Beam interlocks the CERN high energy accelerators

Overview

Rüdiger Schmidt /
Jörg Wenninger

Review on Controls

September 2005

Risks when operating with beam

Interlock systems

- LHC Beam Interlocks
- SPS Beam Interlocks
- From SPS to CNGS/LHC Interlocks
- Injection Interlocks

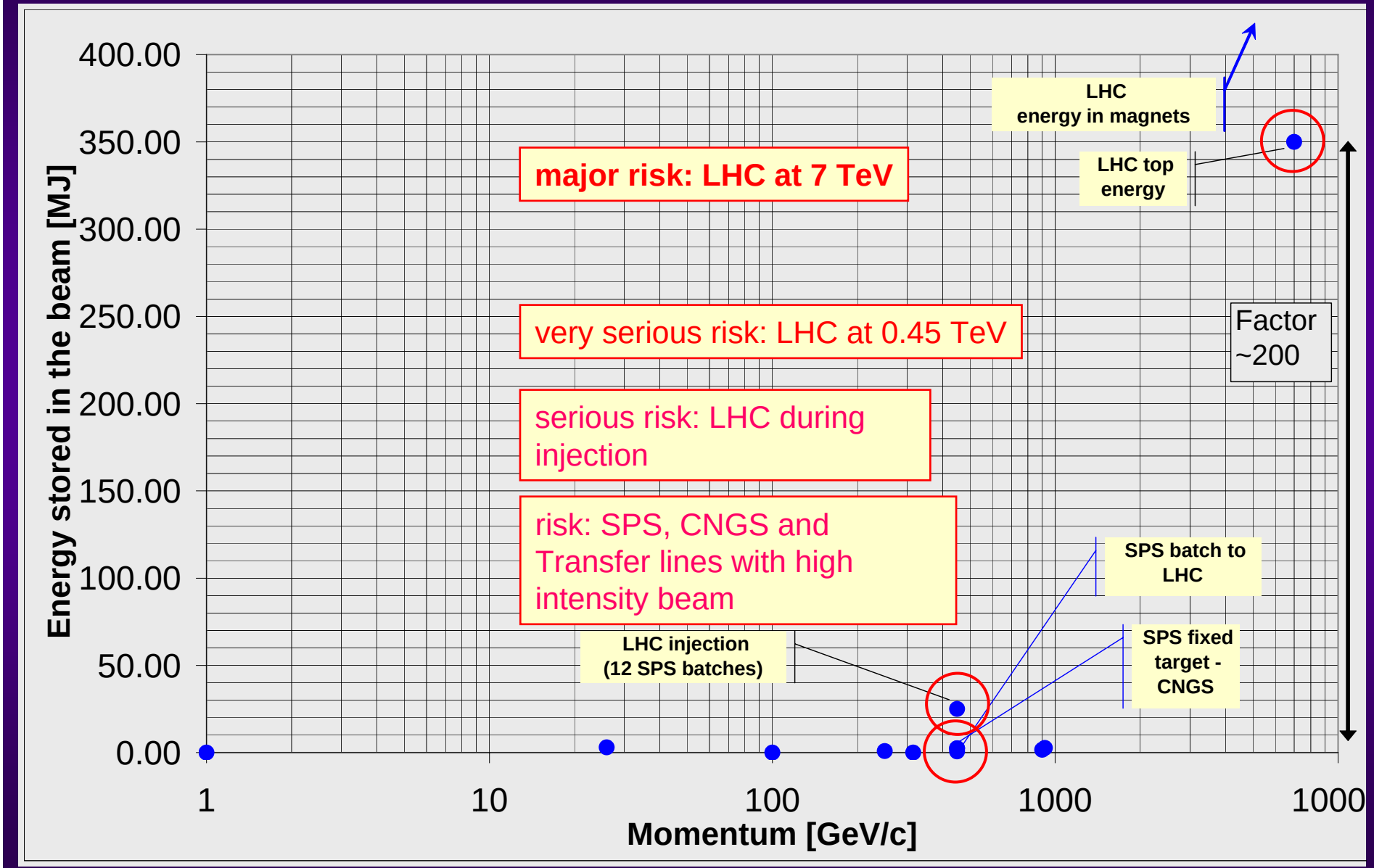
Safe LHC Parameters

Conclusions

Specifications and other material

- B.Puccio et al., THE BEAM INTERLOCK SYSTEM FOR THE LHC, Functional Specification LHC-CIB-ES-0001, *EDMS No: 567256*
- B.Goddard et al., INTERLOCKING between SPS, CNGS, LHC TRANSFER LINES AND LHC INJECTION, LHC-CI-ES-0002 ver.1.0, *EDMS Document No.*602470
- D.Macina, J.Wenninger, LHC EXPERIMENTS BEAM INTERLOCKING, Functional Specification, in preparation
- R.Schmidt, SAFE LHC PARAMETERS GENERATION AND TRANSMISSION (SLPT), Functional Specification, in preparation
- J.Wenninger and R.Schmidt, LHC Injection Scenarios, CERN-LHC-PROJECT-NOTE-287, Geneva, CERN, March 2002
- MPWG minutes and LEADE minutes
- InjWG minutes
- Other papers

Livingston type plot: Energy stored in the beam



LHC circulating beam: detect unsafe situation and dump beam via Beam Interlocks and Beam Dump System

Failure is detected and beam dump requests is issued by hardware and beam monitoring (distributed around LHC)

- Hardware surveillance (for many systems)
- Quench or powering failure detected by Quench Protection System / PC / PIC
