Interlocking strategy

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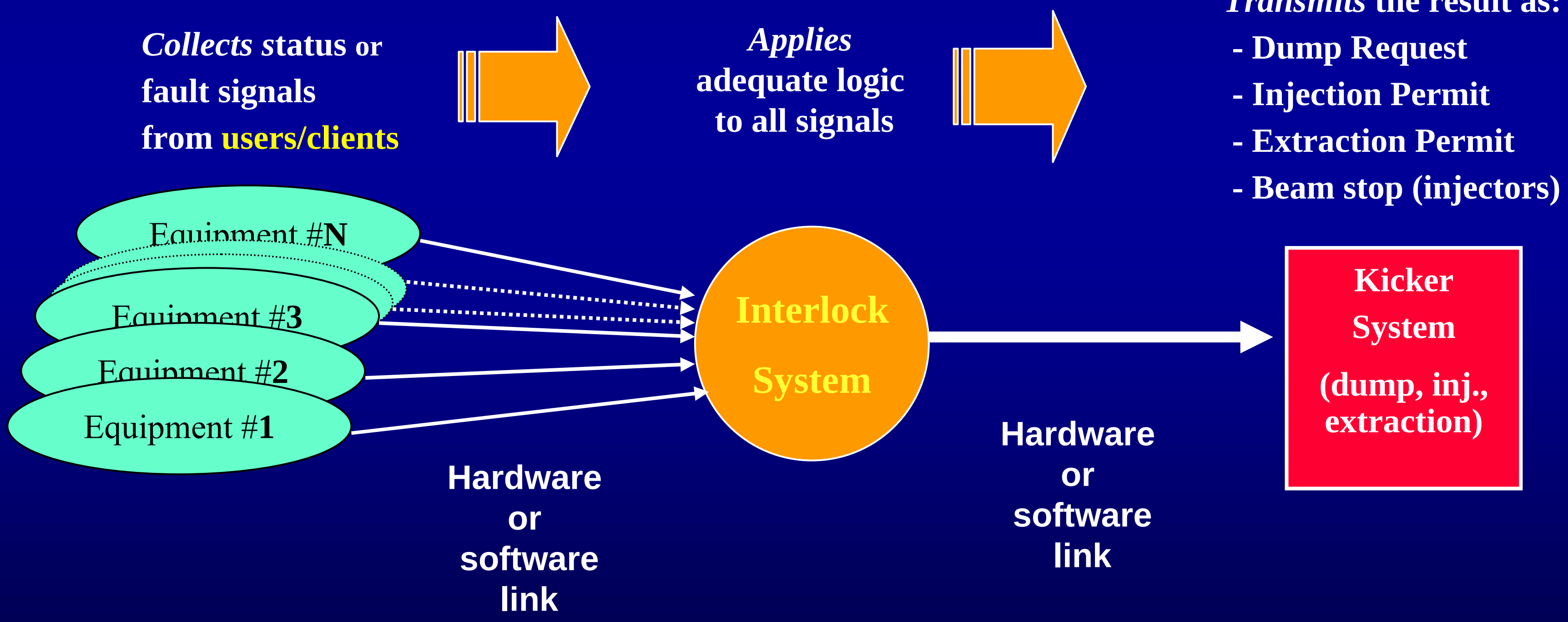
Interlock system,
concepts & architecture.
Injection protection,
safe beams and beam presence.

Acknowledgements : B. Puccio, B. Todd, R. Schmidt

What is an interlock system

As part of the machine protection system, the role of the interlock system is to:

- collect interlock signals from users/clients
- apply an adequate logic to the signals
- transmit result to the relevant system for 'action'



Interlock systems at the LHC

- The powering interlock system
  - Protects the magnets, interacts with power converters, quench protection and energy extraction systems.
  - Provides inputs to the LHC beam interlock system.
  - Not part of this review, some aspects are covered by M. Zerlauth.
- The LHC beam interlock system
  - Interacts with all LHC equipment systems involved in the protection of the machine.
  - Interfaces to the beam dumping system and SPS extraction interlock system.
- The LHC injection / SPS extraction interlock system
  - Protects the transfer lines from SPS to the LHC.
  - Protects the LHC against bad injection.
- The software interlock system
  - Provides additional protection through high level, potentially complex 'algorithms'
  - Provides input to beam, injection & extraction interlock systems
  - Not part of this review, work is just starting on this issue.

Hardware links (powering, beam and injection/extraction interlock systems)

Software links (software interlock system)

Objectives of the LHC beam interlock system

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

- Two roles :
  1) Permit injection when all connected user systems are ready for beam.
  2) With circulating beam, transmit any beam dump request from connected user systems to beam dumping system.

- Additional objectives :
  - Protect the beam
    Faulty trigger signals must be avoided.
  - Provide the ‘evidence’
    For multiple alarms: identify the initial failure.
    Give time sequence of beam dump requests.
    Post-mortem info
  - Assist the operation of the machine
    System Status and diagnostics for failures presented clearly to operation crews.

LHC beam permit

- The signal produced by the beam interlock system is called BEAM_PERMIT.
- The BEAM_PERMIT can be:

  TRUE (beam operation is permitted)

  Injection of beam is allowed.

  If beam is circulating, then the beam operation continues.

  FALSE (beam operation is NOT permitted)

  Beam injection and SPS extraction are blocked.

  If the BEAM_PERMIT changes from TRUE to FALSE, the beam will be extracted by the beam dumping system.

