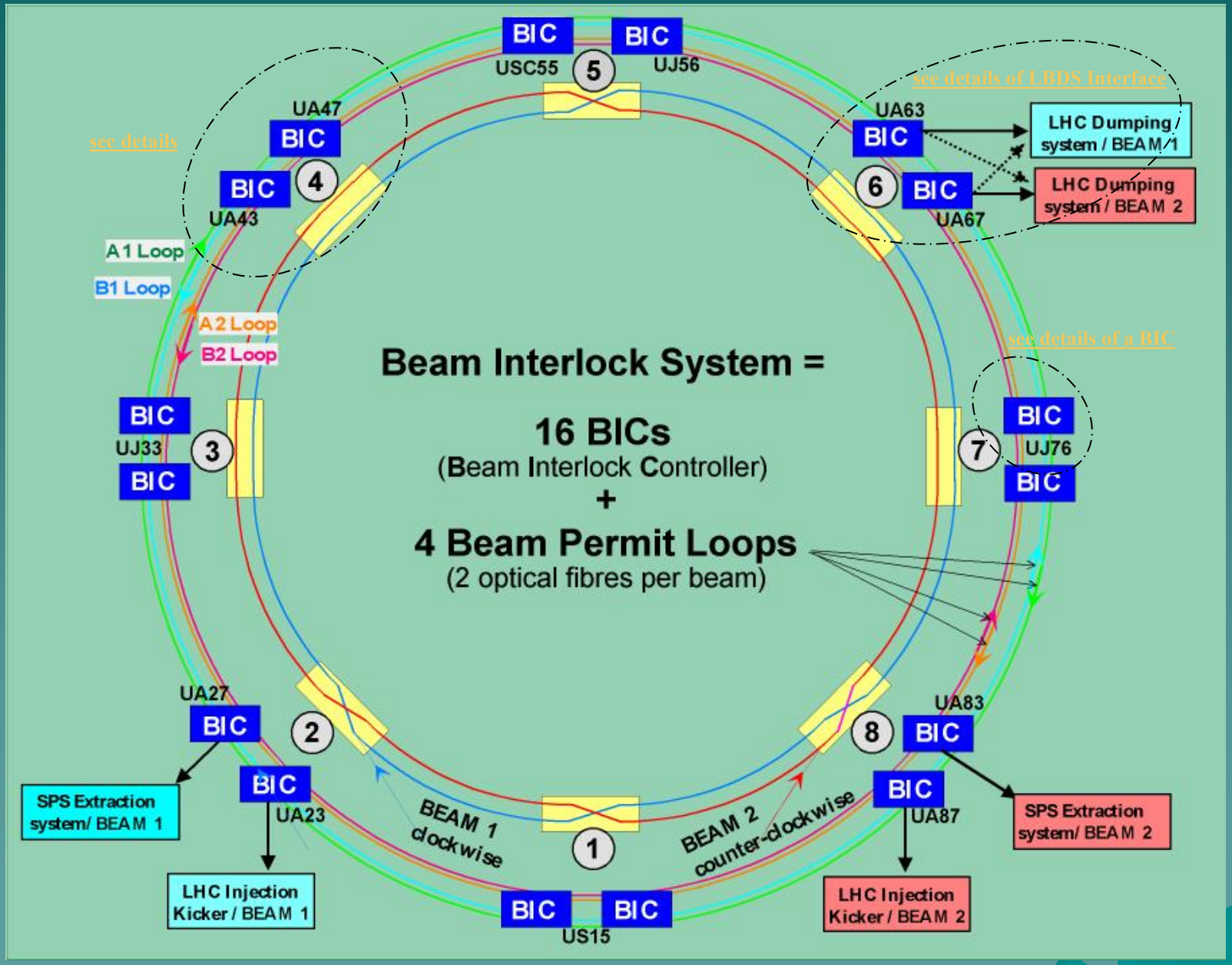
Principle functionality



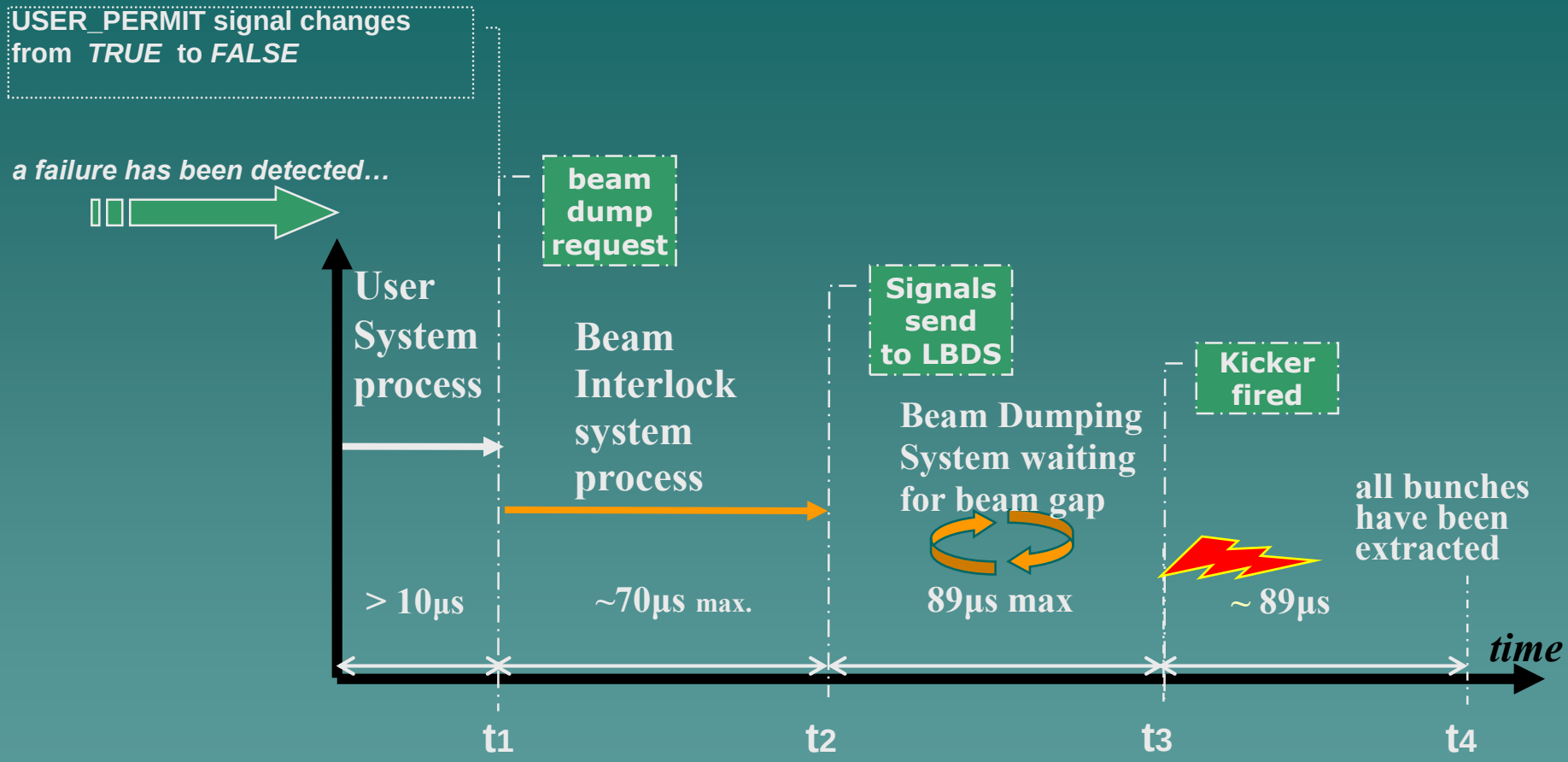
Layout


5
CMS
4
RF
6
Beam Dump
3
Momentum cleaning
LHC
Betatron cleaning
7
ALICE
2
LHC-B
8
ATLAS
1
LHC Dumping system / BEAM 1
LHC Dumping system / BEAM 2
SPS Extraction system/ BEAM 1
SPS Extraction system/ BEAM 2
BEAM 1 clockwise
BEAM 2 counter-clockwise
LHC Injection Kicker / BEAM 1
LHC Injection Kicker / BEAM 2