- Fast magnet current change monitors
- Beam loss monitors in arcs and at collimators and other aperture limitations
- Beam position (change) monitors
- Fast beam current decay ("lifetime") monitors

Beam Interlock System transmits the request to the Beam Dumping System

Time from detection of unsafe situation to start of damage might be very short (some turns)

- Beam must be extracted as soon as possible (~μs response time)
- When a system requests a beam dump, this request must be granted
- 100% safety does not exist: not more than one dangerous failure (for one user request) in 1000 and 10000 years is acceptable (SIL3)

Other requirements to the Beam Interlock System

- Post mortem recoding
  - all requests should be time-stamped with μs accuracy
- It must be possible to test the system and prove that it is working correctly
- Easy interface to user systems providing beam dump requests
- Relaxing conditions when operating with beam below damage threshold
- Inform users that beam might be in the machine (as example, important for vacuum system)
- Commissioning of the system must be (reasonably) fast

SPS circulating beam: detect unsafe situation and dump beam via Beam Interlocks and Beam Dump System

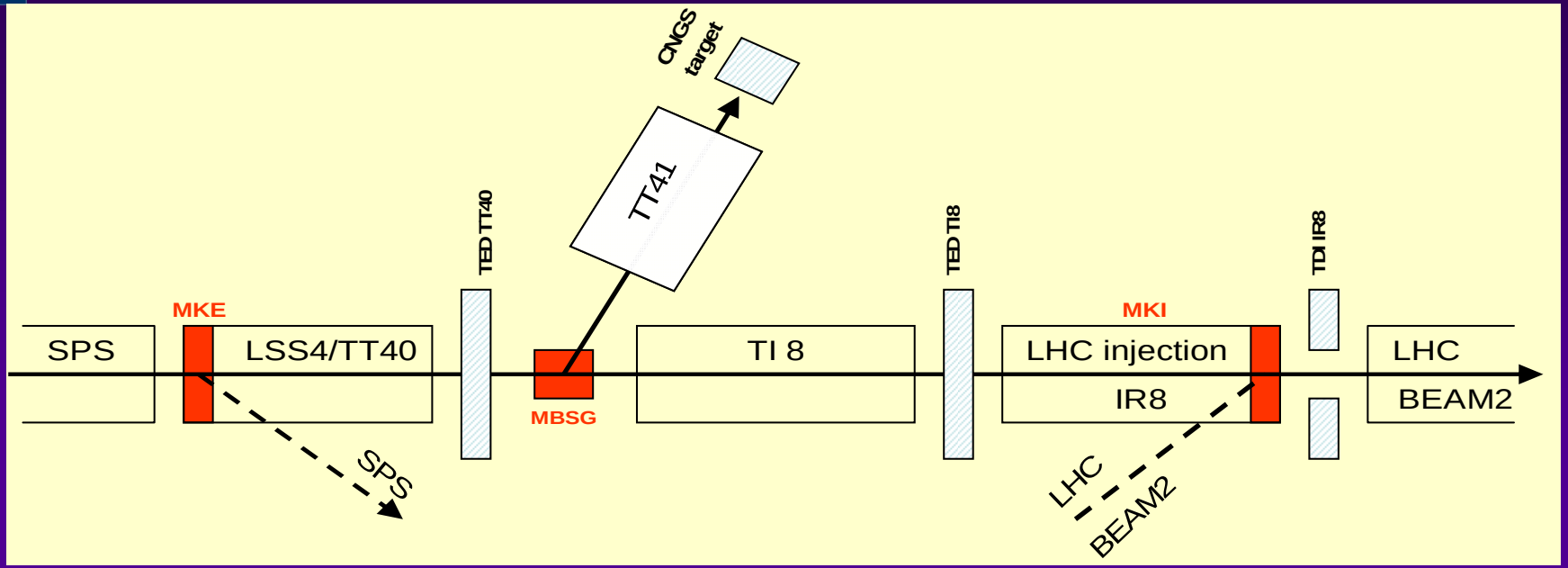
Beam dump requests from hardware and beam monitoring distributed around the SPS