- One BEAM_PERMIT for each beam: BEAM1_PERMIT, BEAM2_PERMIT
- Signals are carried by the beam interlock loops for BEAM1 and BEAM2.
- Distributed over hardware links to:
  - Beam Dumping System
  - LHC injection kickers
  - SPS Extraction systems
  - *User Systems*

User permit signals

- The signal collected from the *User Systems* is called the USER_PERMIT.
- The USER_PERMIT signal can be:

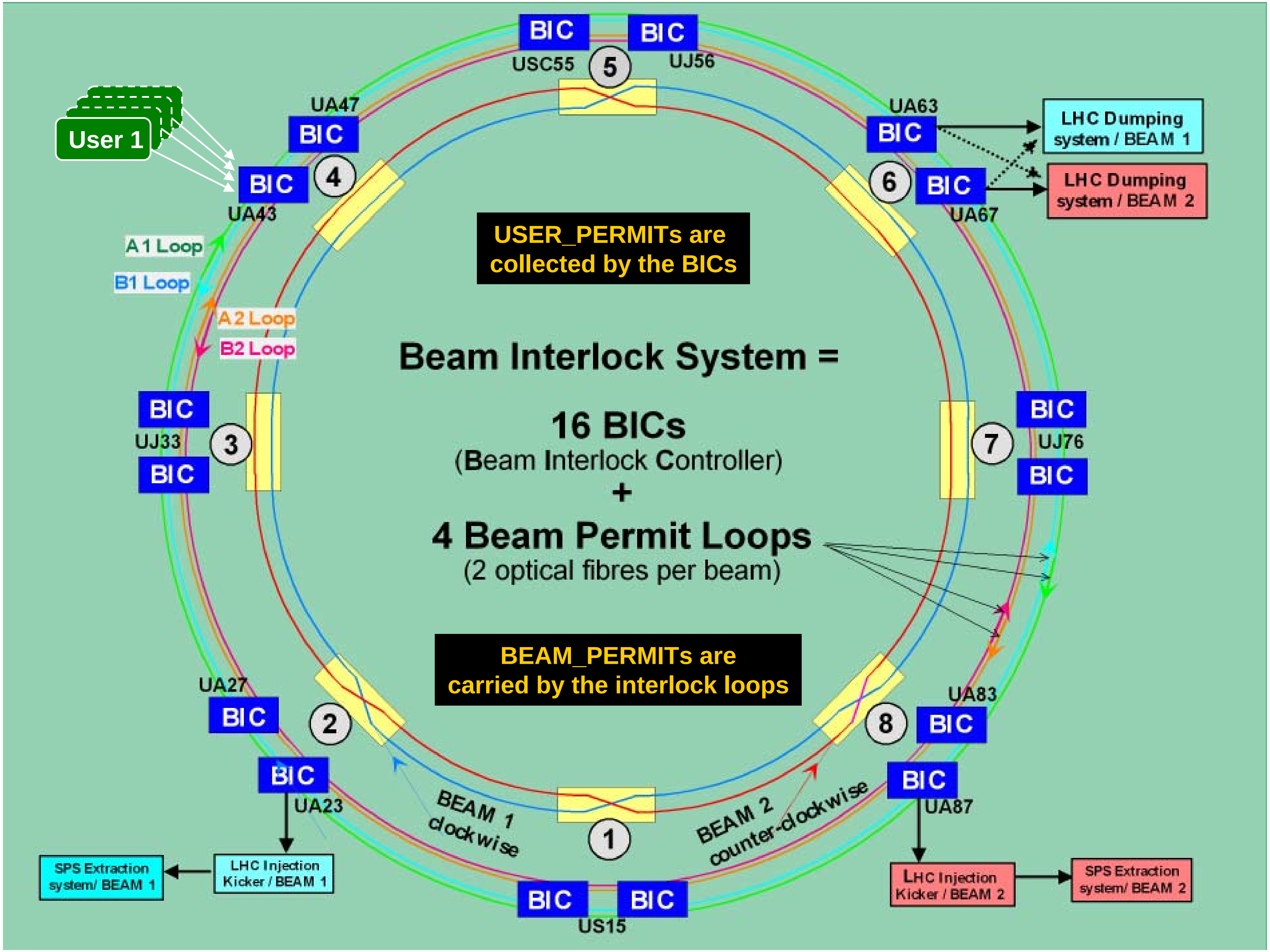
  TRUE

  The User System is ready for beam and beam operation is possible.

  FALSE

  The User System is not ready for beam or has detected a failure.

- Beam operation at the LHC is permitted when all USER_PERMITs = TRUE.
- The USER_PERMITs are gathered via hardware links.
- The USER_PERMITs are processed inside the Beam Interlock Controller.



USER_PERMITs are collected by the BICs
Beam Interlock System =
16 BICs
(Beam Interlock Controller)
+
4 Beam Permit Loops
(2 optical fibres per beam)
BEAM_PERMITs are carried by the interlock loops
User 1
A1 Loop
B1 Loop
A2 Loop
B2 Loop
BIC
USC55
UJ56
UA47
UA43
UA63
UA67
UJ33
UJ76
UA27
UA23
UA83
UA87
US15
1
2
3
4
5
6
7
8
LHC Dumping system / BEAM 1
LHC Dumping system / BEAM 2
BEAM 1 clockwise
BEAM 2 counter-clockwise
SPS Extraction system/ BEAM 1
LHC Injection Kicker / BEAM 1
LHC Injection Kicker / BEAM 2
SPS Extraction system/ BEAM 2

Safe masking

In certain circumstances it can be important / very useful to mask out (i.e. ingnore) user signals that are not critical.

When ?

- **for machine commissioning (reduce number of interlock channels…)**
- **for special operation phases / measurements**
- **but in any case only for SAFE beam intensity, SAFE = below damage threshold.**

The central issue of masking interlocks is to ensure that :

- **Masks can only be set when the beam is SAFE.**
- **Masks are AUTOMATICALLY removed (i.e. the corresponding signal is re-activated) when the beams becomes unsafe:**
  - **→ More beam is injected or the energy is increased.**

For the LHC our concept is to provide an

automatic mechanism to ensure safe masking.