Architecture



Time between a Request to a Beam Dump

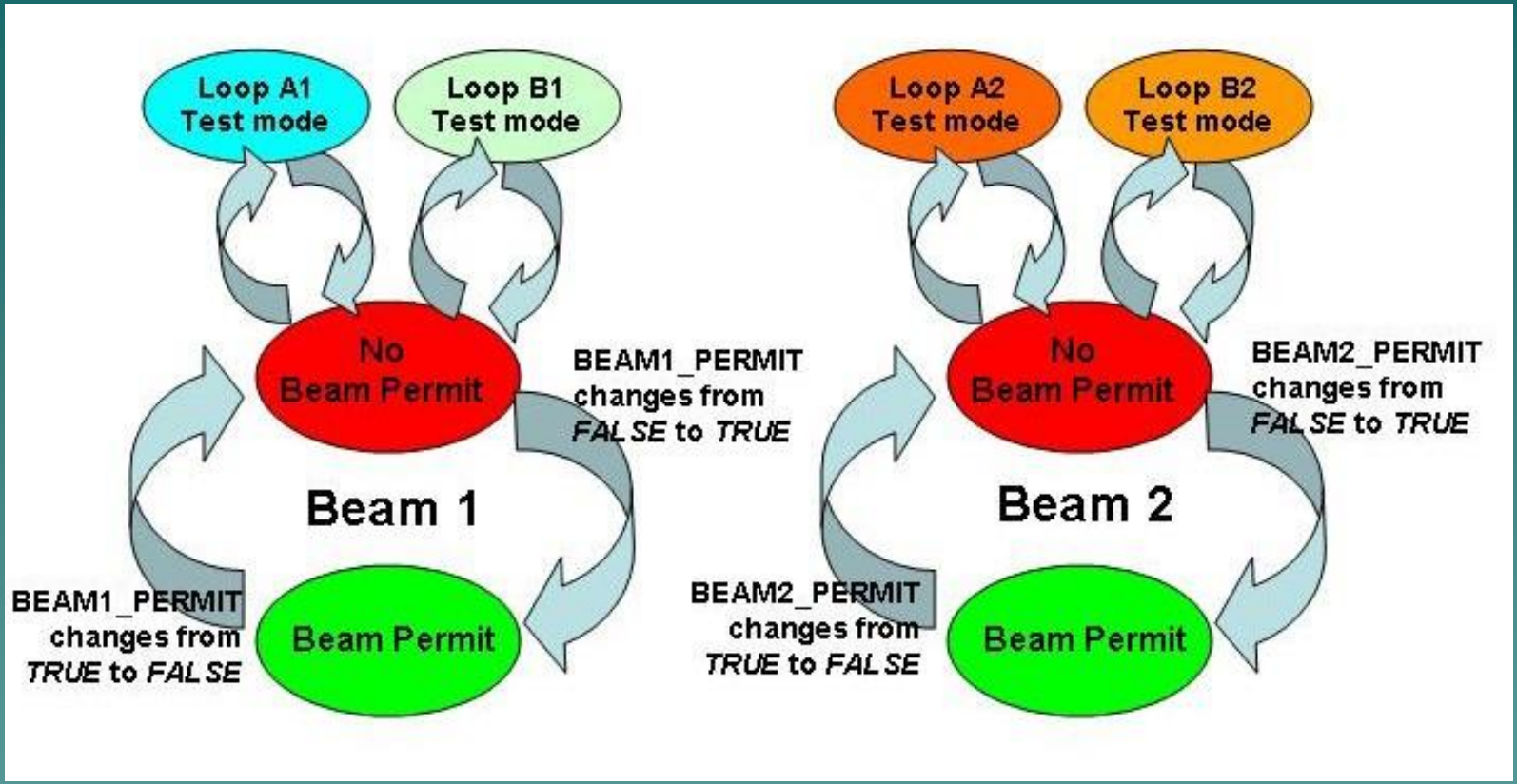


Achievable response time is about 100 µs up to 270 µs

(between the detection of a beam dump request and the completion of a beam dump)

Beam Interlock processing time should be "small" compared to the global time.

Exploitation modes



- 2 modes for the LHC Beam Interlock System:
  - **OPERATION** (one for each beam)
    - BEAM PERMIT
    - NO BEAM PERMIT
  - **TEST** (one for each beam)
    - Close only 1 of the 2 BEAM PERMIT LOOPS ⇒ exclude to give general beam permit.

