

What we will do for beam preparation in 2009

# Beam Interlocks (= 'Beam related' MPS)

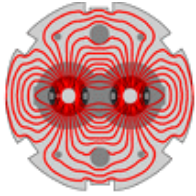
**J. Wenninger BE-OP**

*Acknowledgements :*

*B. Puccio, B. Todd, M. Zerlauth, R. Schmidt, B. Dehning, A. MacPherson, V. Kain, S. Redaelli.  
R. Assmann, B. Goddard, J. Uythoven and many other members of the MPP.*

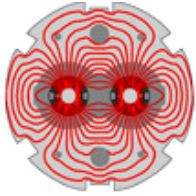
Some related aspects are covered in :

- Powering Interlocks (M. Zerlauth)
- Injection and LBDS (J. Uythoven)



# Outline

- Beam Interlock System
- Soft matters
- Commissioning strategy
- Conclusion



# LHC MPS



The LHC Machine Protection System is:

## *Complicated*

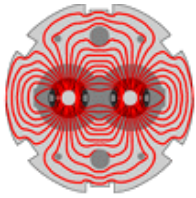
- Many elements.

## *Complex*

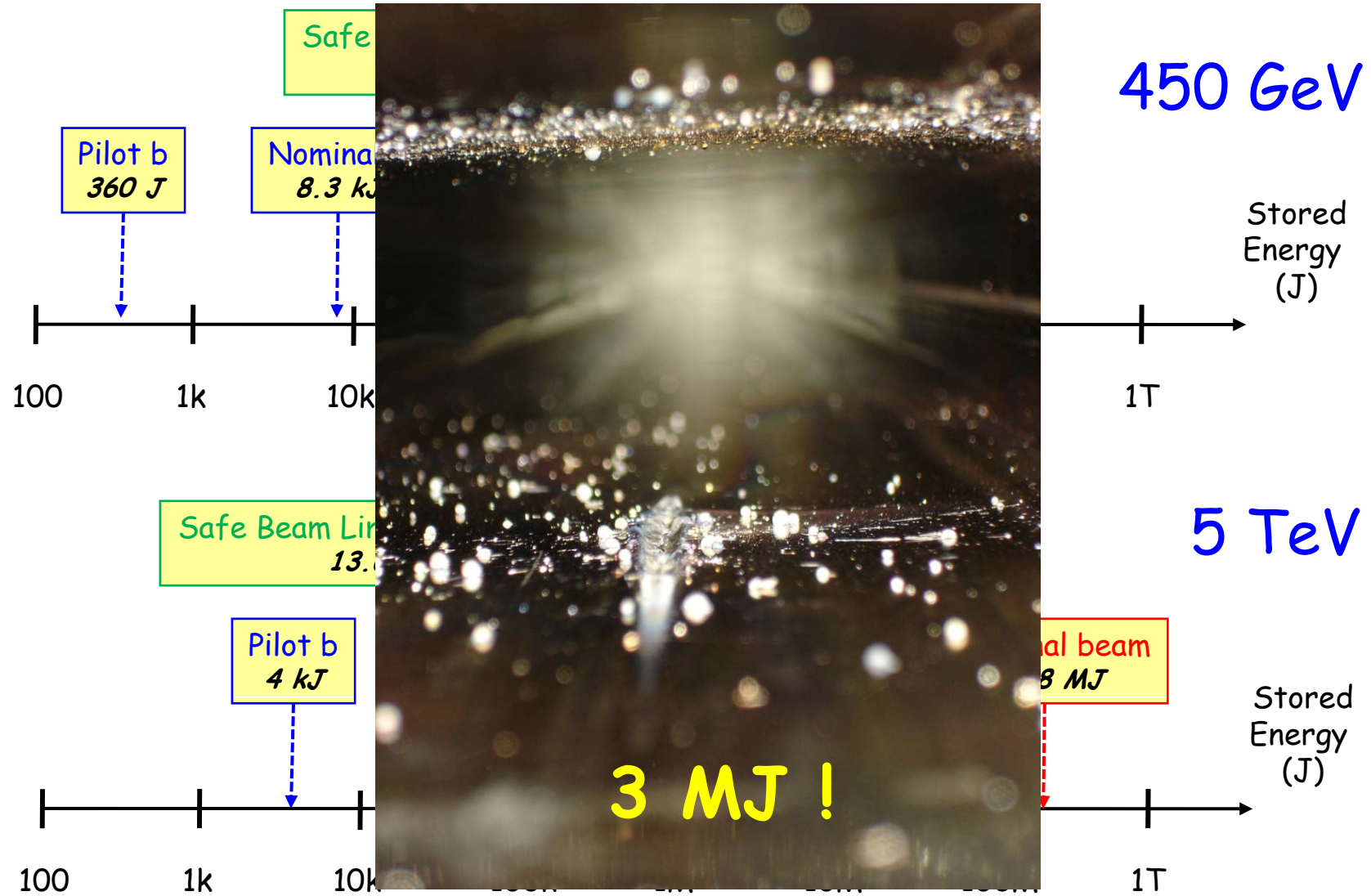
- Interaction of the elements in space and time.
- Large phase-space for failures.

