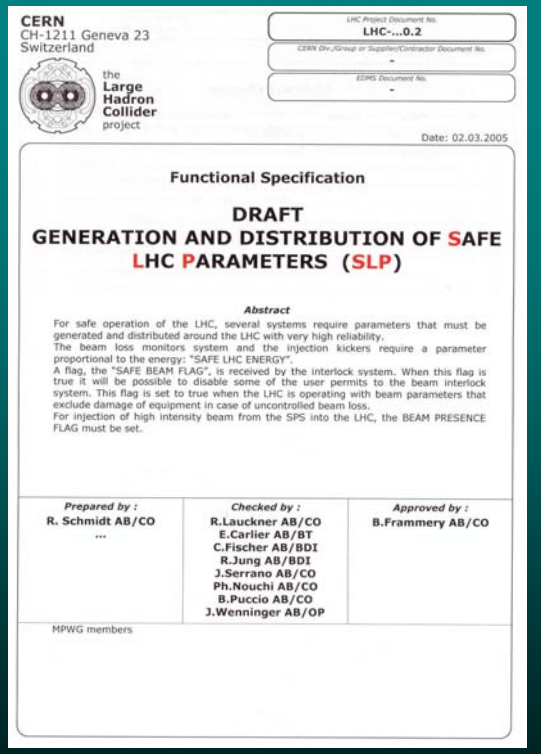
Generation and Distribution of Safe LHC Parameters

Safe_LHC_Energy

Beam_Presence_Flags

Safe_Beam_Flags



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Functional Specification

DRAFT
GENERATION AND DISTRIBUTION OF SAFE LHC PARAMETERS (SLP)

Abstract

For safe operation of the LHC, several systems require parameters that must be generated and distributed around the LHC with very high reliability.
The beam loss monitors system and the injection kickers require a parameter proportional to the energy: "SAFE LHC ENERGY".
A flag, the "SAFE BEAM FLAG", is received by the interlock system. When this flag is true it will be possible to disable some of the user permits to the beam interlock system. This flag is set to true when the LHC is operating with beam parameters that exclude damage of equipment in case of uncontrolled beam loss.
For injection of high intensity beam from the SPS into the LHC, the BEAM PRESENCE FLAG must be set.

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MPWG members

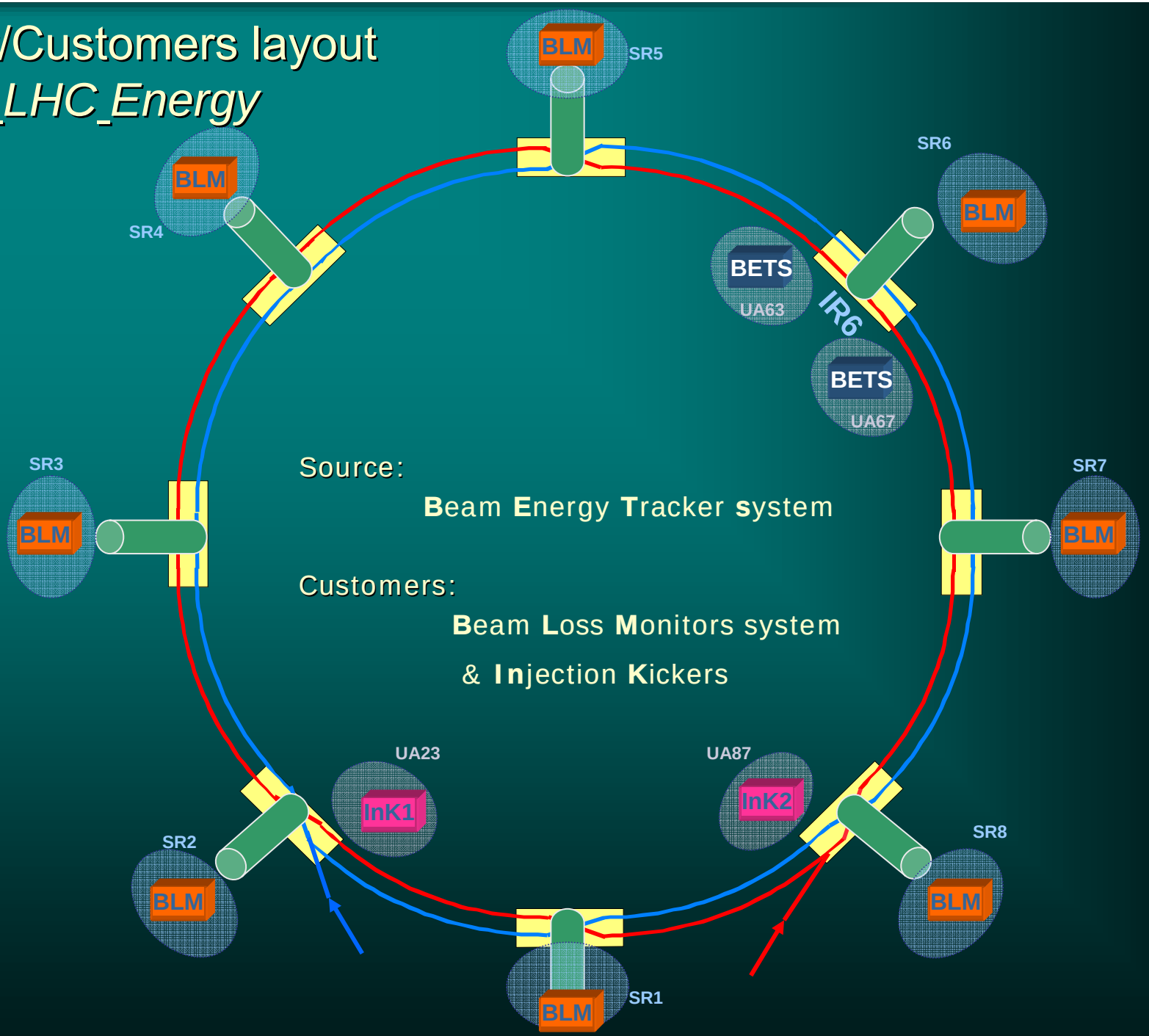
Parameter #1: Safe_LHC_Energy

- Proportional to momentum of proton circulating in LHC, and to the B•ρ
  (B=magnetic field of main dipoles, ρ = bending radius).

- Produced by the **B**eam **E**nergy **T**racker **S**ystem (see E.Carlier's talk).
  Derived from current in main dipole magnets in sectors 5-6 and 6-7.
  Only one value is needed ("identical" for both beams).