- Old system needs to be replaced in the coming years
- Less risk compared to LHC, still equipment can be damaged
- Should be easy and cheap to extend system to new users
- If possible, system should have a similar touch and feel as LHC

Requirements are identical to those for LHC

- Somewhat less critical

Beam transfer from SPS via TI8 to CNGS / LHC



- safe extraction of high intensity beam to stopper TED TT40
- safe extraction of high intensity beam to CNGS target
- safe extraction of high intensity beam to stopper TED IR8
- safe extraction and transfer of high intensity beam to LHC, followed by safe injection into LHC – up to circulating beam
- do the same with low intensity beam without being bugged by interlocks – but still safe
- do the same for TI2 (without CNGS)
- short extraction permit window to be provided

Beam transfer: failures leading to beam loss

- Kicker failures – at extraction from SPS and at injection into LHC
- Magnetic elements having wrong settings (SPS, transfer lines and LHC)
  - some magnets have very short time constants
  - surveillance by ROCS system (some ms) and Fast Magnet Current change Monitor (less than one ms)
- Object in beam pipe (e.g. vacuum valve, screen, collimator, experiment in LHC, …)
- wrong energy in SPS or in LHC
- wrong orbit in SPS during extraction
  - monitoring of orbit position at extraction

Monitoring in SPS, transfer lines, CNGS and LHC:
Only if all parameters are correct, extraction is permitted

Strategy for protection if potentially dangerous actions are planned : Example for transfer and LHC injection

1) Automatic sequencing of actions by software
   - check if all elements are in the correct state
   - allow for injection **only if all OK**

Software layer / sequencer

2) Avoid dangerous situations by applying procedures
   - inject into empty LHC only with low intensity beam
   - only if some beam is circulating, inject high intensity beam

Procedures / Interlocks

3) Hardware surveillance – **only if OK**, do transfer
   - surveillance of equipment to detect last moment change of relevant parameters (e.g. power converter trip just before injection or extraction from SPS)

Interlocks

4) Protect in case of failure
   - beam absorbers for single turn failures

Positioning of collimators

similar for starting the ramp, starting beta squeeze, beam dump at end of fill

Safe LHC Parameter Generation and Distribution

For safe operation of the LHC, several machine parameters must be generated and distributed around LHC and to SPS with high reliability.

Beam loss monitors and injection kickers require beam energy (Bρ). The "**LHC ENERGY**" is derived by a reliable system installed in IR6 (BT).

With beam below damage threshold, not all protection devices are required. If yes, "**SAFE BEAM FLAG**" is set to TRUE (derived from the "LHC ENERGY" and from the beam intensity).

Several **OPERATION MODES** are Filling, Ramping, Adjust, and Stable Beam for Physics. The system will distribute the modes that are required for safety critical systems.

Injection of high intensity beam is only permitted with already circulating beam in LHC. The presence of circulating beam is detected (by a BCT) and the "**BEAM PRESENCE FLAG**" is set to TRUE.

The system should allow the transmission of a few other parameters, if required.