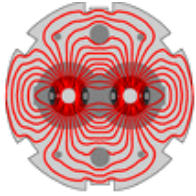
But the MPS can be broken up into testable components...

...and the outcome of the tests allow us to quantify or predict its performance with respect to failures.



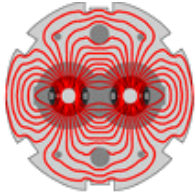
# Energy Scales



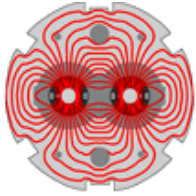


# Stored Energies

Scheme	$K_b$	Nb (charges)	Stored E inj	Stored E 5 TeV	Stored E 7 TeV
Proton	1	1	72 nJ	0.8 $\mu$ J	1.12 $\mu$ J
Pilot bunch	1	$5 \times 10^9$	360 J	4 kJ	5.6 kJ
Nominal bunch	1	$1.15 \times 10^{11}$	8.3 kJ	92 kJ	129 kJ
Inj. Safe Beam	1	$1 \times 10^{12}$	72 kJ	800 kJ	1.12 MJ
5 TeV Safe Beam	1	$1.7 \times 10^{10}$	1.2 kJ	13.6 kJ	19 kJ
7 TeV Safe Beam	1	$1 \times 10^{10}$	720 J	8 kJ	11.2 kJ
Early physics	156	$4 \times 10^{10}$	449 kJ	5 MJ	7 MJ
Nominal beam	2808	$1.15 \times 10^{11}$	23.3 MJ	258 MJ	362 MJ
Ion bunch	1	$5.7 \times 10^9$	410 J	4.6 kJ	6.4 kJ
Early ion	62	$5.7 \times 10^9$	25 kJ	279 kJ	390 kJ
Nominal ion	592	$5.7 \times 10^9$	245 kJ	2.72 MJ	3.81 MJ



# Beam Interlock Systems



# SPS & LHC MPS



## □ SPS + Transfer lines:

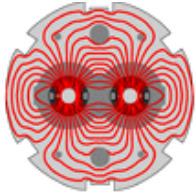
- *1 ring beam permit loop.*
- *2 extraction systems.*
- *16 BIC modules, 2 special 'extraction master' BICs.*
- *≈ 1000 devices/interlocks connected to the BICs, 50% in the high energy TLs.*
- *≈ 1000 SIS interlocks.*

'The guinea pig'