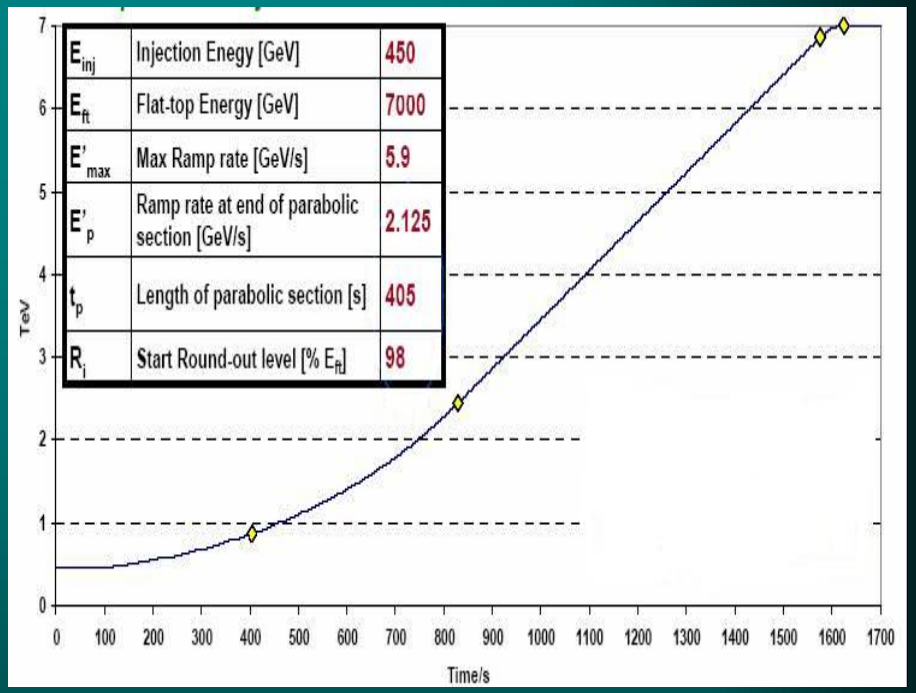
- Required by Beam Loss Monitors system and Injection Kickers
  (see B.Dehning's talk) (see E.Carlier's talk)

Supplier/Customers layout for *Safe_LHC_Energy*



Energy ramping

- Slow process:
  from 450 to 7000 GeV
  in ~28 minutes !



Increase between ~2 Gev/sec (*in the beginning*)

and ~6 Gev/sec (*in the linear part*)

Parameter #2: Beam_Presence_Flags

- Permit injection of high intensity beam from SPS into LHC.
  Derived from beam Intensity of beam 1 and beam 2 measured by the BCTs. (see D.Belohrad's talk)

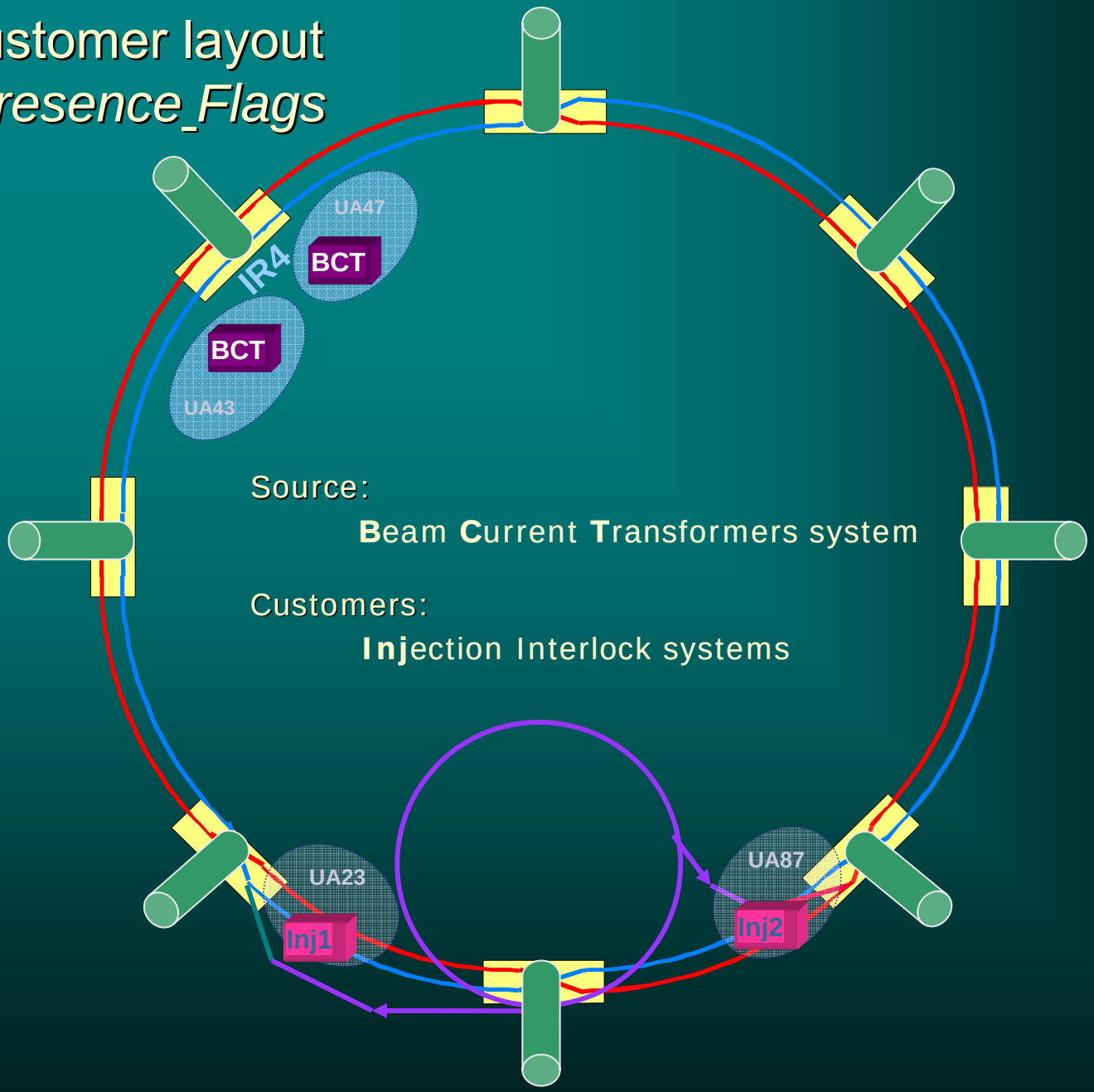
If ($Ibeam_1$ > $MINIMUM\_BEAM\_INTENSITY_1$) then BPF_1 = "TRUE" else BPF_1 = "FALSE"
If ($Ibeam_2$ > $MINIMUM\_BEAM\_INTENSITY_2$) then BPF_2 = "TRUE" else BPF_2 = "FALSE"

- Threshold values "$MINIMUM\_BEAM\_INTENSITY_{1,2}$" should normally be fixed.
  But must be possible to set it to different value after receiving authorization (to be determined) and new value must be logged.

For the time being, the foreseen limit is equal to a probe beam (~10^9 protons)