RELIABILITY AND AVAILABILITY

- System's architecture must ensure the performances, in terms of reliability and availability, and the functions of safety systems according to the *Safety Integrity Level*.
- A full analysis of the reliability and availability (following norm IEC 61508) can only be performed after the system is designed. However, during the design some principles are already being applied: No simple failure of a component in the systems must bring the system into a non safe state (see also IEC 61508-2).
- The System must be always available (also during preparation for operation with beam)
- If the Beam Interlock System redundancy is lost ⇒ be repaired in order to come back to the required SIL level.
- Failures that do not result in a loss of functionality (for example of the monitoring part of the system) must lead to maintenance procedure. The maintenance must be done before the next "mission" (before the next fill), in order to come back to the required SIL level.
- Informing the LBDS about a change of the BEAM_PERMIT is the most critical function. This function must be executed with the highest reliability (SIL3 or SIL4).
- LBDS must inform the BICs when it is armed and ready to dump prior to injection. This function from the must be executed with SIL3.
- The system must be « fail-safe » (all failures of the system must bring the LHC in a safe state that is BEAM_PERMIT = FALSE.).
- The system is connected to UPS system. Reading out of the data in case of power failure must be possible in less than 8 min.
- The long distances and the large number of signals must be taken into account for the architecture and the transmission.

Questions

- About the interface between BIC and injection kickers:
  only one way (from BIC to Kickers)? → to be confirmed
- About the Beam Interlock User Interface:
  only one signal from users, or two (redundant) signals from users?
- About the Masking of input channels:
  what channels need to be masked during safe beam operation?
  what channels should never be masked?
- About a Test mode together with *User Systems*:
  the users should be able to change the USER_PERMIT from TRUE to FALSE on request during testing.
- About the normal conducting magnet interlock:
  two signals from the Interlock Controller to the BIC?
- About the interface between BIC and LHC Machine Timing generator:
  how to trigger the timing system to produce a post-mortem event?

end

LHC Systems connected
to the Beam Interlock System

The (main) *User Systems* are:

Beam Loss Monitors
Powering Interlock system
Warm Magnets Interlock system
Vacuum system
Access Safety system
Beam Energy Meter
Beam Dumping system
LHC Control Room
LHC Experiments
R.F. system
Collimators
Transverse Damper
Beam Aperture Kicker
Beam Excursion Monitors
Fast Beam Current Decay Monitors

back

Beam Permit Status

- The global information produced is named the BEAM_PERMIT
- BEAM_PERMIT can be:
  - **TRUE** (beam operation is permitted)
    - Injection of beam is allowed.
    - if already circulating beam then the beam operation continues.
  - **FALSE** (beam operation is **NOT** permitted)
    - Beam injection is blocked. SPS Extraction is disabled.
    - if (circulating beam) and (BEAM_PERMIT changes from TRUE to FALSE) then the beam will be extracted by LBDS.
- Perform one BEAM_PERMIT for each beam:

  BEAM1_PERMIT **and** BEAM2_PERMIT
- Distribution via **hardware links** to:
  - Beam Dumping System
  - LHC injection kickers
  - SPS Extraction systems
  - connected LHC systems (i.e. *User Systems*)

Individual Permit Signals

- Information collected from *User Systems* is named the USER_PERMIT
- These USER_PERMITs are required to produce the BEAM_PERMITs.
- Beam operation is permitted when **ALL** *User Systems* deliver their own USER_PERMIT.

General case but depending of Masking and of Safe Beam Flag

- USER_PERMIT can be:
  - TRUE
    - *User System* is ready for beam and beam operation is possible.
  - FALSE
    - *User System* is not ready for beam or has detected a failure.
- The USER_PERMITs are gathered via **hardware links**

Masking User Permit Signals

- Depending on intensity, energy and possibly other parameters, some User Systems signals could be masked.
- Masking only possible if the beam is "safe" and cannot result in damaging equipment (see Safe Beam Flag)
- To allow for some flexibility while maintaining safety, the *User Systems* are classified in two families:
  - **MASKABLE** signals
    - Signal could be temporary ignored if the beam is "safe".
    - Mask set by the operator ⇒ USER_PERMIT is not taken into account .
  - **NOT MASKABLE** signals
    - the USER_PERMIT will be **NEVER** ignored to produce the BEAM_PERMIT.
- The partition MASKABLE / NOT MASKABLE is permanently defined by hardware and remotely readable from the Supervision.