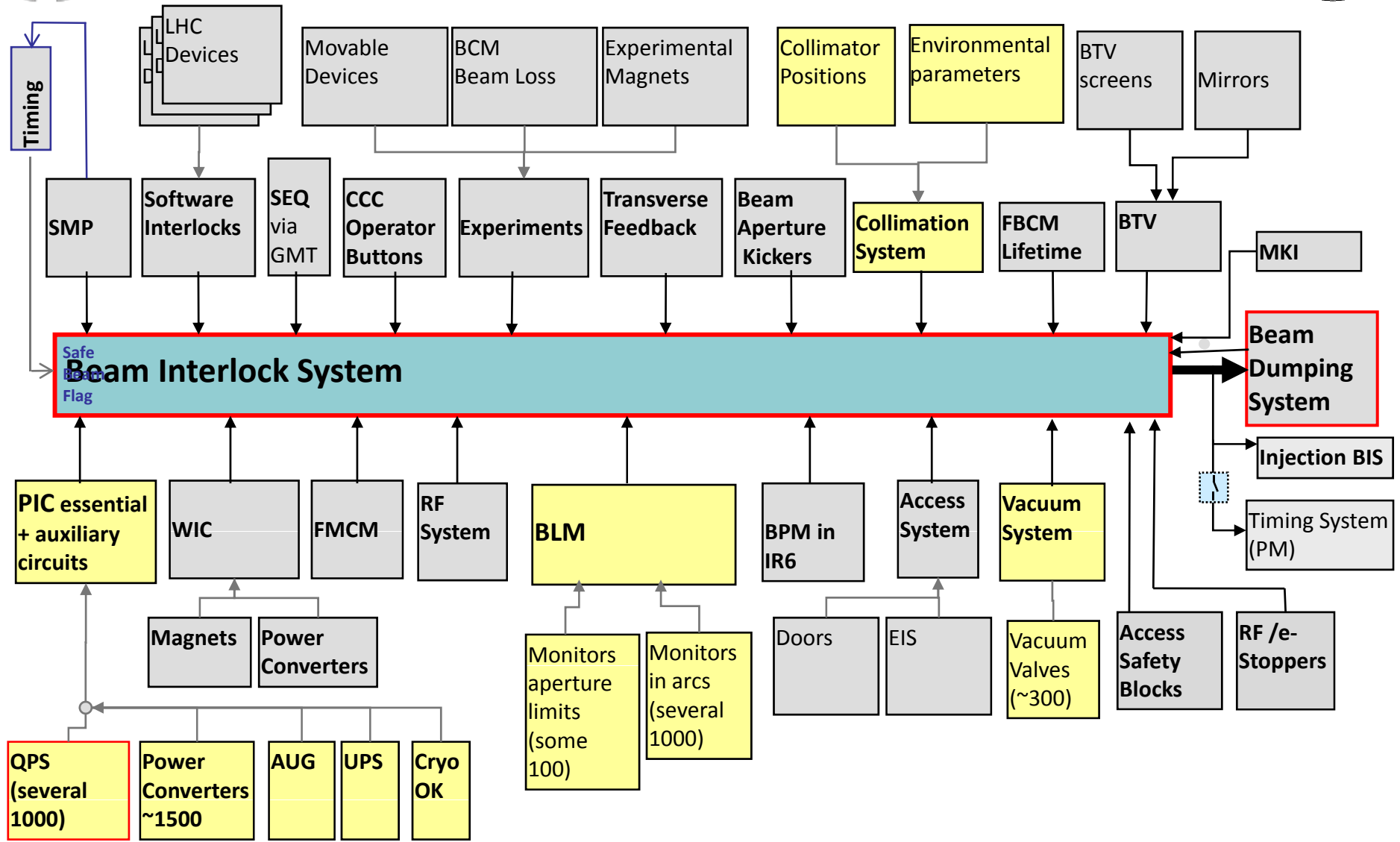
## □ LHC

- *2 ring beam permit loops.*
- *2 injection systems.*
- *21 BIC modules.*
- *≈ 8000 devices/interlocks connected to the BICs.*
- *≈ 3800 SIS interlocks.*

No doubt - a large system !



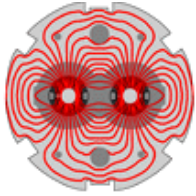
# BIS overview



05.02.2009

Preparation for Beam Interlocks  
Chamonix 09





# BIS changes & tests



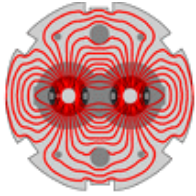
## Changes:

- ❑ New monitoring firmware for BICs.
- ❑ New firmware in CIBG to ease arming sequence and provide diagnostics.
- ❑ Modifications in some optical components.
- ❑ Automated pre- and post-operation checks (IPOC).
- ❑ Automated tests (PIC ok, WIC, BLMs, BTVs ... on going).
- ❑ CIBU user connections:

*all LHC clients will be forced to provide redundant signals → [next slide](#).*

## Tests:

- ❑ All components (BICs, loops etc) will basically be re-commissioned.
- ❑ Aim to retest **ALL CIBU connections**.



# BIS client connections



Several events have led to a complete Blind Failure of a BIS input in 2008

## Event

## Change 2009

1. Two different Equipment systems sharing to the same channel
2. PLC Voltage against rules
3. Transient Voltage Suppressor blocked Short-Circuit
4. Inputs were not redundant
5. Not re-commissioned after change



*No longer tolerated.*



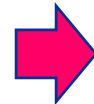
No additional protection possible with existing design... Test, test, test.



*Slight change of the interface (on User system side) for each connection.*



Redundant signals should be supplied. It will become mandatory in 2009.

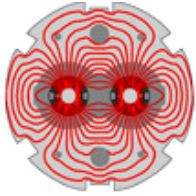


*Tests, tests and tests...*

*Regular tests before every fill will be the best option :*

*=> implementation of **Automatic tests***

B. Puccio, MPP 5<sup>th</sup> Dec. 2008



# Safe Machine Parameter (SMP) systems

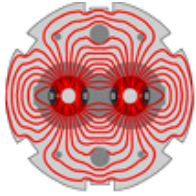


## 2008 Experience:

- ❑ Very good experience on SPS – operational system.
- ❑ LHC never really got going...