Safe beam flag for masking

- Safe masking is achieved using a so-called SAFE BEAM FLAG (SBF).
- The SAFE BEAM FLAG can be:

  TRUE

  The stored beam energy is < damage threshold.

  Masking of USER_PERMITs is taken in account.

  If a masked USER_PERMIT = FALSE ⇒ ignored ⇒ BEAM_PERMIT = TRUE.

  FALSE

  The stored beam energy is > damage threshold.

  Masking of USER_PERMITs is no longer taken in account.

  If one USER_PERMIT = FALSE ⇒ BEAM_PERMIT = FALSE.

- The SBF is distributed to the interlock systems and all concerned users.
- It is derived from the LHC energy and from the beam intensity:

  Energy from Beam Energy Tracking System (E. Carlier).

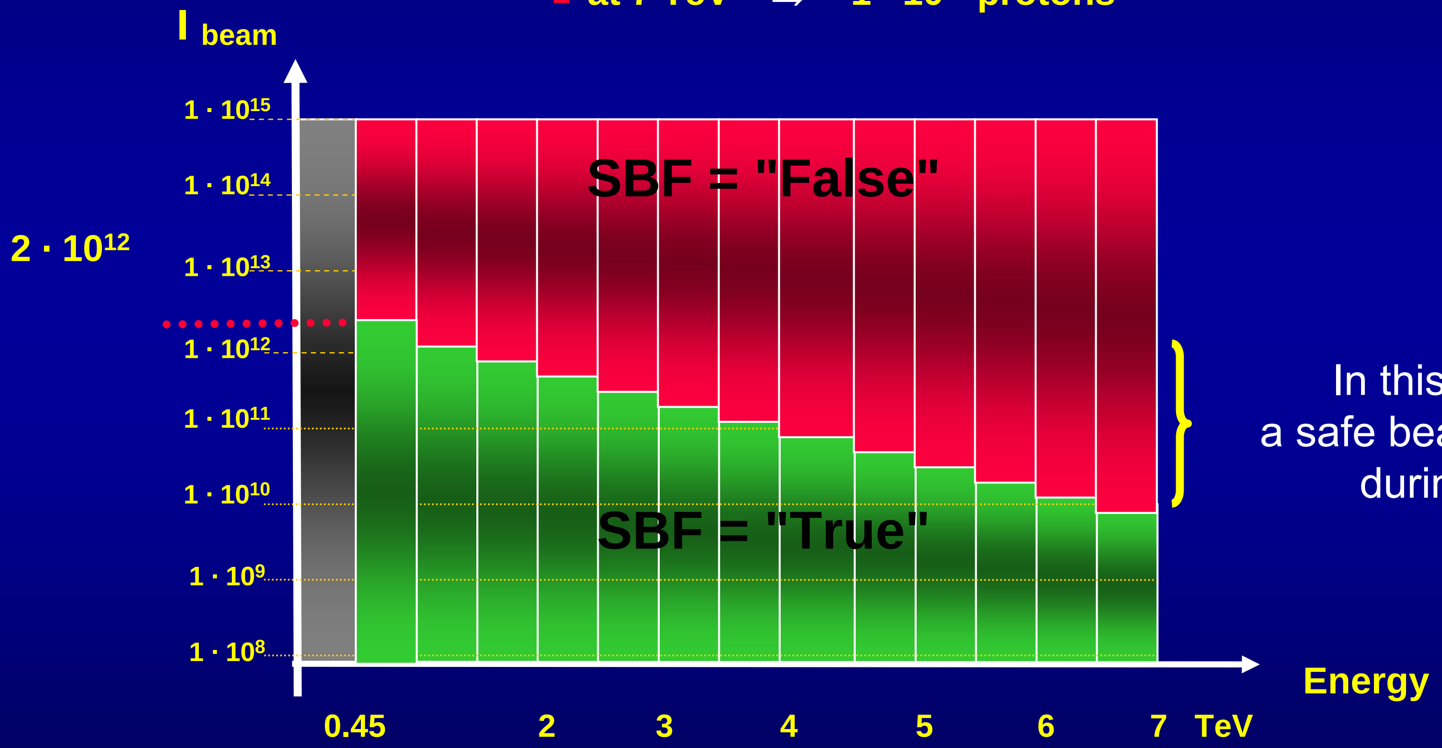
  Intensity of beam 1 and beam 2 measured by BCTs (D. Belohrad).

  Intensity of the beam from the SPS before an injection !

Safe beam flag evolution

Estimated damage level for fast losses

- at 450GeV ⇒ ~ $2 \cdot 10^{12}$ protons
- at 7 TeV ⇒ ~ $1 \cdot 10^{10}$ protons



In this intensity range,
a safe beam becomes unsafe
during acceleration

Masking of user permits

- Masking must only be possible when the SAFE BEAM FLAG = TRUE and a full beam loss cannot result in damage to equipment.

- The *User Systems* are classified in two families:
  - MASKABLE signals

    Signal can be temporarily ignored if the beam is SAFE.

    Mask set by the operator ⇒ USER_PERMIT is not taken into account .
  - UN-MASKABLE signals

    The USER_PERMIT will NEVER be ignored to produce the BEAM_PERMIT.

- The partition MASKABLE / NOT MASKABLE cannot be modified by software, but is remotely readable from the supervision program.