Safe LHC Parameter Generation and Distribution

Name	Format	Rate	Derived from (producer name)	Distributed to	Safety level
LHC ENERGY	2 bytes	1Hz	Current in main dipoles (BEM)	Beam Loss Monitors	SIL2
				Injection Kickers	SIL2
SAFE BEAM FLAGS	2 bits (SBF_1& SBF_2)	1Hz	LHC ENERGY (SLPG) and Beam Intensities (BCT)	LHC Beam Interlock System	SIL2
				SPS Extraction Interlock	SIL1
				Aperture Kickers	SIL2
BEAM PRESENCE FLAGS	2 bits (BPF_1 & BPF_2)	1kHz	Beam Intensities (BCT)	SPS Extraction Interlock	SIL1
LHC BEAM MODES	1 byte	1Hz	Automatic (?) process with Operators input	Experiments	SIL2
				Injection Kickers	??
				Beam Dilutors (at injection)	??

SIL Levels: SIL4 => highest safety level, SIL1 => moderate safety level

LHC Injection Interlock

The LHC experiments request an input to the LHC injection interlock controller (part of SPS-CNGS-Tline system) to prevent injection of beam

Colleagues from BT…. as discussed in the MPWG…

- require such input to inhibit injection while arming the Beam Dumping System
- would use such system to inhibit injection when the aperture kicker is switched on, to prevent injection during the use of this kicker

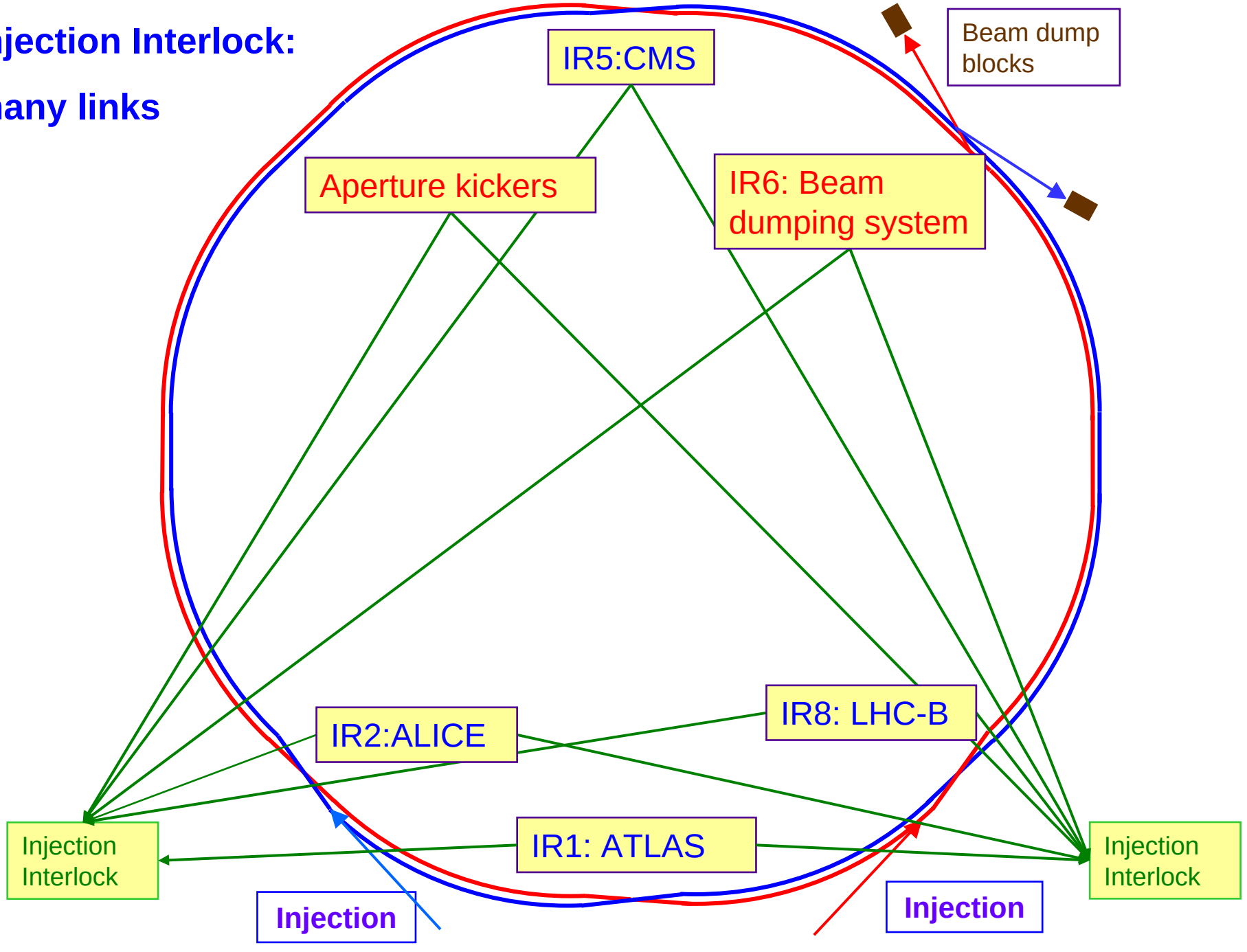
One way would be to install an "injection interlock loop" around the LHC that several systems could use to prevent injection