## Changes for 2009:

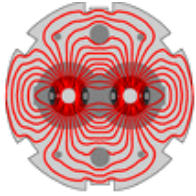
- ❑ No changes for the SPS.
- ❑ LHC:
  - New version (not the last one !).
  - Improvements in the handling of tables for SBF...
  - Signal cross-check and interlocking must be implemented.
  - Ions : adapt 'Safe/Setup Beam Flag' limits – to be analyzed.
  - ...



# Changes to SPS and transfer lines BIS inputs



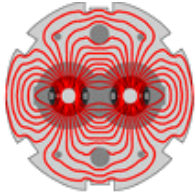
- New [turn-by-turn beam position interlock](#) in the vertical plane.
  - *Horizontal plane protected by existing (old) system.*
  - *Presently only BLMs protect against fast loss/orbit change in V plane.*
- [Beam quality interlocks](#) before extraction.
  - *RF system : bunch pattern, position, bunch length, bunch intensity spread.*
  - *Fast BCT : bunch intensities.*
- Test of a new [beam 'position before extraction' interlock](#).
  - *New system to replace existing system based on the SPS orbit system.*
  - *Much faster and higher availability (present system ~ 2-3% un-availability).*
- Some 'input reshuffling' between TI2/TI8 and LHC Injection BICs.



# Changes to LHC BIS inputs

## 3 new inputs:

- ❑ Access Safety block : independent input (was coupled to Vac.)
- ❑ Electron stoppers : independent input (was coupled to Vac.)
- ❑ Fast beam lifetime interlock : will be connected.



# Software Interlock System changes



- Minor changes to the SIS software itself.

*SIS core process has multiple dependency on CO software products (FESA, JAPC, etc) - must follow trend...*

- For the LHC new tests will be added:

- *Powering interlocking with access zone – tbc.*
- *Orbit and COD current surveillance.*
- *IR6 beam position wrt TCDQ and secondary collimators.*
- *...*

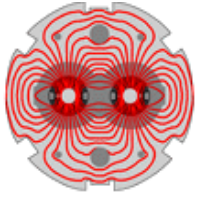
- Core of the interlocks on PC states (~ 3600 tests) will not be touched to avoid necessity of complete re-commissioning.

The role of SIS will become more and more important since it is the only system to implement interlocks that perform 'LHC wide correlations'.

*See yesterday's talk by B. Goddard – multiple failures.*

*No limit to interlock complexity – but watch the availability !*

*Response time limit ~ 1 second.*



# Soft matters

CERN  
CH-1211 Geneva 23  
Switzerland



the  
Large  
Hadron  
Collider  
project

LHC Project Document No.

LHC-OP-MPS-0003.v2

CERN Div./Group or Supplier/Contractor Document No.

AB/XX/XX

EDMS Document No.

889343

Date: 2007-02-16

## MPS Commissioning Procedure

### THE COMMISSIONING OF THE LHC MACHINE PROTECTION SYSTEM

### MPS ASPECTS OF THE INJECTION PROTECTION SYSTEM COMMISSIONING

#### *Abstract*

This document describes the set of tests which will be carried out to validate for operation the machine protection aspects of the **LHC Injection Protection system**. The area concerned by these tests extends over the LHC injection regions (including SPS extraction to some extent) for each of the two LHC beams.

These tests include the Hardware Commissioning, the machine check-out and the tests with beam.

# Commissioning procedures

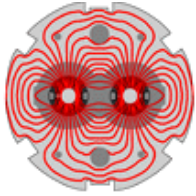


- ❑ Most procedures have been reviewed based on 2008 experience.
- ❑ Procedures should be released by April 2009 !

### Procedures:

- Powering interlock system *approval closed*
- Fast magnet current change monitors *approval closed*
- Warm magnet interlock system *under approval*
- Beam interlock system *released*
- Collimators *work in progress*
- Beam loss monitors *under approval*
- Injection *approval closed*
- Beam dumping system *work in progress*
- Vacuum system *work in progress*





# Documentation

To find a good documentation schema for the diversity of test that have to be performed for each system involved in MPS has been a moving target...

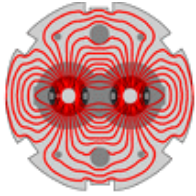
*Results range from simple YES/NO to extensive analysis for beam related tests.*

- In 2008 documentation was based on a WEB page and EXCEL sheets.