Partition : maskable / non-maskable

family	(main) *User Systems*
Non-maskable	Powering Interlocks (for essential electrical circuits)
	Warm Magnet Interlocks
	Vacuum system
	Access Safety system
	Beam Energy Tracking System
	Beam Dumping system
	Critical Beam Loss Monitors
	LHC experiments (several signals / exper.)
	Software interlock
	LHC Control Room (manual dump switch)
Maskable	Beam Loss Monitors (less critical)
	Powering Interlocks (for less critical circuits)
	R.F.
	Collimators
	Transverse Feedback
	Beam Aperture Kicker
	Beam Position Interlocks
	Fast Magnet Current Decay Monitor
	Fast Beam Current Decay Monitor

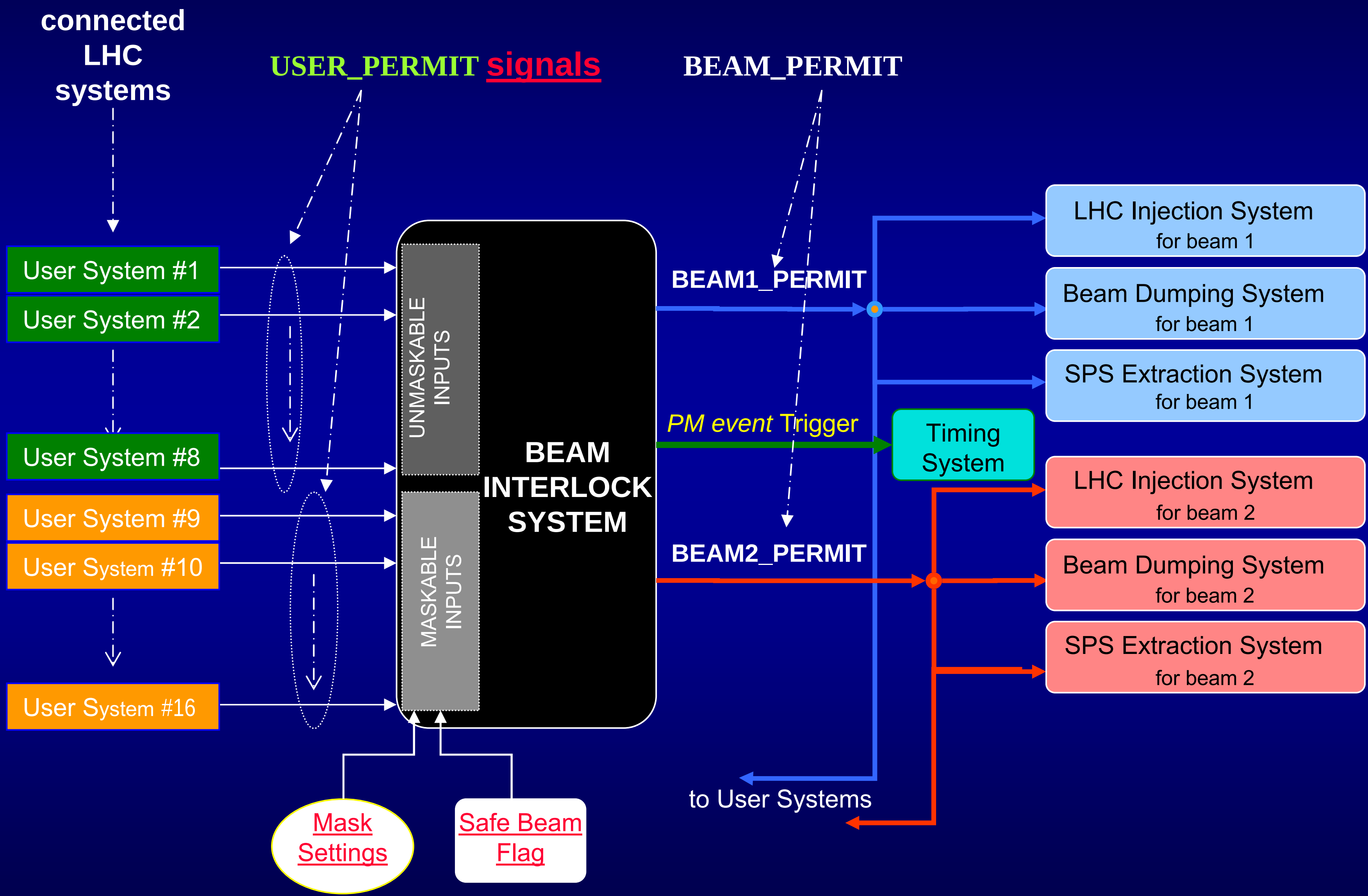
Fundamental elements, must be OK for beam to circulate