There might be other ways to provide such functionality, but an injection interlock loop would be the most clean method

This is a new request that was worked out by LEADE (LHC Experiment-Accelerator Data Exchange WG) with MPWG

Injection Interlock:

many links



Classification of machine protection safety systems

Priority 1: avoid uncontrolled beam loss in LHC at 7 TeV

- catastophic accident could stop LHC for (very) long time (~years)

Priority 2: avoid uncontrolled beam loss in LHC beam at 450 GeV

- major accident could stop LHC for long time (~months - year)

Priority 3: avoid uncontrolled injected beam in LHC beam at 450 GeV

- major accident could stop LHC for some time (~months)

Priority 4: avoid uncontrolled beam loss in SPS or transfer line

- severe accident could stop accelerators for some time (~weeks)

Priority 5: avoid quenching LHC magnets

- minor accident could stop accelerators for some time (~hours)

Classification of machine protection safety systems

Priority 1: avoid uncontrolled beam loss in LHC at 7 TeV

- catastophic accident could stop LHC for (very) long time (~years)
- LHC Beam interlock system (and LHC Safe Parameter Distribution)

Priority 2: avoid uncontrolled beam loss in LHC beam at 450 GeV

- major accident could stop LHC for long time (~months - year)
- LHC Beam interlock system (and LHC Safe Parameter Distribution)

Priority 3: avoid uncontrolled injected beam in LHC beam at 450 GeV

- major accident could stop LHC for some time (~months)
- Transfer Line Beam interlock system and LHC Safe Parameter Distribution

Priority 4: avoid uncontrolled beam loss in SPS or transfer line

- severe accident could stop accelerators for some time (~weeks)
- Transfer Line Beam interlock system

Priority 5: avoid quenching LHC magnets

- minor accident could stop accelerators for some time (~hours)
- LHC Beam interlock system

Overview interlock systems and their criticality

	LHC Beam Interlock System	LHC Injection Interlock Loop	SPS-CNGS-LHC Beam Interlock System	Safe LHC Parameter Distribution	SPS Beam Interlock System
System type	BIC	BIC / other ???	BIC	Timing ?	BIC
Criticality	Very high	High	High	High	Moderate
Required for avoiding damage	2007	2007 / 2008	2006	2007	2007 - later
Desired installation	end 2006	2007	2006	2007	2006
Response time	µs	~sec	µs	~sec / ~ms	µs

Conclusions

Beam Interlock LHC: confident – first generation prototypes have been used in SPS, and next generation pre-series just before completion

Beam Interlock Transfer lines: same technology, some issues to be clarified

Beam Interlock SPS: identical to LHC, would be EXTREMELY VALUABLE as validation of one complete “LHC type” interlock system

Safe LHC Parameters: less advanced – but some new ideas

LHC Injection Interlock (Loop): new system, not budgeted in investment and manpower. Will be discussed in MPWG

MPWG future topics: Injection Interlock and new ideas for SLPT

Acknowledgements

Contributions of **many colleagues** are acknowledged, in particular for the discussions in……

- Machine Protection WG
- Collimation WG
- Injection WG
- LEADE