*Difficult to maintain for such a complex system.*

- As from 2009 we are starting a more rigorous approach:

*MTF/EDMS 'tuned' for MPS – work in progress.*



# Issue tracking



- ❑ In 2008 the AB-CO software issue tracking tool was used for tracking MPS issues. Apart from some software development specific 'overhead' it works fine.  
>> Propose to continue with this tool.

AB-CO Issue Tracking Tool Interface

Navigation: HOME | BROWSE PROJECT | FIND ISSUES | CREATE NEW ISSUE | PLANNING BOARD | TASK BOARD | QUICK SEARCH: [ ]

Project: MACHINE-PROTECTION-SYSTEMS (Key: MPP)

Filter: View | Edit | New | Manage

You are currently using a new, unsaved search.

Summary

- Project: MACHINE-PROTECTION-SYSTEMS
- Components: LHC-BIS
- Resolutions: Unresolved
- Sorted by: Priority descending

Operations

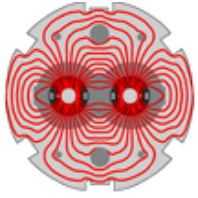
- Save

### Issue Navigator

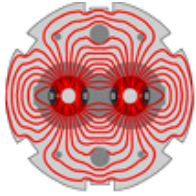
Displaying issues 1 to 11 of 11 matching issues. [ Permlink ]

Current View: Browser ( Current Fields | Printable | Full Content ) | XML | RSS ( Issues | Comments ) | Word | Excel ( All fields | Current fields ) ?

Key	Summary	Assignee	Status	Created	Updated	Pr	Importance	T	Due
<a href="#">MPP-12</a>	Activation of TOTEM_DET input to BIS for CMS	<a href="#">Bruno Puccio</a>	Open	16/Sep/08	16/Sep/08	↑	10	[ ]	
<a href="#">MPP-20</a>	SMP Safe Beam Flag forced to TRUE	<a href="#">Bruno Puccio</a>	Open	17/Sep/08	17/Sep/08	↑	10	[ ]	24/Sep/08
<a href="#">MPP-21</a>	SMP SAFE-STABLE-BEAMS and MOVABLE-DEVICES flags not operational	<a href="#">Bruno Puccio</a>	Open	17/Sep/08	17/Sep/08	↑	10	[ ]	
<a href="#">MPP-24</a>	BIC Monitor Boards (CIBM) upgrade to 4v0 (firmware)	<a href="#">Benjamin Todd</a>	Open	10/Oct/08	10/Oct/08	↑	9	[ ]	
<a href="#">MPP-23</a>	Generator Boards (CIBG) upgrade to 1v0 (firmware)	<a href="#">Benjamin Todd</a>	Open	10/Oct/08	10/Oct/08	↑	9	[ ]	19/Dec/08
<a href="#">MPP-17</a>	FMCM in IR2 input to BIS disabled (B1 and B2)	<a href="#">Bruno Puccio</a>	Open	16/Sep/08	16/Sep/08	↓	4	[ ]	
<a href="#">MPP-16</a>	BCT-lifetime inputs to BIS (IR4) DISABLED	<a href="#">Bruno Puccio</a>	Open	16/Sep/08	16/Sep/08	↓	1	[ ]	
<a href="#">MPP-13</a>	ATLAS MOVABLE_DET input to BIS DISABLED	<a href="#">Bruno Puccio</a>	Open	16/Sep/08	16/Sep/08	↕	1	[ ]	
<a href="#">MPP-15</a>	TOTEM inputs to INJECTION BICs DISABLED	<a href="#">Bruno Puccio</a>	Open	16/Sep/08	16/Sep/08	↕	1	[ ]	
<a href="#">MPP-14</a>	TOTEM MOVABLE_DET input to BIS DISABLED	<a href="#">Bruno Puccio</a>	Open	16/Sep/08	16/Sep/08	↕	1	[ ]	
<a href="#">MPP-19</a>	LHCf input LHCf_DET to BIS DISABLED	<a href="#">Bruno Puccio</a>	Open	16/Sep/08	16/Sep/08	↕	4	[ ]	



# Commissioning strategy

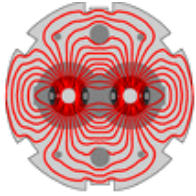


# General commissioning strategy



## Test everything again!

- ❑ Repetition (with improvements) of 2008 work.  
*Signification number of changes (HW, SW)*
- ❑ Complete what was NOT done.