Highly critical elements

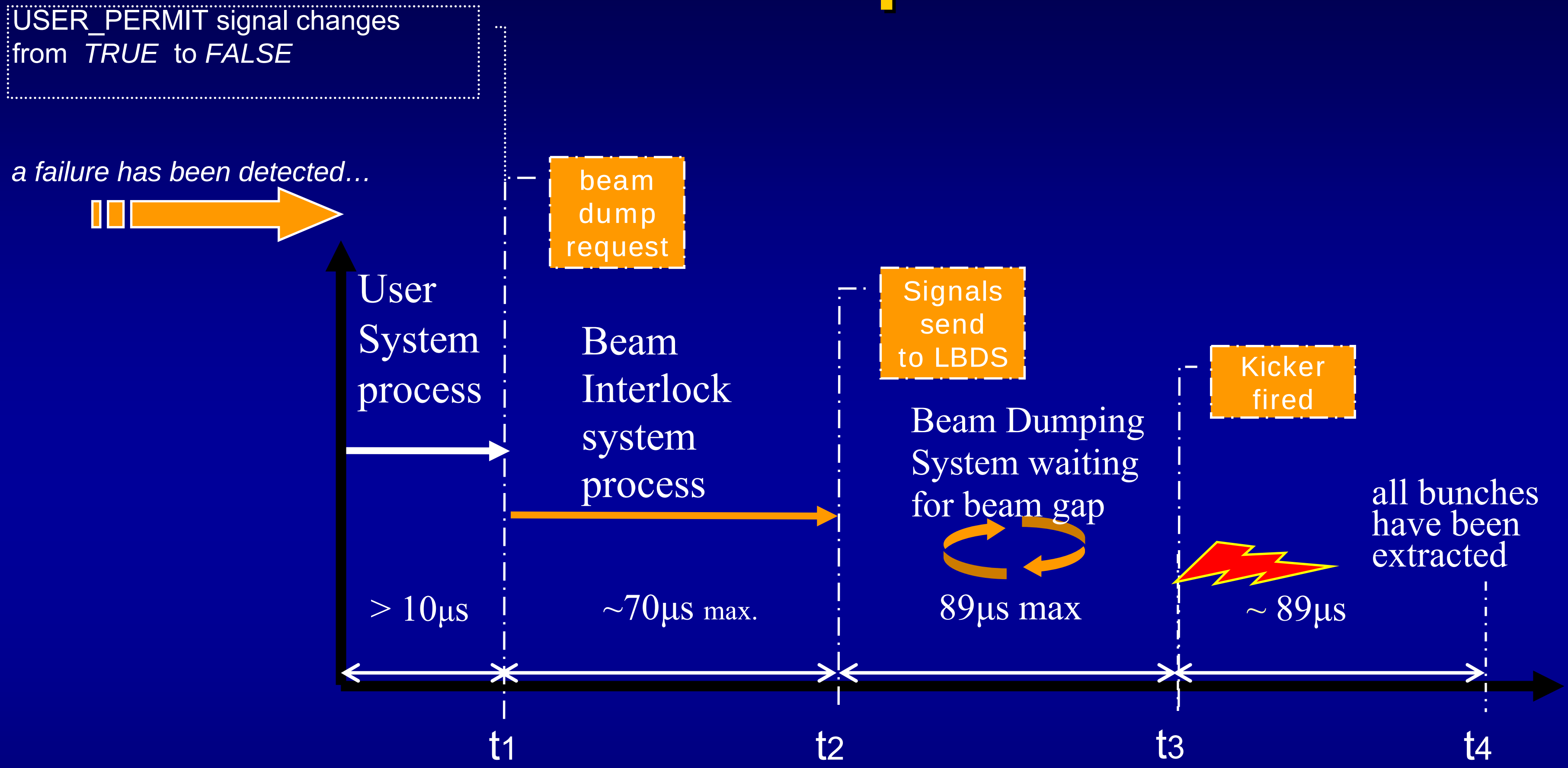
! Preliminary !
Not complete

Details on the user signals will be given throughout the review.

Basic functionality



Response time



The achievable TOTAL response time is in the range of 100 μs to 270 μs

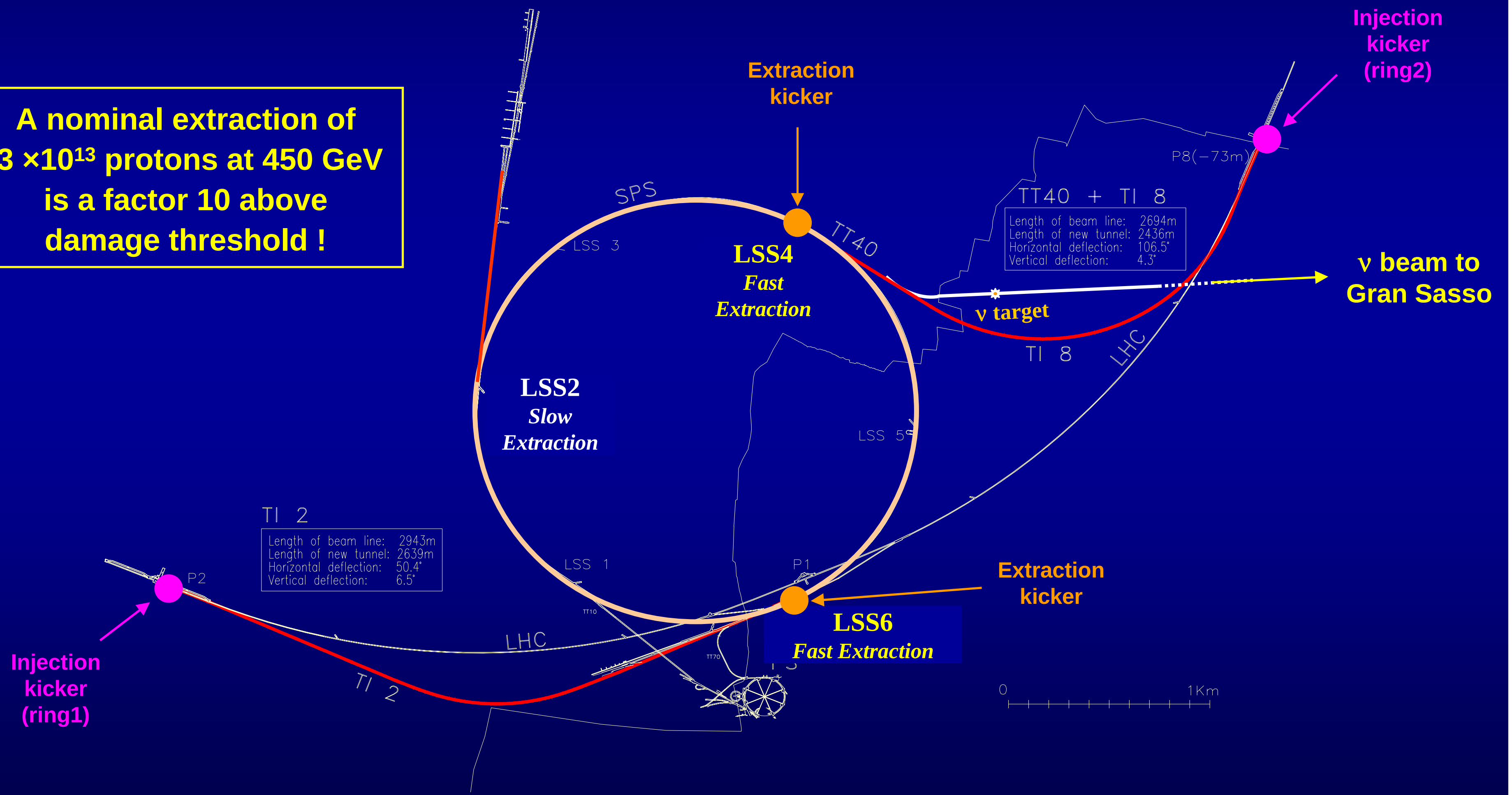
(between the detection of a beam dump request and the completion of a beam dump)