- Required for interlocking the Injection

Supplier/Customer layout for *Beam_Presence_Flags*

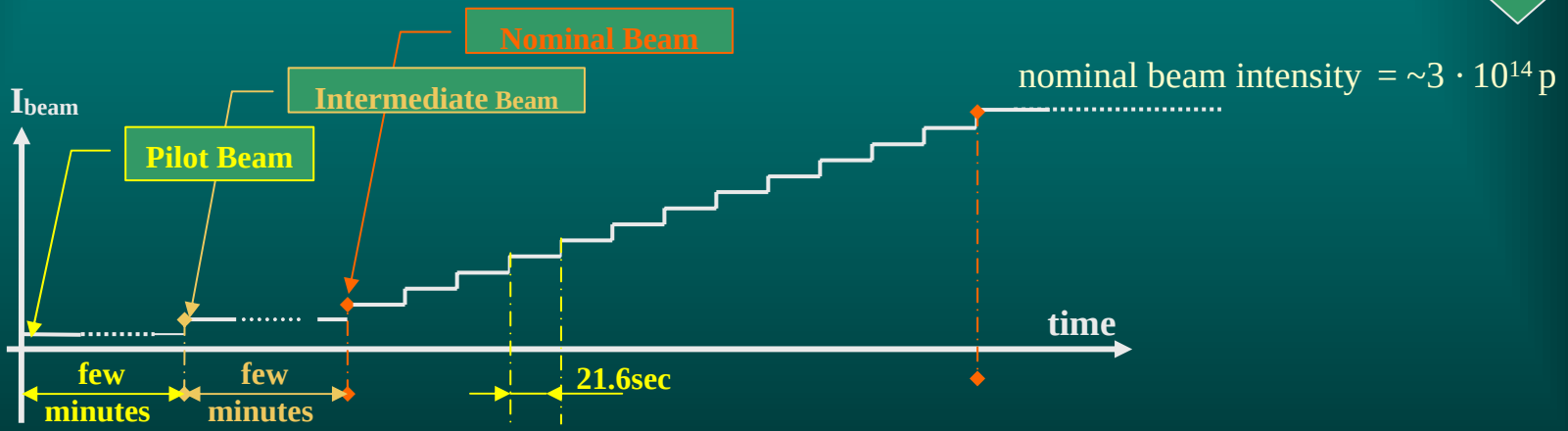


Beam_Presence_Flag change

After injections of probe beams,

there will be the injection of Nominal beam
with 12 cycles of 3 to 4 batches of 72 bunches
(with the 25ns spacing scheme)

(nominal bunch = $1.15 \cdot 10^{11}$ p)



Parameter #3: Safe_Beam_Flags

- Permit “flexibility” by masking (some) interlocks.
- Derived from: - Beam intensities measured by **B**eam **C**urrent **T**ransformers system
  - LHC energy value coming from the **B**eam **E**nergy **T**racking **s**ystem

If **f**($Ibeam_1$, Energy) < $Threshold_1$ then SBF_1 = "TRUE" else SBF_1 = "FALSE"

If **f**($Ibeam_2$, Energy) < $Threshold_2$ then SBF_2 = "TRUE" else SBF_2 = "FALSE"

- Threshold values should normally be fixed

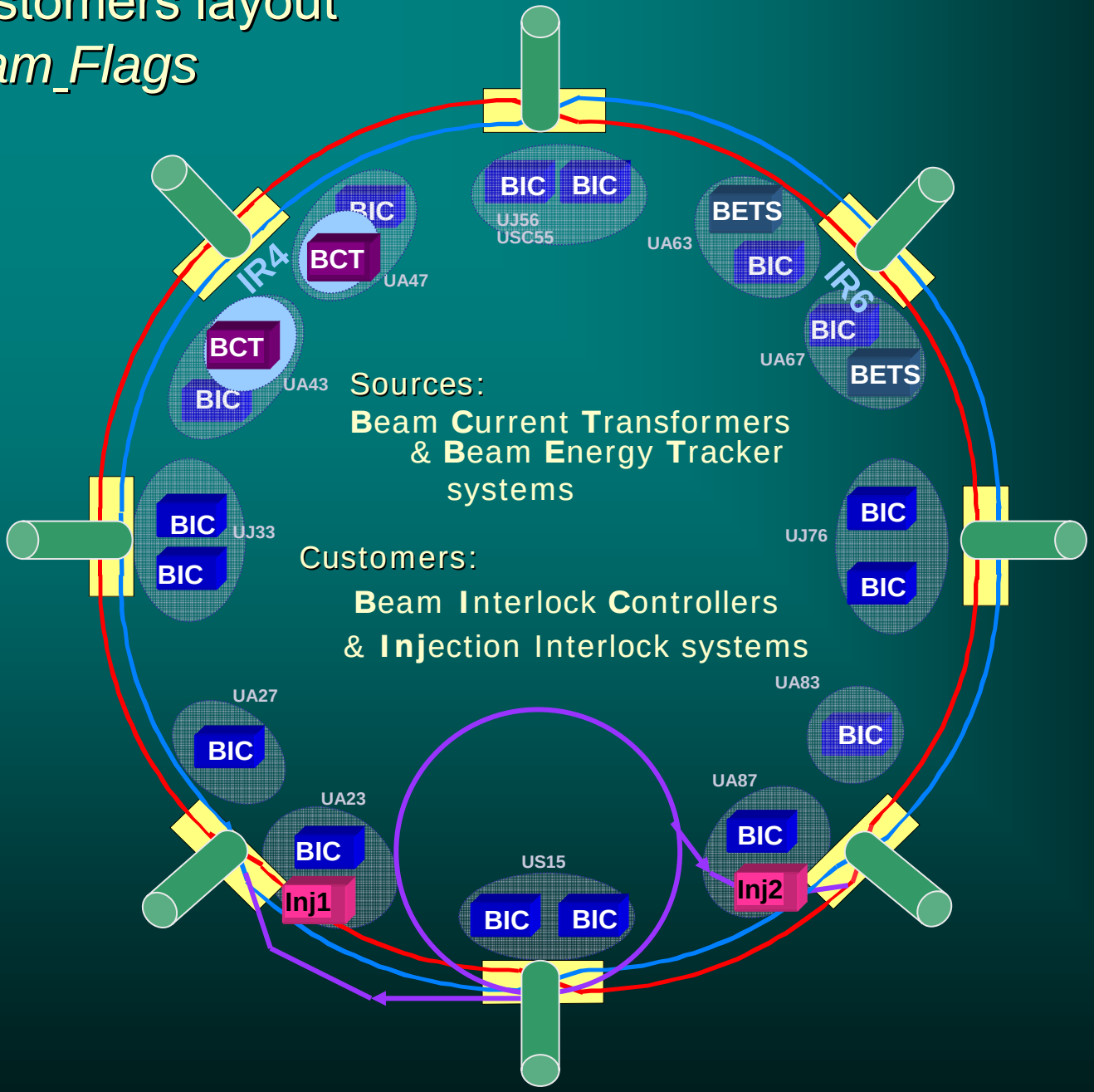
  But must be possible to set it to different value after receiving authorization (to be determined) and new value must be logged.