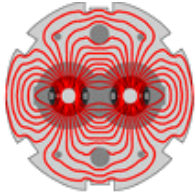
# Automate, automate, automate...



Guideline: *systematic testing - not sample testing !*

- A few systems concentrate a large amount of devices.
  - *PIC, BLMs, Vacuum, Collimators...*
  - *They are tedious and lengthy to test.*
  - *Automation to avoid mistakes due to repetitive work.*
- Automated testing:
  - *Transfer line PCs and BTVs already operational.*
  - *PIC already in place in 2008 – consolidated for 2009.*
  - *Collimator tests largely automated in 2008, improvements in the pipeline.*
  - *Tests of BLMs (pre-fill).*
  - *Vacuum : preparations ongoing.*
  - *...*

>> Requires carefully testing of the SW !



# Reliability (dry) runs



Reliability runs were made for

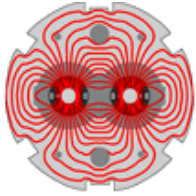
- the LBDS,
  - the beam permit loops.
- >> Important & successful !

>> For 2009 we should aim for a BLM reliability run ~ July/Aug !

*Conditions to be specified... beam energy distribution !*

*Essential since a large no. of BLMs of 4 sectors will to be  
dismounted / reinstalled.*

*BLM monoitor tests with radioactive source will be repeated.*



# Post-mortem



This year we need a rather complete (BIS + powering + essential BI) post-mortem to analyze:

- the MPS tests,
- the programmed dumps,

*Even a perfect dump provides information on abort gap population, TCDQ and TCT settings and protection.*

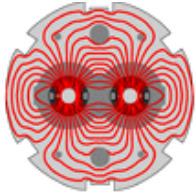
- the 'natural' failures that will occur.

*They provide invaluable info on MPS performance and complete the information obtained from tests.*

>> We need people to look at this data !!

>> We must analyze the MPS performance for ALL events due to failures.

***Build an 'event' database.***



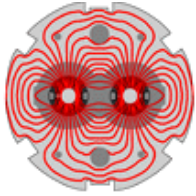
## MPS test with 'entire' LHC



- ❑ Some MPS components can only be tested when the **Beam Energy Tracking System (BETS)** of the LDBS is working.
- ❑ Requires dedicated periods where *eventually* at least  $\frac{1}{2}$  of the LHC must be available (also ramps !) – sectors 45,56,67 and 78.
- ❑ Systems:
  - BETS – internal interlock tests.
  - LBDS dry dumps.
  - SMP : Safe Energy.
  - BLM thresholds with energy.
  - Full chain interlock tests (source → dump) on a selection of inputs.

>> we must avoid to push that to the 'last minute' !





# Towards beam operation



In an *IDEAL WORLD* we would perform all MPS test as soon as possible, and then go on with (beam) commissioning.

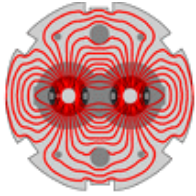
But:

*Some critical tests require beam...*

*There is a margin for beam operation without fully tested MPS.*

*There is a pressure to go ahead (cannot ignore !!).*

*>> Strategy to provide LIMITED flexibility for safely interleaving beam and MPS commissioning!*

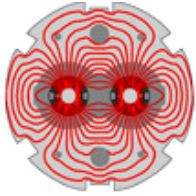


# Beam commissioning stages - principle



## Guidelines for when to perform MPS tests:

- Follow the definition of 'Safe/Setup Beam' :  $I \leq 10^{12} * (450/E)^{1.7}$
- Take into account uncertainties on 'what is safe'.
  - Uncertainties arising from  $E \gg 450$  GeV.
  - Shock damage, plastic deformation. Note that the **87 J/cm<sup>3</sup> limit** is derived from plastic limit of Cu – consistent with SBF definition.
- ALARA : even safe beams should not be lost in the machine too frequently.
  - Only allowed with 'very very safe' beams during the initial beam commissioning, e.g. with few  $10^9$  at 450 GeV.
    - >> see 2008.
- Anticipation:
  - Need time for test analysis (PM data).
  - Tests may ... fail !!



# Tests with beam

Beam tests are essential part of the MPS commissioning.

- BLMs and collimators are essential elements for failure protection.

*The BLMs cover the largest volume in failure phase-space.*

- Some failures must be provoked to verify assumptions on reaction times, loss patterns and BLM thresholds, and ensure that the machine can be protected at higher intensity/energy.

