Machine Protection Issues
OP Cold Checkout Review

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Tasks of the protection system

Protect the machine

- **First priority:**
  - Protect (sensitive) LHC equipment and transfer line equipment from damage
- **Second priority:**
  - Prevent superconducting magnets from quenching by dumping the beam BEFORE particle losses become too large.
    - Downtime after a quench is in the range of 1 hour – 8 hours

Protect the beam

- The protection systems should only dump the beam when necessary.
  - False beam dumps to be avoided

Provide the evidence

- In case of failure, complete and correct diagnostic performed
  - Post Mortem Analyses must be done
  - Post operational checks must be done

NB: I will not address issues of system reliability, as a full MPS study has already been done, but at this, stage statistically meaningful data sets have not been obtained

Protecting the Machine: Interlock Flags

- SPS_Probe_Beam Flag
  - TRUE when beam to be extracted from SPS is less than 10^{11} protons.
  - Required when injecting into an empty LHC
- SPS_SafeBeam Flag
  - TRUE when beam to be extracted from SPS is less than 10^{12} protons
  - No limits on the number of bunches
  - SPS_Safe_Beam==TRUE includes SPS_Probe_Beam==TRUE
- LHC_Beam_Presence Flag
  - TRUE if any beam is circulating in the LHC
  - When FALSE, SPS extraction permitted only if SPS_Probe_Beam==TRUE
- LHC_Safe_Beam Flag
  - TRUE if beam circulating in LHC has intensity of less than 10^{12} protons
  - Masking of maskable interlocks only if LHC_Safe_Beam==TRUE
  - High intensity injection into LHC is forbidden if any interlocks are masked.
  - LHC_Safe_Beam==FALSE is required for injecting high intensity beam

Protecting the Machine: SPS extraction logic

SPS Extraction is allowed if….

ProbeBeam .OR.

(LHC_Beam_Presence .AND. ((NOT.LHC_Safe_Beam).OR. SPS_Safe_Beam))

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SPS Probe beam Flag	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
SPS Safe beam Flag	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	0
Beam Presence Flag	0	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1
LHC Safe Beam Flag	0	1	0	1	0	1	1	0	0	1	1	0	0	1	1	0
Extraction						YES	YES	YES		NO	YES	YES		NO	NO	YES

- High Intensity Injection Trick: convert from Case 15 to Case 16
  - High Intensity Injection requires that LHC_Safe_Beam flag be forced FALSE
  - Forcing is done in software via LHC sequencer
    => Safe Machine Parameter Controller overwrites measured LHC_Safe_Beam flag
    => Sequencer must check for masks prior to overwrite
- Concern:
  - Details of extraction logic need to be finalised so SMP controller can be done

Protecting the Machine: MPS aspects of putting beam in the LHC

MPS aspects of putting beam into the LHC

- Cascaded Beam Permits
  LHC_Ring_Beam_Permit -> LHC_Injection_Permit -> SPS_Extraction_Permit
- LHC_Ring_Beam_Permit defined from LHC_Ring_BIC inputs
- Requires Safe Beam Paramters from Safe Machine Parameter (SMP) Controller
- Masked interlocks permitted only when LHC_SAFE_BEAM==TRUE

LHC Safe Beam Flag

- SBF=SBF(I,E) determination: Baseline was for measurement from only one DC BCT.
- Need reliable SBF as can mask maskable interlocks when LHC_SAFE_BEAM==TRUE
- Concern: Can we build in redundancy => Can two DC BCTs be used?
  - In addition, do we use SIS to calculate SBF from FBCT/DCBCT intensity?
    - ie Compare with timing system distributed SBF.Discrepancy $\Rightarrow$ beam dump

Safe Machine Parameter Controller

- Safe Beam Parameters are distributed from the SMP Controller to:
  - To SPS_Extraction BIC via a hardware link
  - To the user systems via the GMT
- Safe Machine parameters logged into history buffer by the SMP Controller
  - History buffer is readout and logged
- LHC timing not necessary for safety aspects of SMP Controller or SPS_Extraction BIC

Protecting the Machine
Concerns related to BIS and SMP

Present Schedule:

- SPS_Extraction_BIC Interlock tests:
  - Scheduled for week 46 (next week)
  - Status: SPS_Extraction BIC tests => interlock tests essentially postponed
    - Reason: SMP implementation not possible + BETS not in final state

Scheduling status

  - Present planning: Full system commissioned by end of March
    - Includes: SMP + SPS_Extraction_BIC + Regular BICs + Interface to Individual systems + BCT + BETS
    - Tracking of progress of MPS aspects of BIS to be done in MTF

Concerns:

  - Final specifications for SMP need to be set, so implementation can be done
  - XPOC and IPOC was foreseen for the BIS but as yet not implemented
  - Internal Post mortem analysis planned by not yet implemented
  - Schedule is tight