~$2 \cdot 10^{12}$ p. at 450GeV

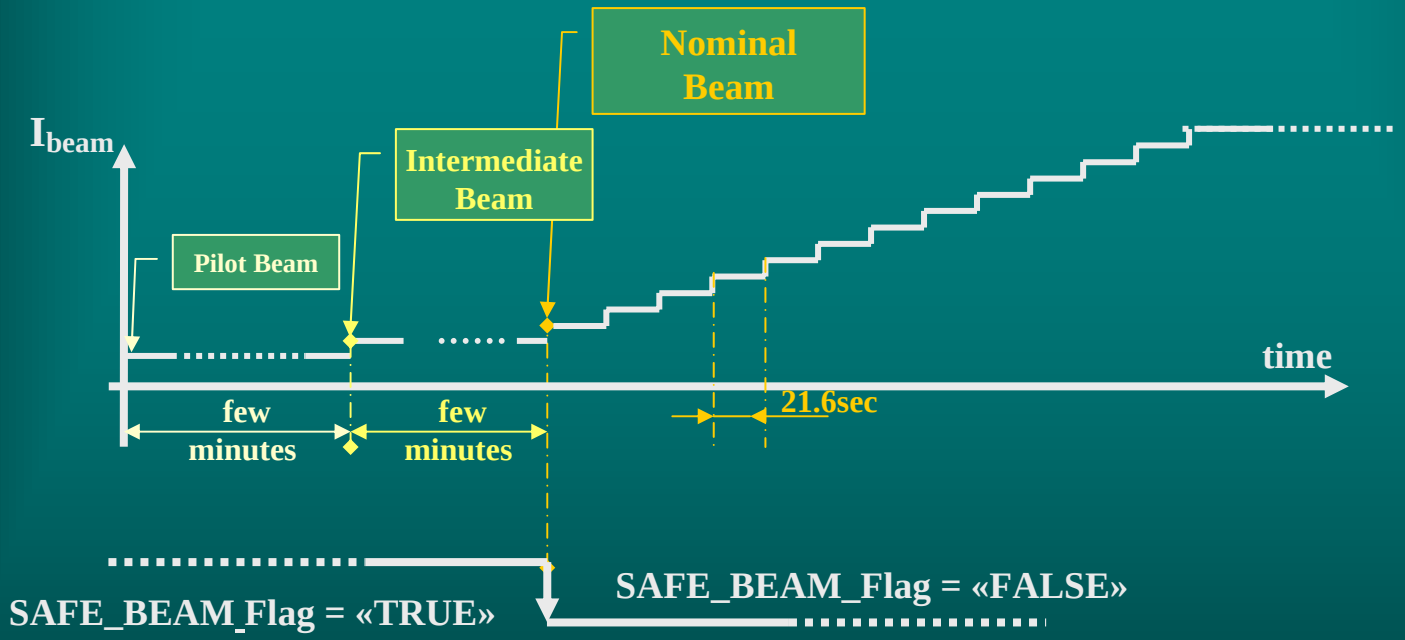
~$1 \cdot 10^{10}$ p. at 7 TeV

- Required by **B**eam **I**nterlock **C**ontrollers & by Injection Interlock system

Supplier/Customers layout for *Safe_Beam_Flags*



Safe_Beam_Flag change

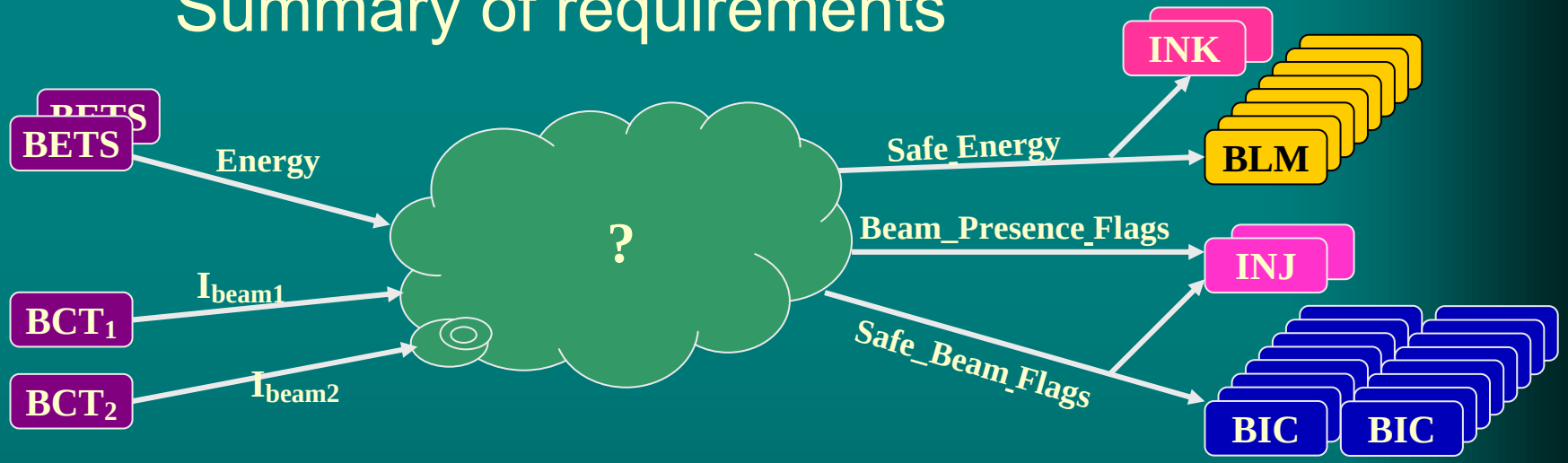


After the 1st batch of the 1st injection : ~8.3 · 10^{12} protons in the ring

=> the beam is not longer under damage level

estimated damage level for fast losses:
~2 · 10^{12} protons @ 450GeV

Summary of requirements



BETS: Beam Energy Tracker System

BCT: Beam Current Transformer

INK: Injection Kicker System

BIC: Beam Interlock Controller

	En.	Int.
Safe_Energy	X	
BPFs		X
SBFs	X	X

- 3 Parameters built from 2 types of information:
- But 3 parameters with different features:
  - A integer value and a slow ramping for the Safe_Energy…
  - Some bits for the **B**eam_**P**resence_**F**lags (not really time critical) and the **S**afe_**B**eam_**F**lag (time critical)
- To be delivered to various systems
- To be distributed over Long Distance

Why a dedicated system ?

- Because a high level of Reliability is expected
- Control network and Timing system do not fulfil requirements
- But: - How to collect needed information?
  - How to generate the 3 Safe Parameters? how to transmit & receive them?
  - How to check? What to do in case of error or failure?

- **Main technical choice for the 3 parameters management:**

“ All in One ”

⇒ Generation, Transmission and Reception in using a unique solution

👍 Put Reliability effort on only 1 system instead of 3

👍 Increase Maintainability & Reduce cost

✋ Oblige to send different parameters in using a same format

Technical proposals for the Generation and Distribution of Safe LHC Parameters

Transmit Parameters using serial frames

- Exploit existing solution:

  The CERN Machine Timing system is broadcasting information using serial transmission of 32-bit messages.

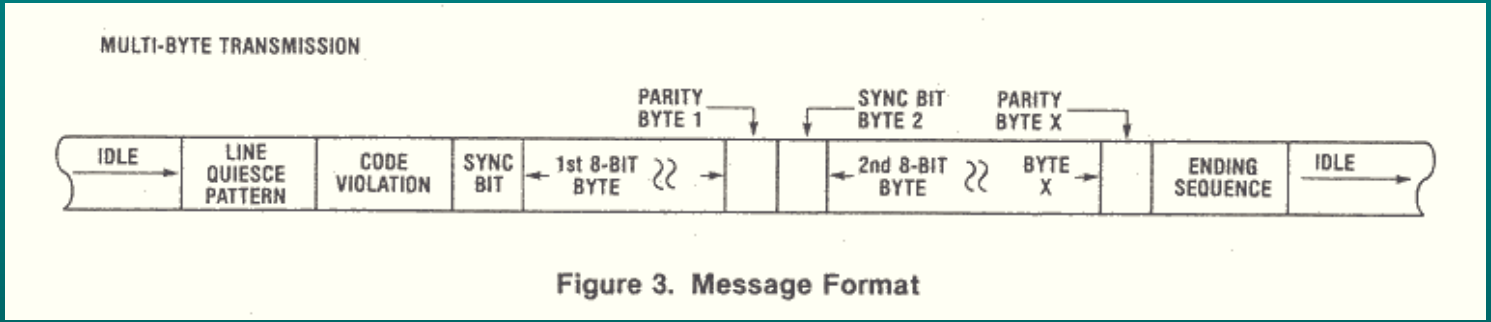


Figure 3. Message Format

- Up to 8 messages per 1ms with 512Kbits

  👍 very fast speed is not required for Safe Beam Parameters transmission

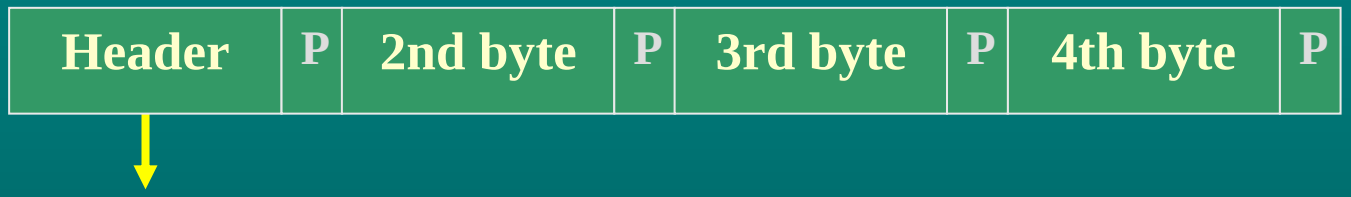
- Reliable and improved transmission system