- The beam tests begin with low intensity  $\sim 10^{10}$  p at 450 GeV ( $< 1$ kJ).

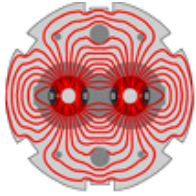
*Factor 100 below safe beam limit !*

- Beam tests are performed/repeated for higher intensity/energy as required.

*Only if lower intensity/energy tests are passed !*

- **One cannot rely on 'natural' occurrence of failures.**

*Or else their frequency would drive the LHC commissioning !*



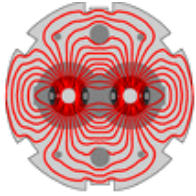
# MPS 'Rule of the Probe'

A probe beam ( $2-5 \times 10^9$  charges) must be used when

- ❑ New energy ranges are explored.
- ❑ New squeeze steps are explored.
- ❑ Significant changes are made that affect the aperture:
  - *Beta-beat/optics corrections.*
  - *Changes to the reference orbit.*

*Exact conditions to be defined*

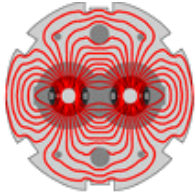
>> Actions to be performed in collaboration with MPS expert(s).



# MPS Commissioning Phases



Phase	Energy	Int.	Comments
MPS-1: Probing 450 GeV	0.45	$\leq 10^{10}$	<ul style="list-style-type: none"><li>• Early commissioning phase.</li><li>• Can run with 'minimal' interlocks – <b>'2008-style'</b>.</li><li>• 'Light' powering interlocking (maskable).</li><li>• Experiments protection must be ready !</li></ul>
MPS-2: Ramp	0.45 – 7	$\leq 10^{10}$	<ul style="list-style-type: none"><li>• All interlocks commissioned.</li><li>• Post-mortem recording operational.</li><li>• Beam related MPS tests passed at 450 GeV.</li><li>• Commission in steps of 0.5-1 TeV.</li></ul>
MPS-3: Increased intensity at 450 GeV (injection $\leq 10^{11}$ )	0.45 – 7	$\geq 10^{11}$	<ul style="list-style-type: none"><li>• All interlocks commissioned.</li><li>• Post-mortem recording operational.</li><li>• Beam related MPS tests passed at 450 GeV.</li></ul>
MPS-4: Squeeze			<ul style="list-style-type: none"><li>• All interlocks commissioned.</li><li>• Subset of beam tests must be <u>repeated</u> for every significant squeeze step.</li></ul>
MPS-5: Unsafe injection	0.45	$\geq 10^{11}$	<ul style="list-style-type: none"><li>• All beam related injection MPS tests passed.</li></ul>



# Conclusions

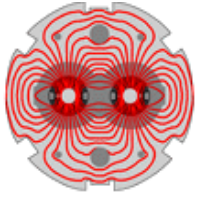


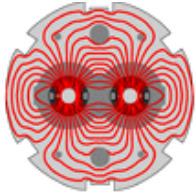
- ❑ The BIS will see 'minor' modifications – SPS is the usual guinea pig.
- ❑ General strategy is to (re)test everything.
- ❑ The MPS beam tests are essential.
- ❑ The Post-Mortem system will be essential to analyze MPS beam tests and 'natural' failures – BI data integration & analysis is top priority.
- ❑ Coexistence of beam and machine protection commissioning is possible with appropriate coordination (anticipation !).

*We profit from the natural commissioning evolution in steps of energy, complexity and intensity.*

- ❑ A core MPS team should 'review' the MPS performance at (to be defined) intensity/energy stages in the LHC commissioning.