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

From SPS to LHC

Protection of the LHC starts in the SPS !

A nominal extraction of 3×10^{13} protons at 450 GeV is a factor 10 above damage threshold !



LHC injection interlock system

- The role of the injection interlock system is to survey LHC elements that are relevant for the injection process (kickers, absorbers, injection collimators…), but not necessarily for the circulating beam (V. Kain).

- This system produces a signal called INJECTION_PERMIT (one per beam).
- The INJECTION_PERMIT can be

  TRUE

  Beam injection of beam is permitted.

  All user systems involved in injection are ready.

  FALSE

  Beam injection and SPS extraction are NOT permitted.

- The INJECTION_PERMITs are available locally in IR2 (Ring 1) and IR8 (Ring 2) and distributed over hardware links to the corresponding :
  - LHC injection kicker
  - SPS Extraction system

SPS extraction interlock system

- The SPS extraction interlock system surveys all critical components of the transfer line from SPS to LHC and of the SPS extraction channel, from power converters and magnets to absorbers.

- This system produced a signal called EXTRACTION_PERMIT (one per extraction / LHC ring).
- The EXTRACTION_PERMIT can be:

  TRUE

  Extraction of beam from the SPS is permitted.

  All user systems involved in extraction to the LHC are ready.

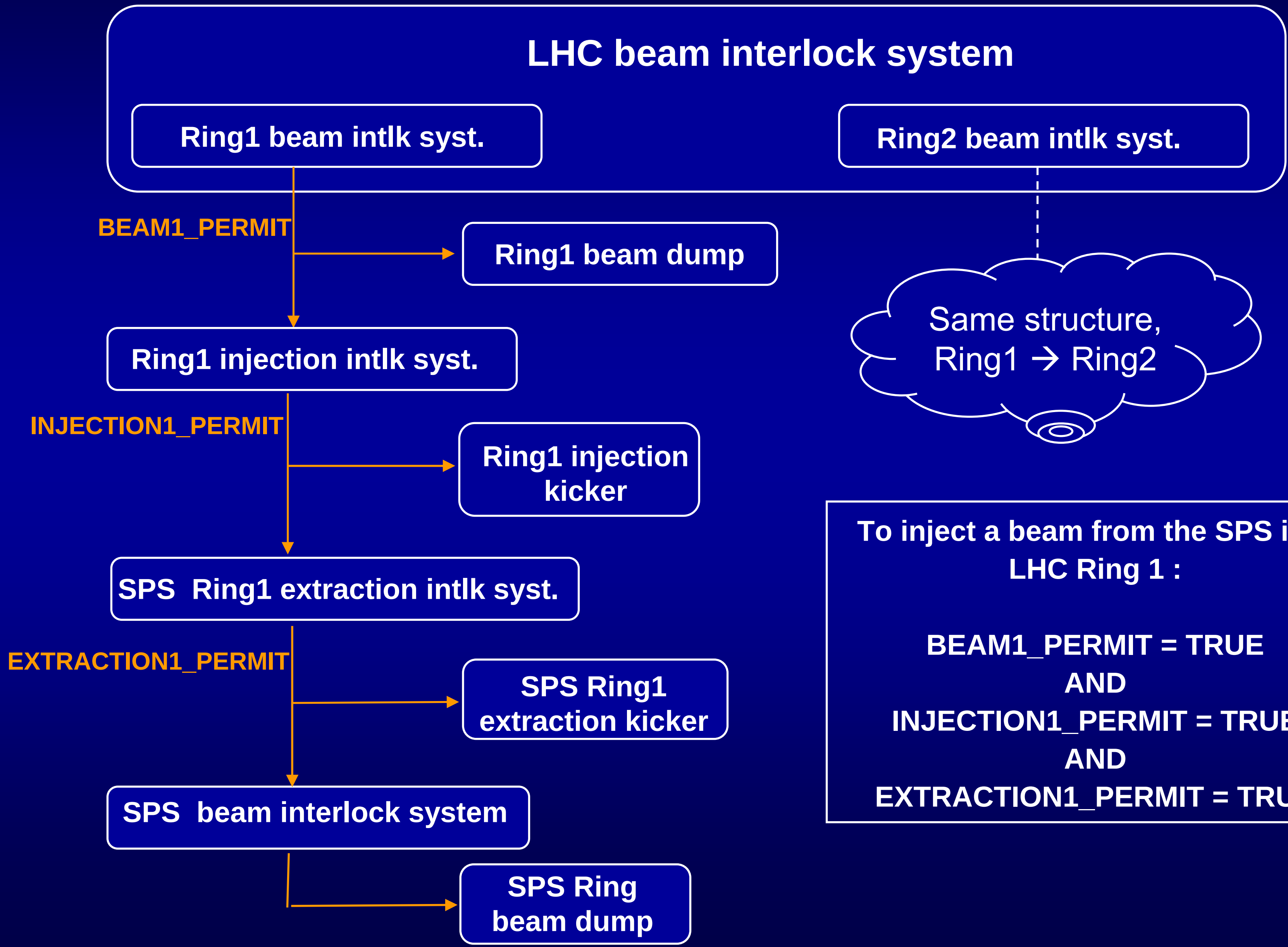
  FALSE

  Extraction of beam from the SPS is NOT permitted.