- Easy to re-use Timing Generator and Timing Receptor electronics or by VHDL recovering. (VHDL: **V**ery high speed integrated circuit **H**ardware **D**escription **L**anguage)

Distinguish Parameters using a Header byte

The 1st byte will be used to identify the 32-bit frame

$\Rightarrow$ 24 bits can be used as payload



One Header for each Safe Beam Parameter:

- one for the Safe_Energy message

  If payload on 2 bytes ($2^{16} \leftrightarrow$ 7TeV) $\Rightarrow$ 1 bit $\leftrightarrow$ 0.1GeV

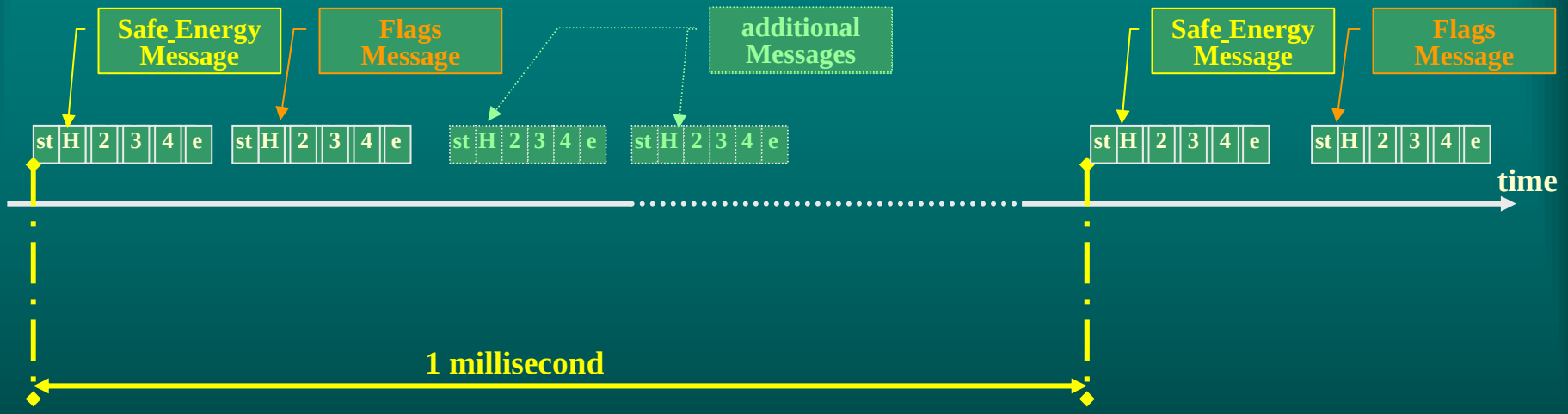
- one for the Flags = Safe_Beam_Flags + Beam_Presence_Flags

- Others are foreseen for additional Safe Beam Parameters:

  Beam1 Intensity, Beam2 Intensity, “Stable beams” flag, etc…

Time diagram for the Messages

- For the time being: 2 messages per 1ms



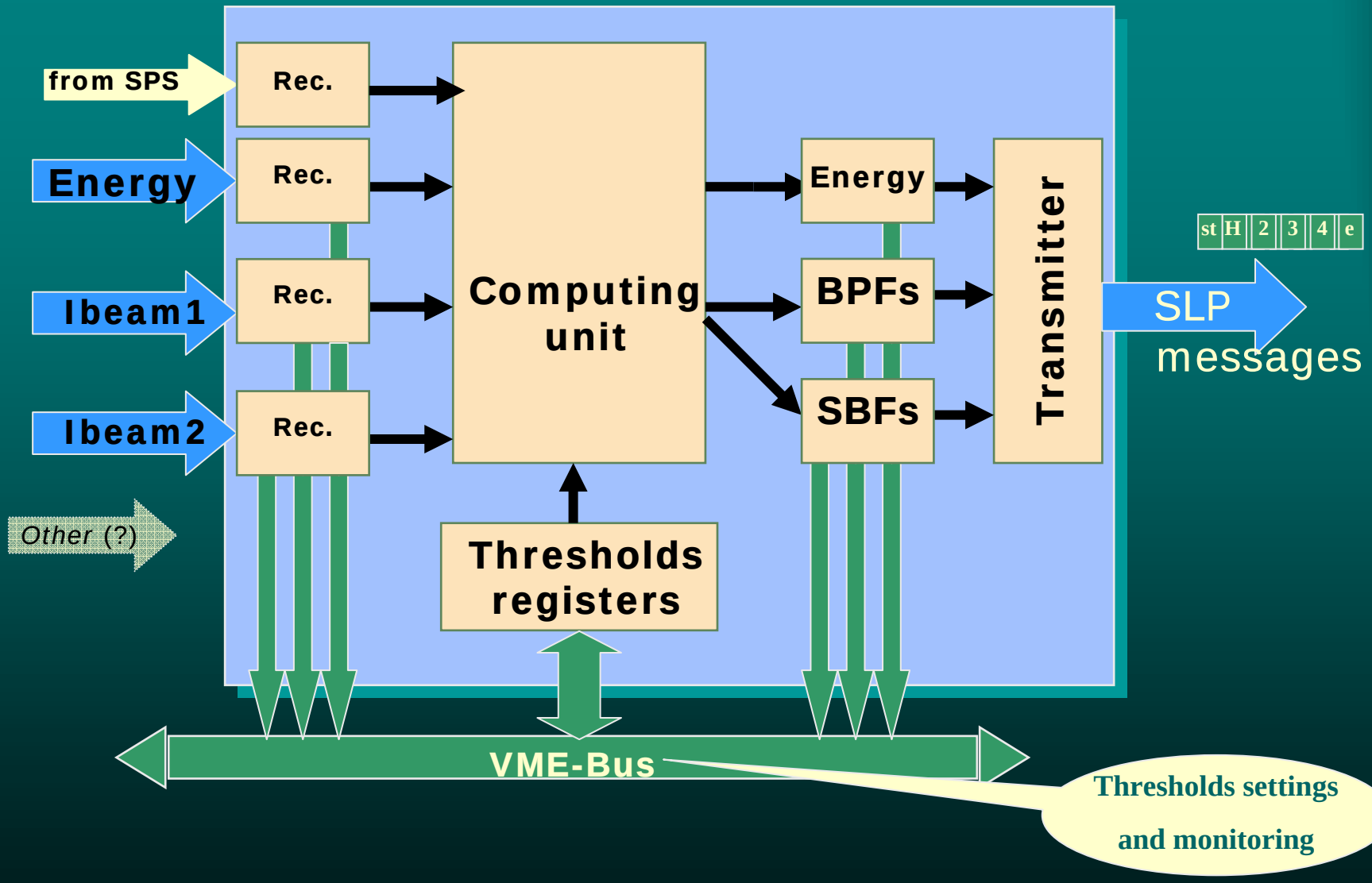
- Free slots in the millisecond slot for additional messages:
  - It will be possible to transmit up to 8 messages @512Kbits/s