Safe Beam Flags

- Permit "flexibility" by masking (some) interlocks.
- Derived from LHC energy and from beam intensity:
  - Energy value coming from BEMs in IR6.
  - Intensity of beam 1 and beam 2 measured by BCTs

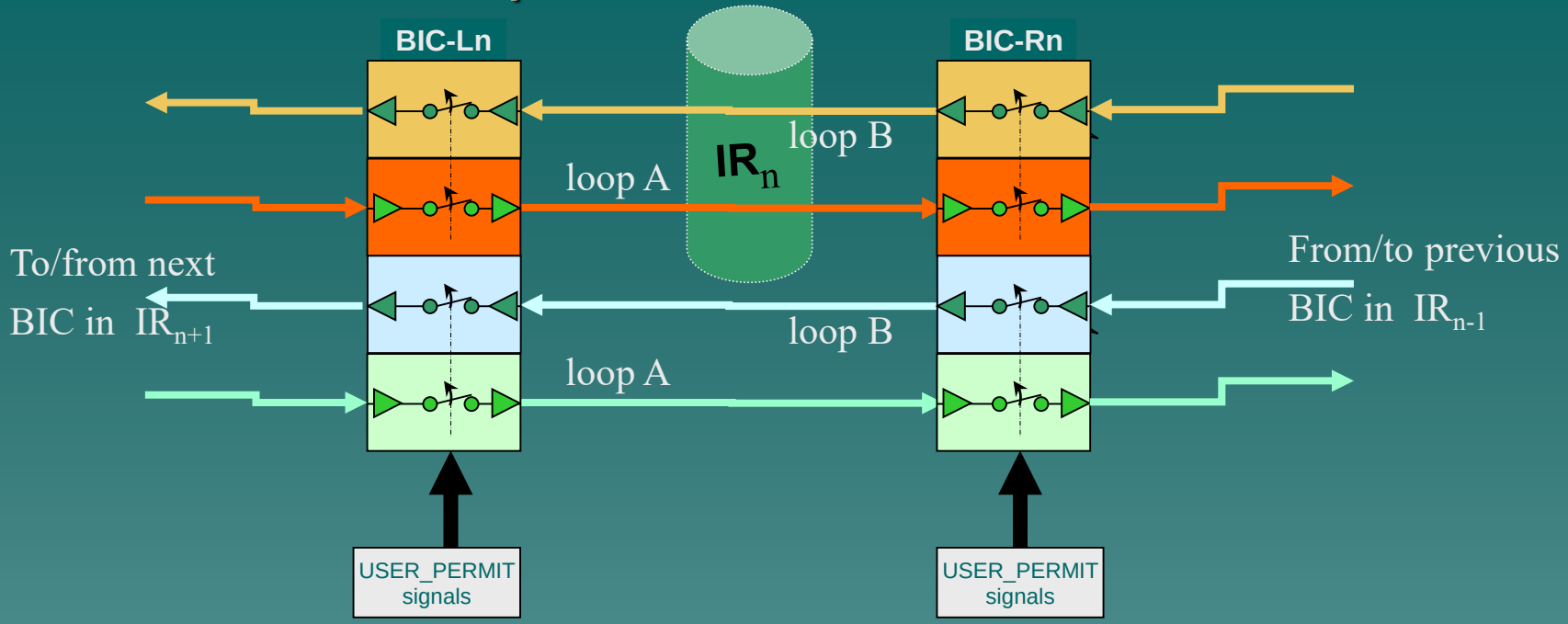
If (Ibeam1 · Energy) < Threshold1 then SFB1 = TRUE else SFB1 = FALSE
If (Ibeam2 · Energy) < Threshold2 then SFB2 = TRUE else SFB2 = FALSE

- SBFs generated in IR4 by a dedicated system (see the S.L.P. project)
- SAFE BEAM FLAG can be:
  - **TRUE** *(as an example, if low intensity beam is circulating at 450 GeV)*
    - Masking of USER_PERMITs is taken in account.
    - If one of the masked signals is indicating FALSE ⇒ be ignored ⇒ beam operation could continue.
  - **FALSE** *(as an example, if beam is accelerated and becomes unsafe due to increasing stored energy density)*
    - The masking is not longer taken in account.
    - If one USER_PERMIT = FALSE ⇒ BEAM_PERMIT changes to FALSE ⇒ beam will be dumped.