  The beam remains in the SPS ring / is dumped in the SPS.

- The EXTRACTION_PERMIT is distributed over hardware link to the SPS extraction kicker.

Interlock system hierarchy



To inject a beam from the SPS into LHC Ring 1 :

BEAM1_PERMIT = TRUE
AND
INJECTION1_PERMIT = TRUE
AND
EXTRACTION1_PERMIT = TRUE

Four systems – one hardware solution

The LHC beam interlock system,
the LHC injection interlock system,
the SPS extraction interlock system
and the SPS beam interlock system

will be (re)build with the same hardware components (B. Todd).

The existing SPS beam interlock system will be progressively replaced by the new system in the coming years.

Extraction / Injection interlocking

- Injection is a potentially one of the most dangerous processes

  → failures may happen in a single passage, no chance to react…

- To ensure safe beam transmission through the lines and into the LHC for a fast extraction, *all equipment settings must be verified IN ADVANCE !*

- For the transfer lines, all relevant elements settings are surveyed as close as possible to the extraction time to minimize / eliminate the risk of damage by the extraction interlock system (V. Kain).

  →The beam is only extracted from the SPS if all settings are correct.

- How do we ensure on the LHC side that everything is correct ?

  There are 1600 power converters to survey !

  Unrealistic to prepare all settings of the LHC in advance for high intensity.

Probing with beam

For the LHC ring we use the concept to verify the settings directly with beam :

1 - Injection of a safe beam never leads to equipment damage.

- A safe beam is below damage threshold.
- Beam interlock system must give BEAM_PERMIT, and settings surveillance is done by SW interlock system.

2 - If a safe beam is circulating in the LHC – lifetime > few minutes.

- Injection of high(er) intensity will not lead to a loss over a single turn.
- The lifetime of the high(er) intensity beam may be poor, but this leaves time for beam loss monitors …to react.

→ We implement a scheme where we only permit injection of a safe beam into an empty ring.

Beam Presence Flag

- To ensure safe injection, we introduce a signal called the

  Beam Presence Flag (one per beam).

- The BEAM_PRESENCE flag is a signal that can be :

  TRUE

  Beam is present, intensity > ~1-2 × 10^9 protons

  FALSE

  No measurable beam, intensity < ~1-2 ×10^9 protons

- We enforce the following logic for injection (implemented in the extraction interlock system) :

  BEAM_PRESENCE = FALSE

  Only a SAFE beam can be injected from the SPS.