SLP* Generator

* SLP stands for **S**afe **L**HC **P**arameters

- Features:
  - Receives Energy and Beam Currents data
  - Computes the Presence_Beam_Flags and Safe_Beam_Flags
  - Merges Flags and built corresponding SLP messages
  - Broadcasts the messages
  - Has a VME-bus interface for reading thresholds and for monitoring purpose
  - The Generator will be installed in IR4
    - Beam Currents information already produced in this area
    - But Energy parameter should be transmitted from IR6 to IR4

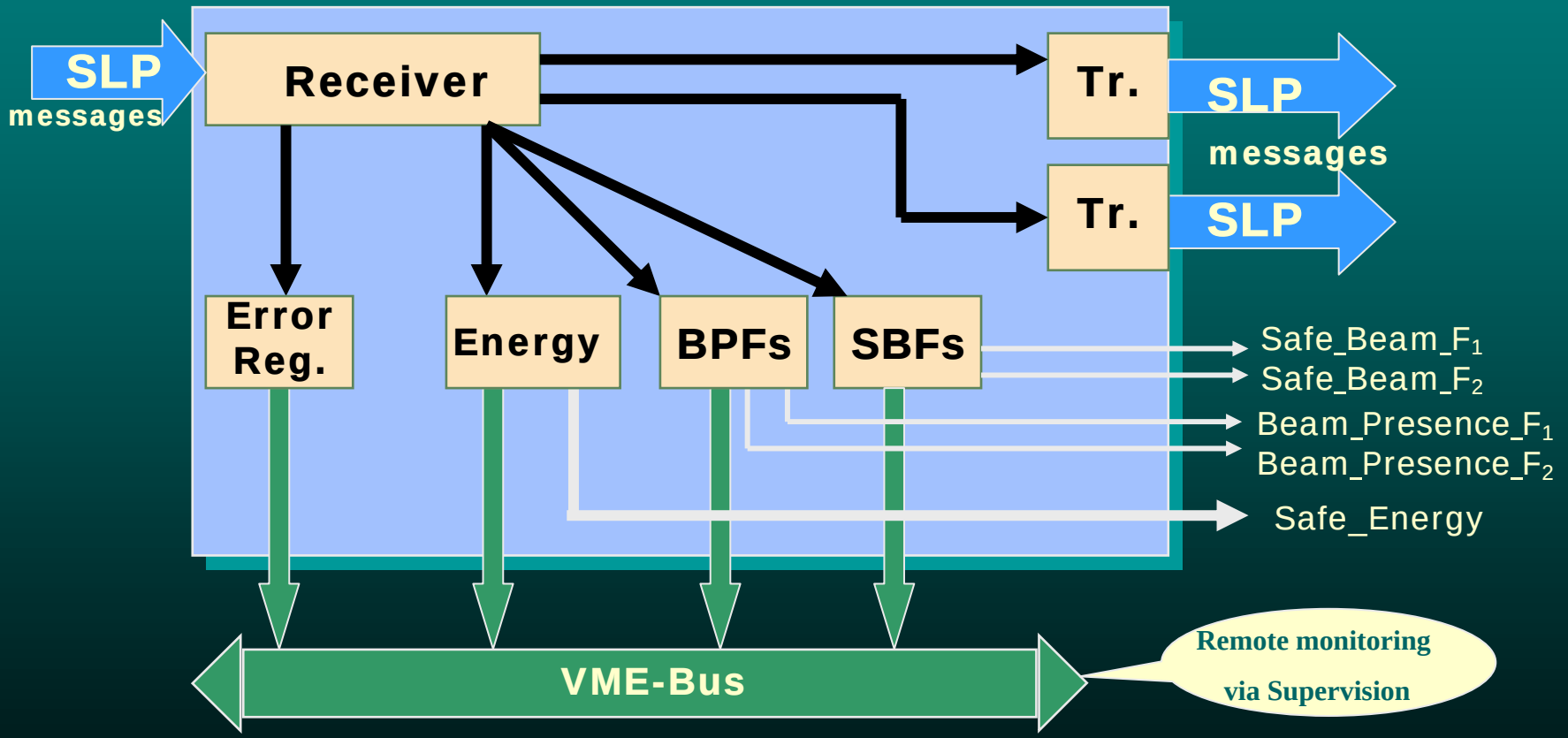
Simplified block diagram for the Generator



Receiver/Transmitter board

- Features:
  - Receives, decodes the SLP* messages.
  - Gives local information via 3 different outputs.
  - Retransmits the SLP messages to the next R/T board.
  - Has a VME-bus interface for monitoring purpose.