Maskable / Not Maskable Partition

family	(main) *User Systems*
Not maskable	Critical Beam Loss Monitors
	Powering Interlock Controllers (for essential electrical circuits)
	Warm Magnet Interlock Controllers
	Vacuum system
	Access Safety system
	Beam Energy Meter
	Beam Dumping system
	LHC Control Room
Maskable	Beam Loss Monitors (less critical)
	Powering Interlock Controllers (for less critical circuits, namely the auxiliary circuits)
	LHC Experiments
	R.F.
	Collimators
	Transverse Feedback
	Beam Aperture Kicker
	Beam Excursion Monitors
	Fast Beam Current Decay Monitors

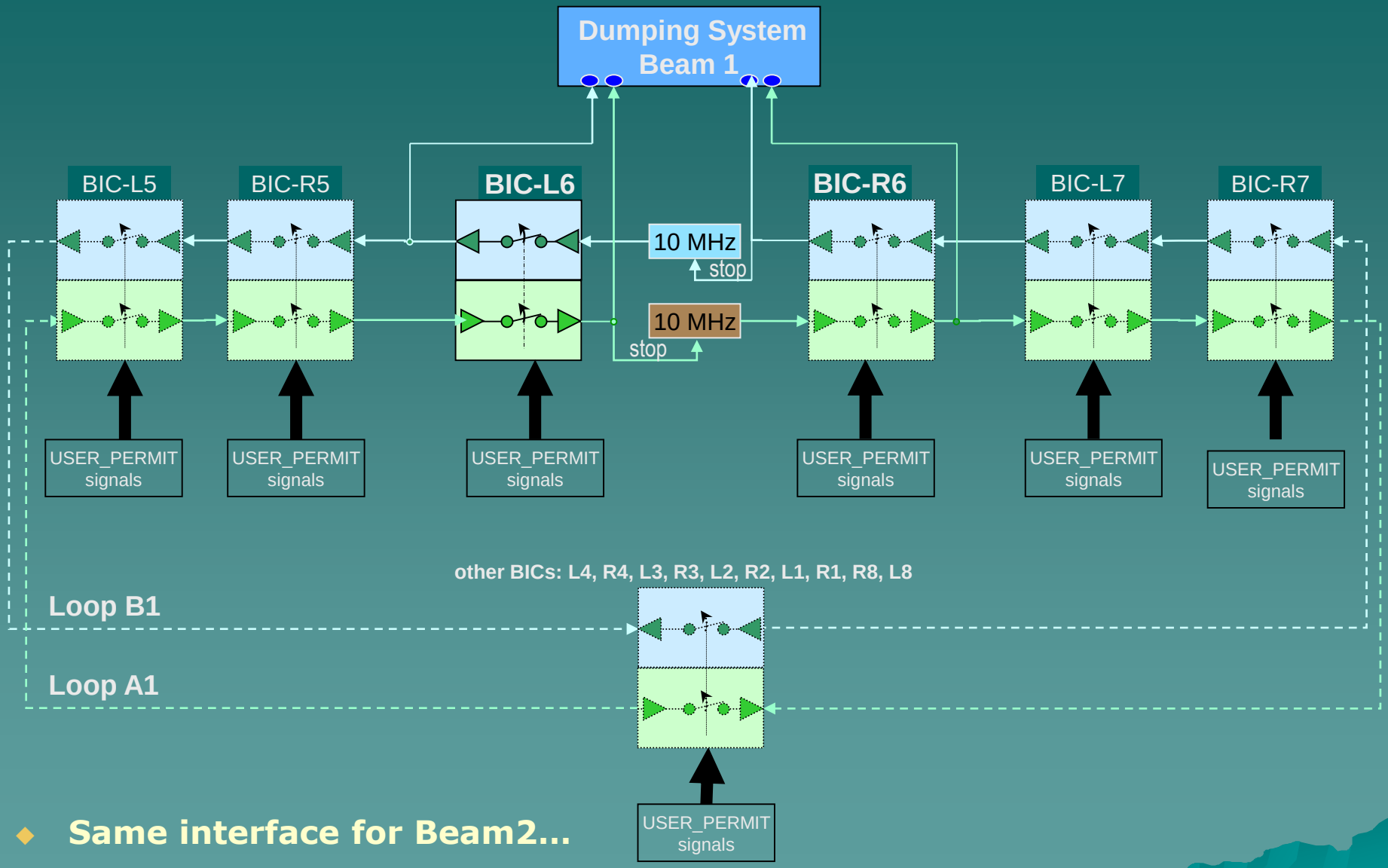
Beam Permit Loops



- Two "Beam Permit Loops": loop A and loop B per beam
- The frequency signals (10 MHz) generated in one of the 16 BICs and send across one loop to the next BIC.
- Only if necessary conditions for beam operation are fulfilled, the signals are further transmitted to the following BIC. If NOT ⇒ signals are interrupted.
- The other loop is used in the same way.