*Can we safely continue to increase intensity/energy?*





# User Diversity



## LHC Beam Interlock System Connections

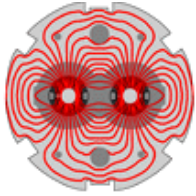
B.P.  
27th May 08

User Systems	LHC ring																	Injection		Abbrev.	
	L1	R1	L2	R2	U3	S3	L4	R4	L5	R5	L6	R6	U7	S7	L8	R8	CCR	#	1		2
1 Collimation (Environmental par.)	••	••	••	••	••				••	••	••		••		••	••		22	•	•	COLL_ENV
2 Collimation (Motor positions)		••	••	••	••				••	••	••		••		••	••		20	•	•	COLL_MOT
3 Vacuum system ("sector valves")	••		••	••	••		••	••	••	••	••	••	••	••	••	••		24			VAC
Vacuum system ("X valves")		•		•					•						•	•		6	•	•	"
4 PIC for essential circuits	•	•	•	•	••		•	•	•	•	•	•	•	•	•	•		16			PIC_UNM
PIC for auxiliary circuits	•	•	•	•	••		•	•	•	•	•	•	•	•	•	•		16			PIC_MSK
5 BLM at aperture limitations*	•		•			•	•	•		•				•	•			8			BLM_UNM
BLM in arcs	•		•			•	•	•		•				•	•			8			BLM_MSK
6 Fast Magnet Current Change Monitors	•		••	••	•••				•		••	••	•••					12	•	•	FM_xxxx
7 Warm Magnets Interlock	•		•		•		•	•		•		•	•		•			8			WIC
8 Screens		•		••			••	•			••	•	•		•			8			BTV
9 RF & Transverse Damper						••	••											4			RF
10 Beam excursion (BPM)										••	••							4			BPM
11 LHC Beam Dumping system										•	•							2	•	•	LBDS
12 LHC Control Room (Operator Buttons)																••	••	2	•	•	CCC
13 Programmed Beam Dump (via Timing)																••	••	2			LSEQ
14 LHC Safe Machine Parameters																••	••	2			SMP
15 ATLAS (movable devices)	••																	2			ATL_MOV
16 TOTEM (movable devices)									••									2			TOT_MOV
17 Fast Beam current Change Monitors							••											2			FBCM
18 Beam Aperture Kicker							••											2			MKA
19 Injection Kicker			•												•			2	•	•	MKI
20 LHC Access Safety System																••	••	1			LASS
21 ATLAS (Detector part)		•																1	•	•	ATL_DET
22 LHCf (Detector part)		•																1	•	•	LHCF_DET
23 ALICE (Detector part)				•														1	•	•	ALI_DET
24 CMS (Detector part)										•								1	•	•	CMS_DET
25 TOTEM (Detector part)										•								1	•	•	TOT_DET
26 LHCb (Detector part)																•		1	•	•	LHCB_DET
LHCb (movable devices)																•		1			LHCB_MOV
28 ATLAS Experiment Magnets		•																1			ATL_MAG
29 ALICE Experiment Magnets				•														1			ALI_MAG
30 CMS Experiment Magnets										•								1			CMS_MAG
31 LHCb Experiment Magnets																•		1			LHCB_MAG
32 ALICE-ZDC (movable device)																			•	•	ALI_ZDC
33 MSI Convertor Sum Fault																			•	•	MSI_SUM
<i>Total of connections</i>																	186	14	13		

•• : Individual Beams connections  
(•• if Unmaskable)

• : Both Beams connection  
(• if Unmaskable)



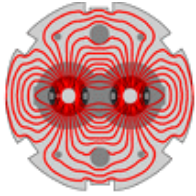


# Readiness for MPS-1



- ❑ Ring and injection BIS fully commissioned:
  - All USER\_INPUTs operational
  - BEAM\_PERMIT loops operational.
  
- ❑ Fully commissioned clients (non-beam part):
  - ❑ All injection BIC inputs.
  - ❑ PIC and WIC inputs.
    - PIC configuration is 'light' – all maskable.
  - ❑ Vacuum inputs.
  - ❑ Collimator inputs.
  - ❑ Experiment inputs.
  - ❑ SIS experiments protection.
  - ❑ BTV inputs (also SIS).
  - ❑ BLM inputs.
  - ❑ LBDS ready 450 GeV operation/commissioning.

Proposal

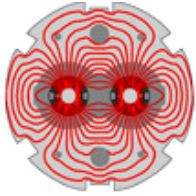


# Readiness for MPS-2



- ❑ FMCs operational.
- ❑ PIC configuration :
  - MBs, MQs and IPQs declared essential.
  - PIC configuration re-tested.
- ❑ Collimators with minimal setup.
- ❑ Some BLM beam tests passed :
  - Thresholds adjusted, collimator tests passed.
- ❑ BPM interlocks IR6.
- ❑ Safe Machine Parameters :
  - Safe Energy
- ❑ Ramp:
  - RF frequency.
  - LBDS fully tested in dry-ramps (BETS !).
  - Programmed dumps on first ramps for LBDS.

Proposal



# Readiness for MPS-3++



- ❑ Collimators early setup & beam tests.
- ❑ TCDQ setup & tests.
- ❑ All BLM beam tests passed :
  - Thresholds adjusted, quench test(s).
  - Collimator BLMs tests.
- ❑ BPM interlocks IR6.
- ❑ Beam tests of WIC, PIC and FMCMs (overlap with BLM tests).

Proposal