* SLP stands for **S**afe **L**HC **P**arameters



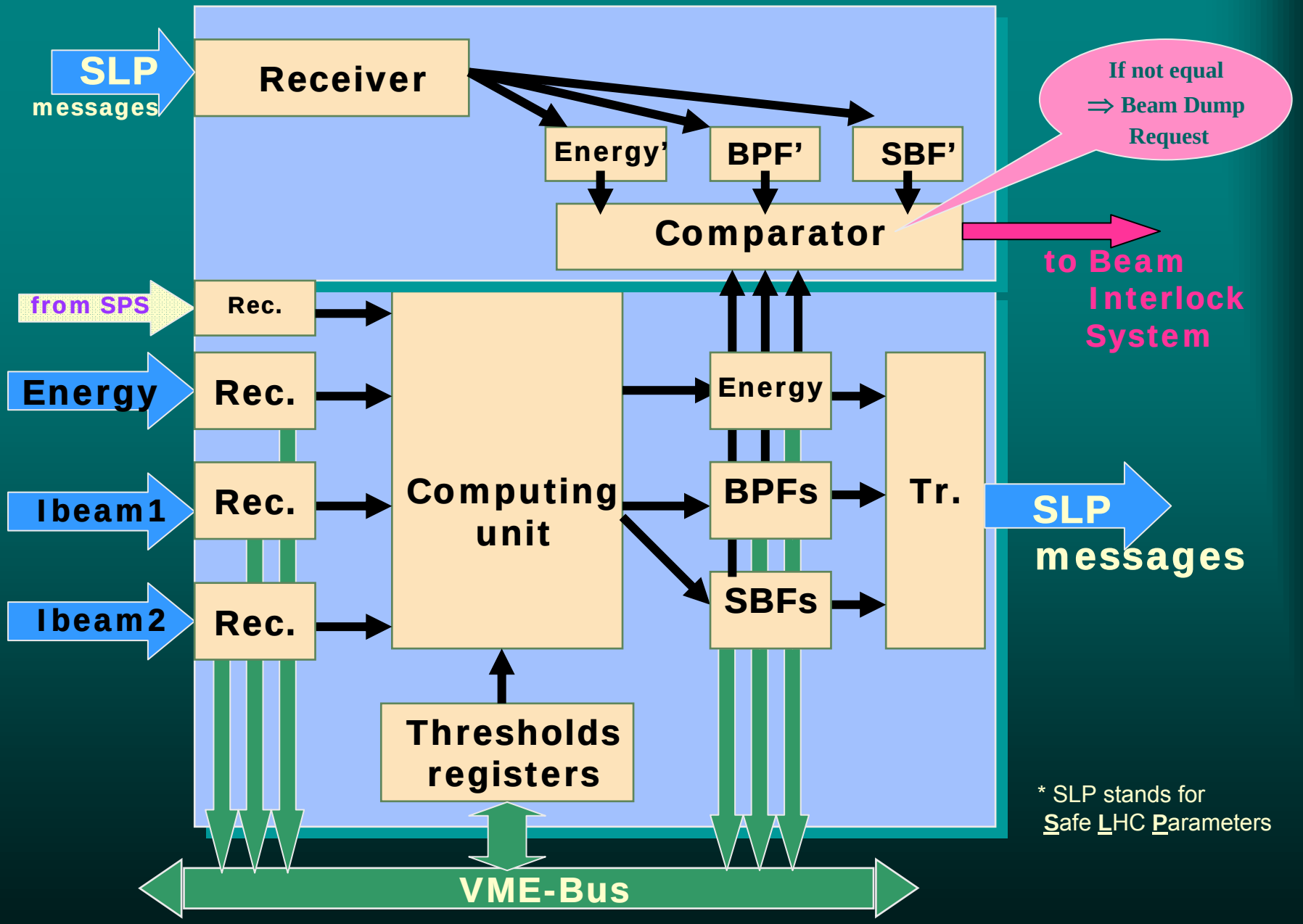
Link between the R/T boards

- Using Optical Fibres (Fail safe transmission support)
- Link as a loop to ensure that all clients receive the same information
- Close the loop at the level of the Generator:
  - Allow a check of the transmitted messages
  - If ERROR then activate a Beam Dump Request to Beam Interlock System

(→ next slide)

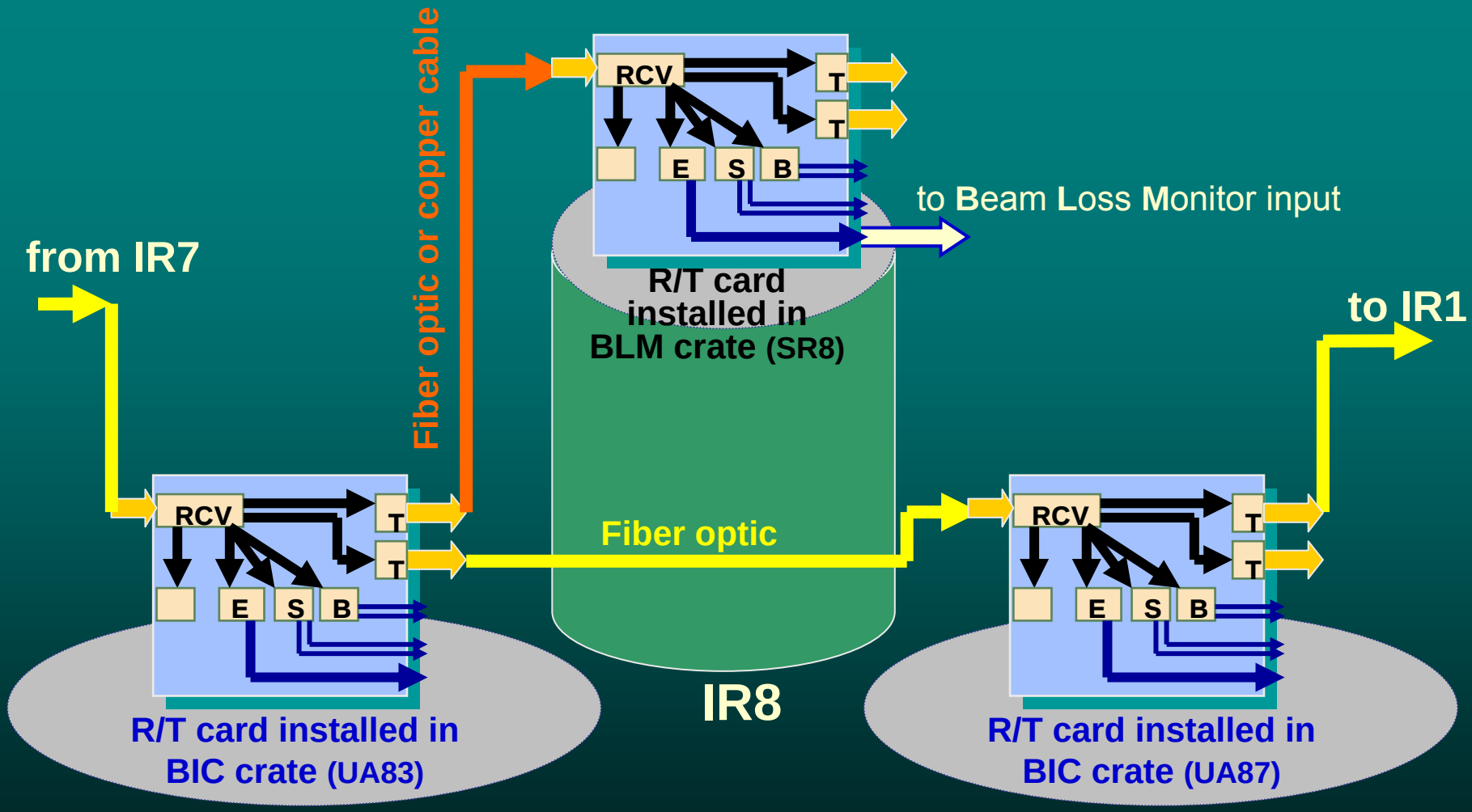
- Make a second transmitter output:
  - Give possibility for adding new Users
  - Mix Ring distribution (major clients) & Star distribution (see layout on following slide)