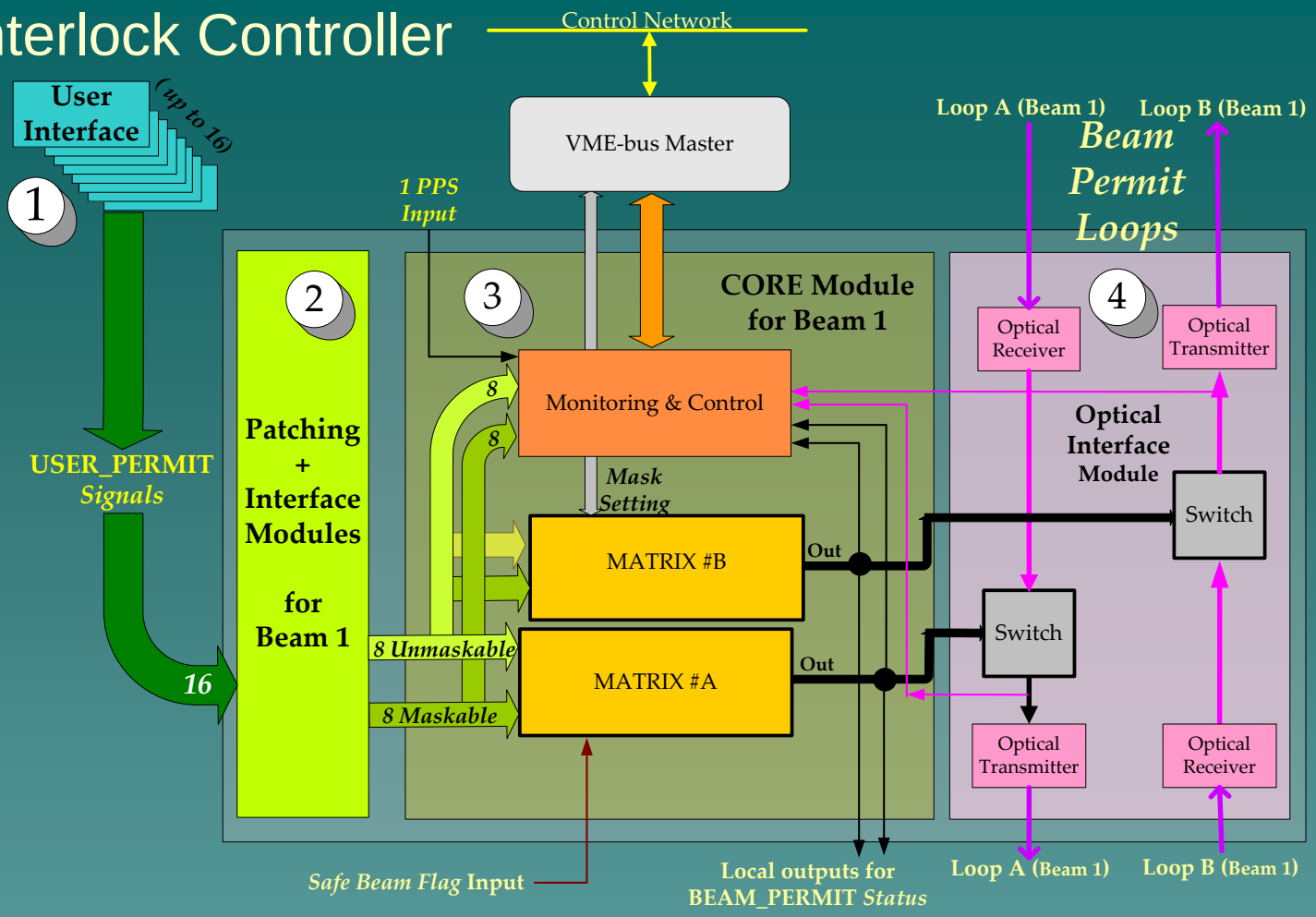
- Same for other beam with two other loops (clockwise and counter-clockwise)

Interface with LBDS (example with Beam1)