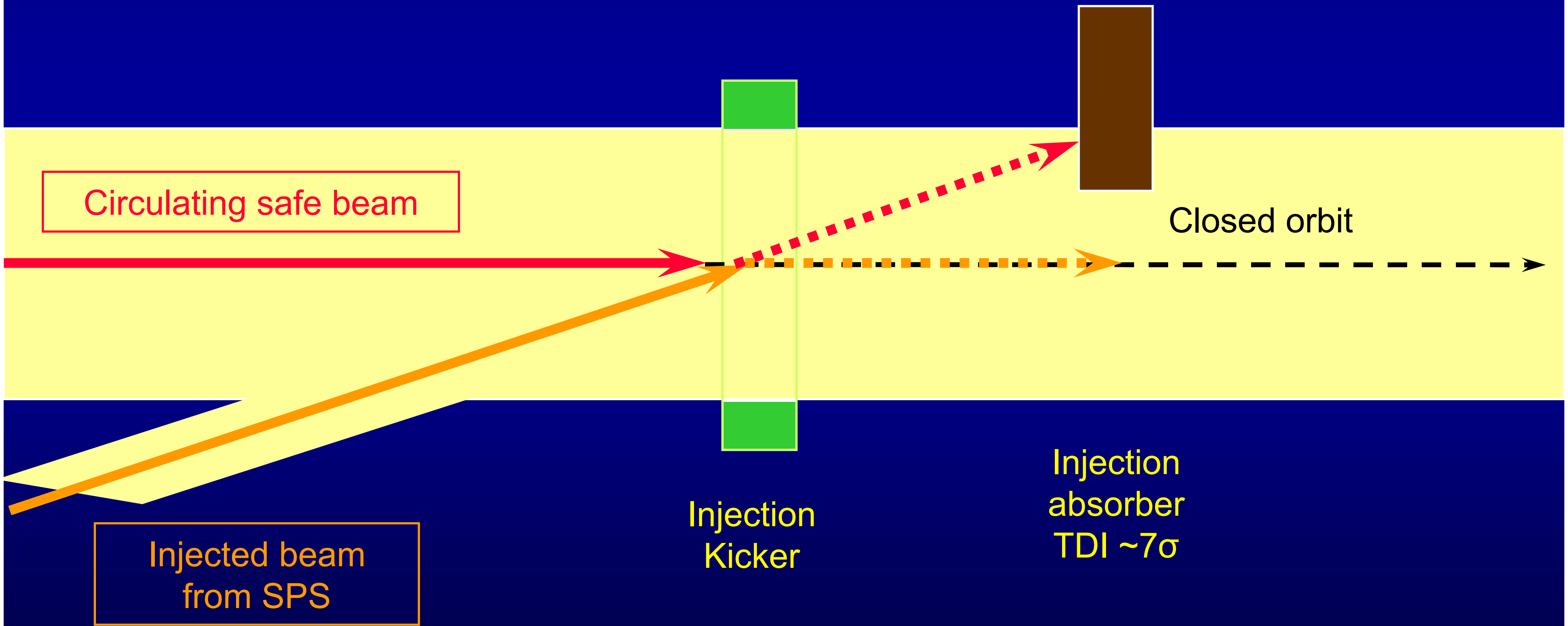
  BEAM_PRESENCE = TRUE

  Any beam may be injected

In practice

Since the low intensity safe beam may not fit into the desired bunch pattern :

- The injected beam is placed into same longitudinal position than the circulating safe (low intensity) beam.
- The circulating safe beam is dumped onto the injection absorber (TCDI).



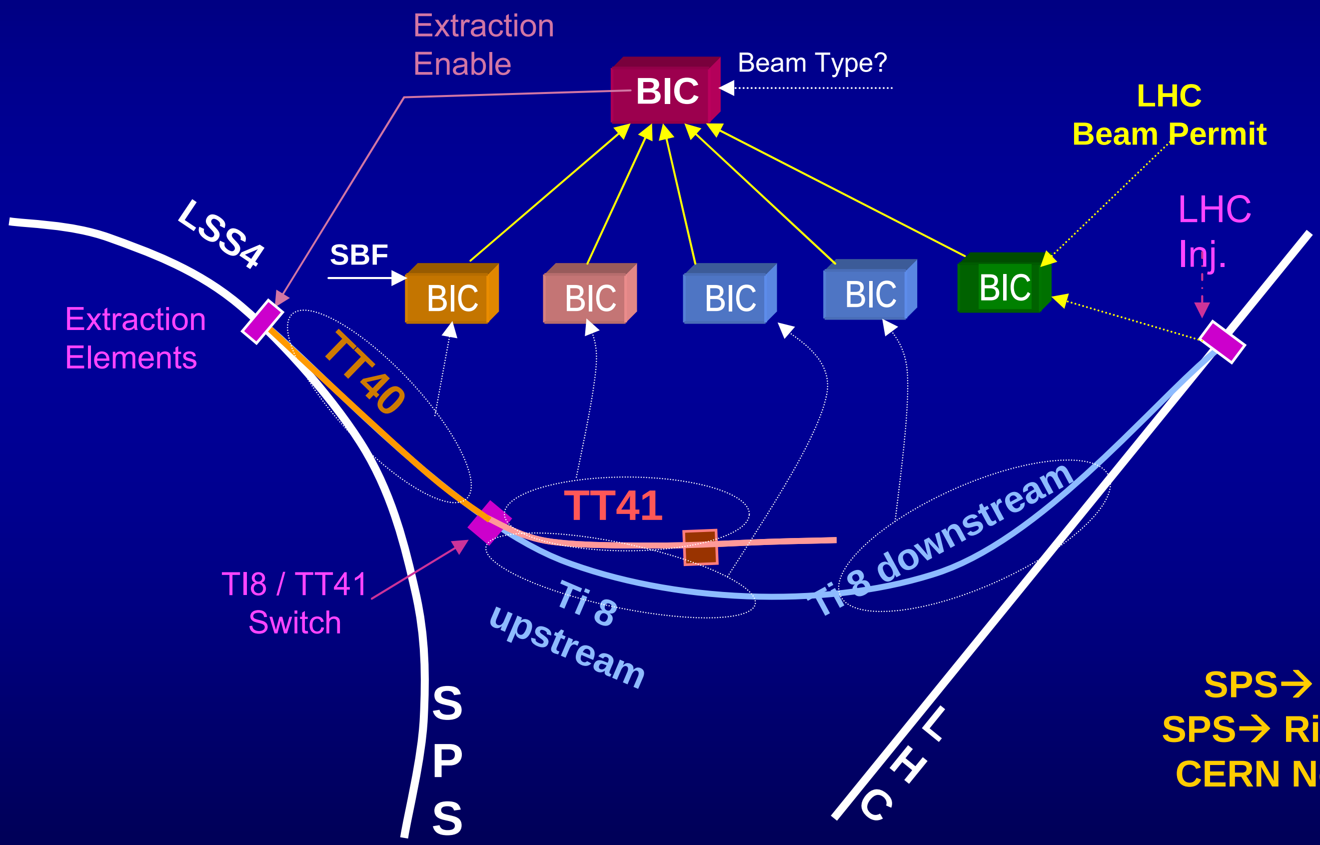
Summary

- The interlock systems collect the user interlock signal and provide green light for beam operation when conditions for safe operation are met.
- To provide more flexibility for operation, some interlock signals will be maskable provided the beam is safe.
- Two important signals are needed for safe LHC operation
  - A safe bean flag that indicates if the beam intensity is < damage threshold (SPS & LHC)
  - A beam presence flag that indicates if beam is present in a given LHC ring.
- Safe injection is enforced by ensuring that only safe beams may ever be injected into an empty LHC ring.
- The Interlock systems for the LHC ring and for injection/extraction are coupled and are based on the same HW components.

Extraction interlock architecture

Architecture for SPS → Ring2 extraction system :

The system is segmented to allow operation of the line / extraction system independently of the LHC



SPS→ Ring2 is more complex than SPS→ Ring1 due to 'interference' of the CERN Neutrino to Gran Sasso (CNGS) beam