SLP Generator with verification of data



* SLP stands for
Safe LHC Parameters

Two Outputs for Ring and Star Distribution



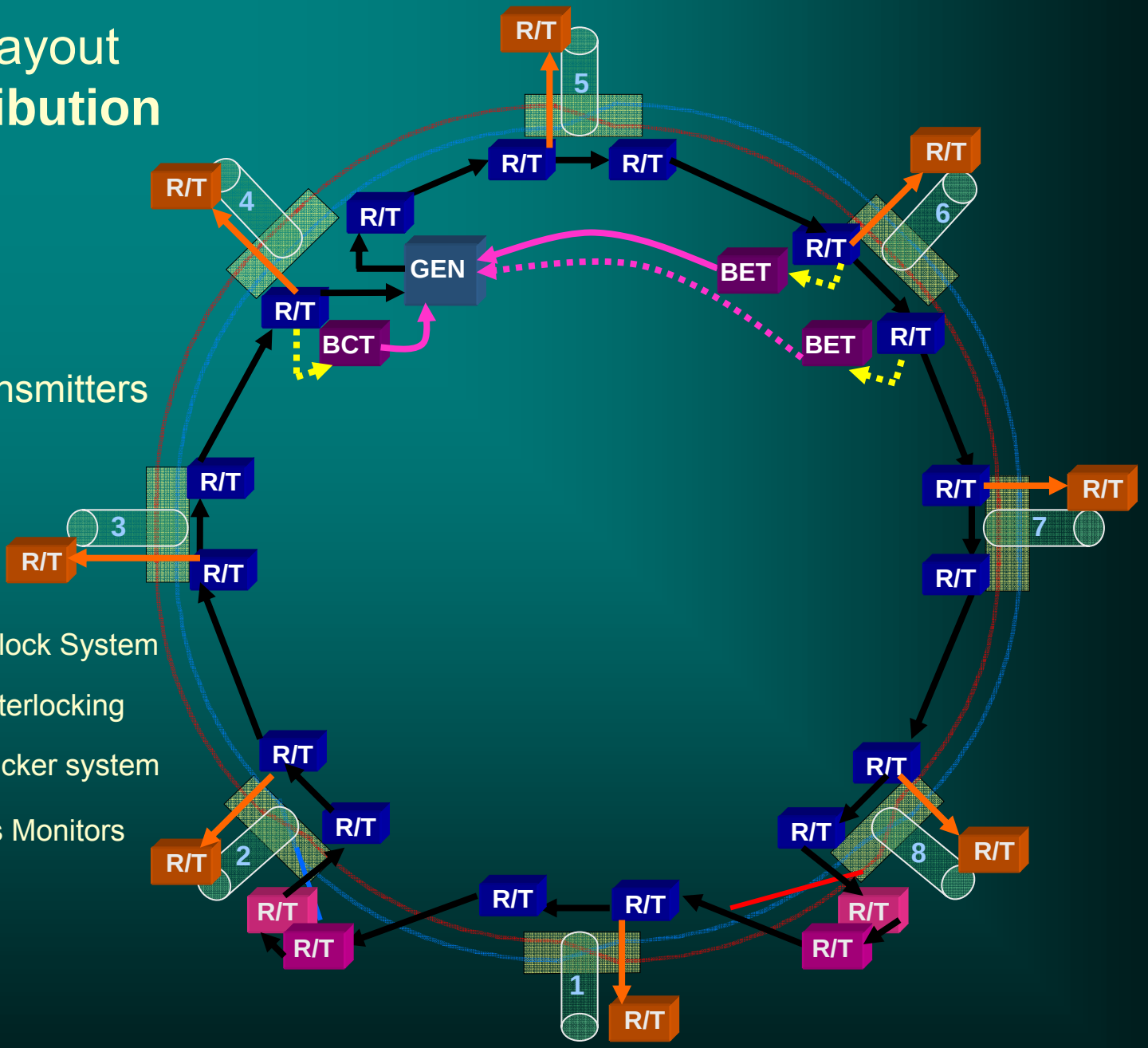
BIC: Beam Interlock Controller

Proposed layout for the **distribution**

1 Generator

+

28 **R**eceiver/**T**ransmitters



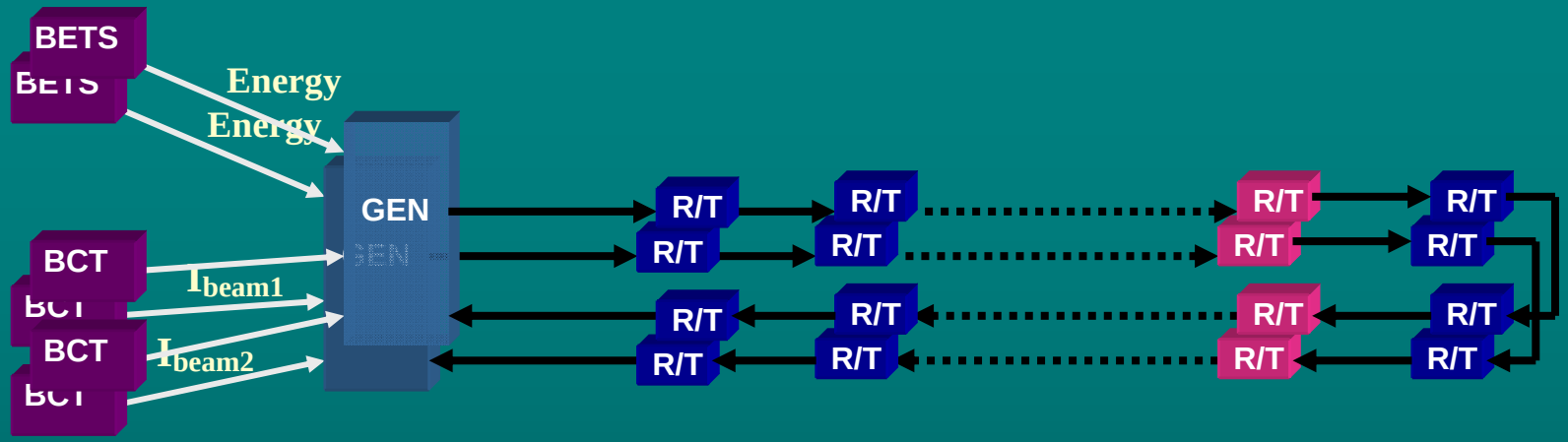
16 R/T for Beam Interlock System

2 R/T for Injection Interlocking

2 R/T for Injection Kicker system

8 R/T for Beam Loss Monitors

How to achieve the overall Safety & Reliability?



- To be protected against Generator faults:
  - Install a redundant unit?
    - With a different FPGA programmation?
  - Cross-checking with Sw application?
- To recover transmission errors:
  - Use 2 redundant Optical Fibers links to distribute the SLP messages?
  - Repeat 2 (or more) times the SLP messages?
  - Introduce a Cyclic Redundancy Check (CRC)?
- To guarantee that the client is reading a right value:
  - Duplicate the receptor channel?
  - Cross-checking with another source?

Summary of the proposals

- All parameters managed by one system using in serial messages
- Use improved solutions with speed of 512kb/s with 1 KHz rate
- Use Optical Fibers to transmit all around LHC areas
- 2 types of modules:
  - Unique generator to built and broadcast the messages
  - T/R *User Board* to get local outputs
- Chain all (main) R/T User boards in one loop
- Check at the end of the loop and Generate Beam Dump request if Error
- Process 100% made by Hw (but Sw Monitoring via Supervision)

Some conclusions…

- A new reliable system must be supplied for the Safe Beam Parameters
- Difficult to estimate its expected Safety Integrity Level: SIL3? or SIL2?
  - Different parameters, different constraints, Various Clients,…
  - Need further studies to examine the different failure scenarios
- First design is going to be launched using proven solutions.
  In the future, this design choice allows us to increase the number of parameter and/or the number of connected User. In addition, it permits a full redundancy (from the sources to the clients) if required.
- Safety Analysis have to be anyway performed
- Tests, tests and tests will be necessary for confirmed the first choices

And advices, support, and willingness are obviously welcome…

Thank you !

Acknowledgments to:

Rüdiger Schmidt, Philippe Nouchi, Javier Serrano, Benjamin Todd and Jorg Wenninger.

Milestones

- Phase 1: Q4/2004
  - Meetings with suppliers (BCT system and BEM system)
  - Meetings with clients (Kickers, BLM, Timing,…)
  - Hw designs set-up and Reliability Studies
  - Sw requirements set-up
- Phase 2: Q2/2005
  - Produce Hw units: Generator module + R/T cards
  - Complete Engineering Specification
  - Finalize requirements for Sw Monitoring
- Phase 3: July → Dec.05
  - Lab Tests, Endurance Tests, Users tests
  - Finalize Reliability Studies
  - Upgrade Hw and Sw
- Phase 4 :
  - Pre-series of R/T cards
  - Installation in ~April 2006 for the next SPS startup
  - …
  - Installation later on in LHC (2007)

Safe Beam Flag threshold

- Estimated damage level for fast losses
  - at 450GeV $\Rightarrow$ ~ $2 \cdot 10^{12}$ protons
  - at 7 TeV $\Rightarrow$ ~ $1 \cdot 10^{10}$ protons