- **Same interface for Beam2…**

Beam Interlock Controller



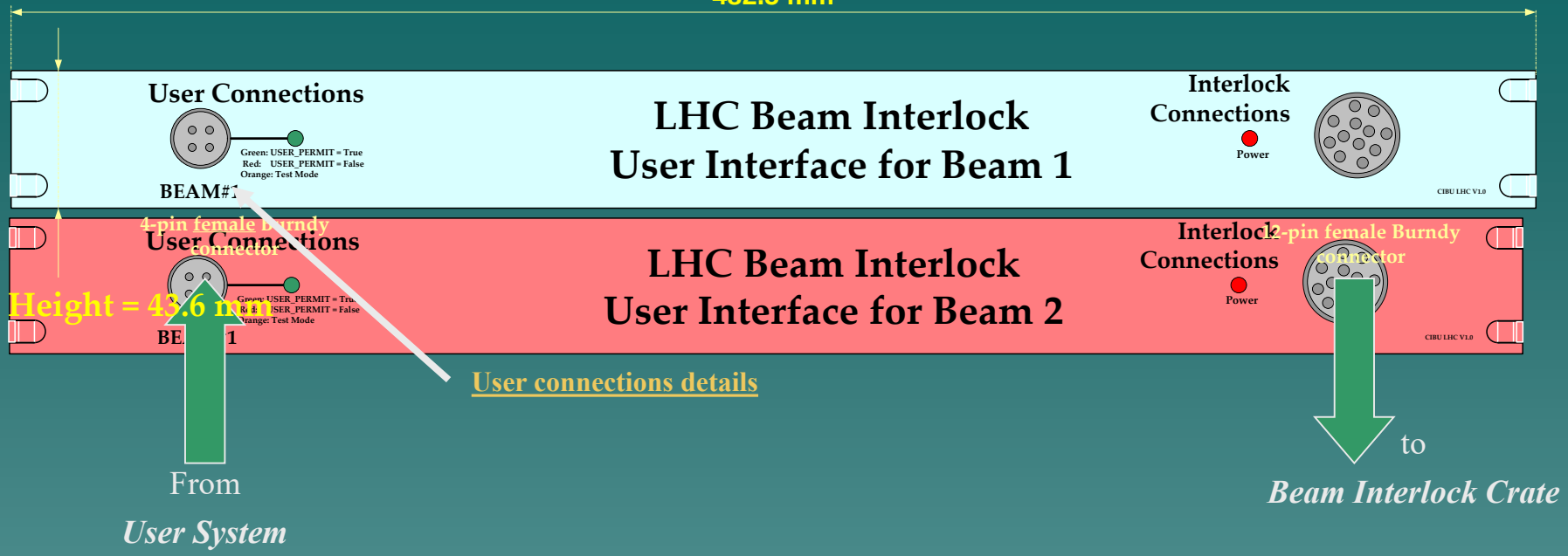
a BIC is composed of:

1) (Beam Interlock) User Interfaces
2) Patching and Interface modules
3) Core modules
4) Optical Interface modules

It consists of 2 sets of modules (one per beam) therefore:

2 x Patching and Interface modules,
2 x Core modules and
2 x Optical Interface modules.

Beam Interlock User Interface



- Receives USER_PERMIT coming from any type of LHC system.
- Converts this information and transmits it to the BIC crate.
- Some *User Systems* will always provide the USER_PERMIT for both beams.
  If failure ⇒ both beams will be dumped.
- Some *User Systems* will dump beam selectively, either Beam 1 or Beam 2.
- In addition, Status for each beam is provided for the *User Systems*

Return to BIC slide

Partition for Separate or Both Beam(s) signal

family	(main) *User Systems*	USER_PERMIT signal on:
Not maskable	Critical Beam Loss Monitors	Both beams
	Powering Interlock Controllers (for essential circuits)	Both beams
	Warm Magnet Interlock Controllers	Both beams
	Energy Meter	Both beams
	Access Safety system	Both beams
	Vacuum system	Beam 1 or Beam 2
	Beam Dumping system	Beam 1 or Beam 2
	LHC Control Room	Beam 1 or Beam 2
Maskable	Beam Loss Monitors (less critical)	Both beams
	Powering Interlock Controllers (for less critical circuits)	Both beams
	LHC Experiments	Both beams
	R.F.	Beam 1 or Beam 2
	Collimators	Beam 1 or Beam 2
	Transverse Feedback	Beam 1 or Beam 2
	Beam Aperture Kicker	Beam 1 or Beam 2
	Beam Excursion Monitors	Beam 1 or Beam 2
	Fast Beam Current Decay Monitors	Beam 1 or Beam 2

Beam Interlock User Interface : Input details