To be noted:

- Schedule is tight => AB/CO (BIS group) + MPS need to confirm objectives and milestones
- Need to estimate if sufficient manpower to complete system required by MPS
- Careful coordination and progress tracking is required for commissioning of BIS with individual systems

Protecting the Machine: Individual systems

Machine protection (from beam) is built from quasi-modular individual systems

- Systems input into Beam Interlock system. Can also input directly into LBDS.
- Many MPS issues already resolved in HWC and in individual system commissioning

Hardware surveillance essential

- Surveillance of critical settings:
  - Setting out of tolerance => system USER_PERMIT=FALSE => beam dumped
- MPS not designed to react to non-critical settings
- Concern: If SIS used to cross-check critical settings what is the feasible refresh rate?
  - Dependent on size of critical setting data set and or DB access

Post operational Checks: XPOC and IPOC

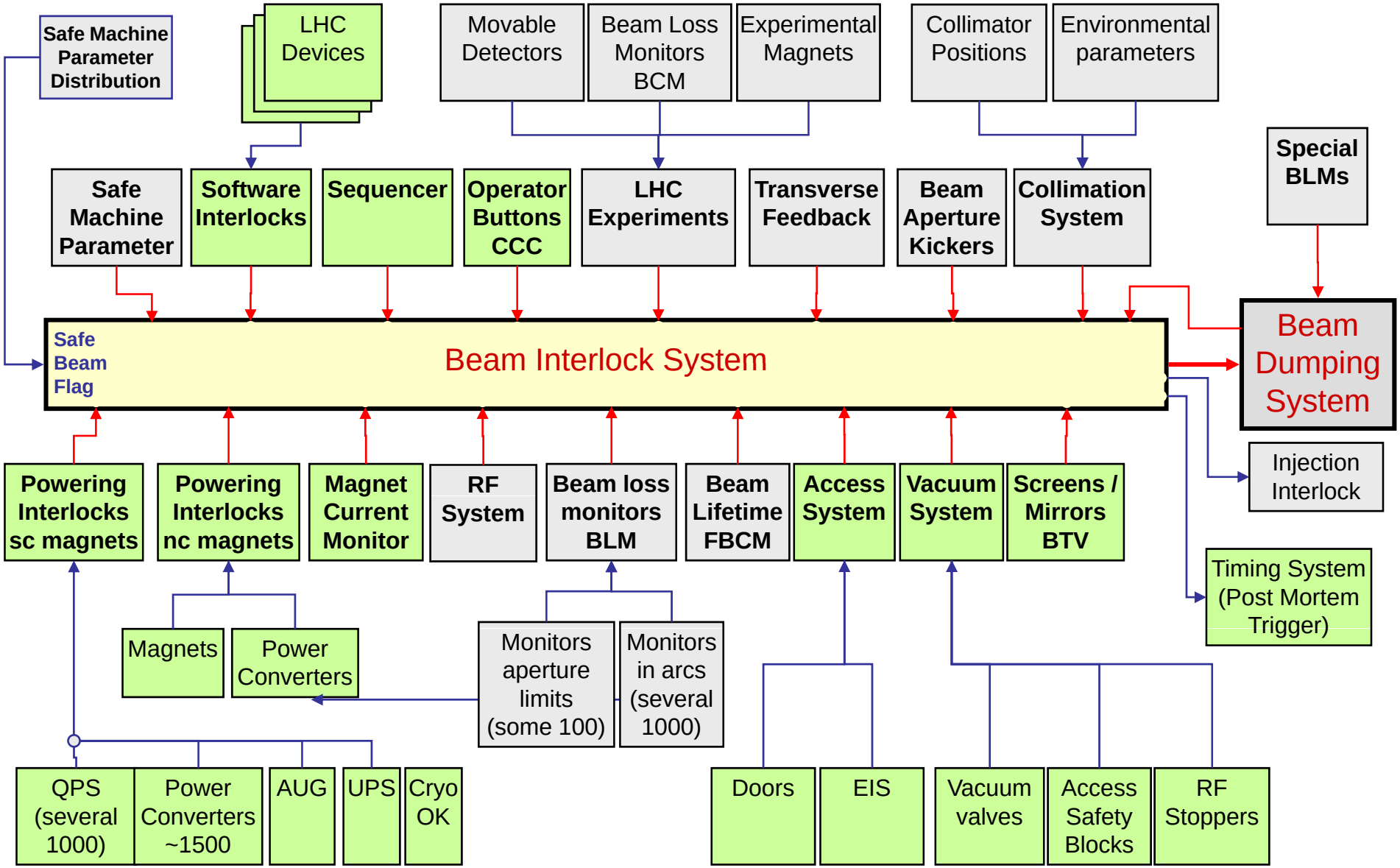
- At resent, only LBDS requires XPOC and IPOC to reassert the USER_PERMIT

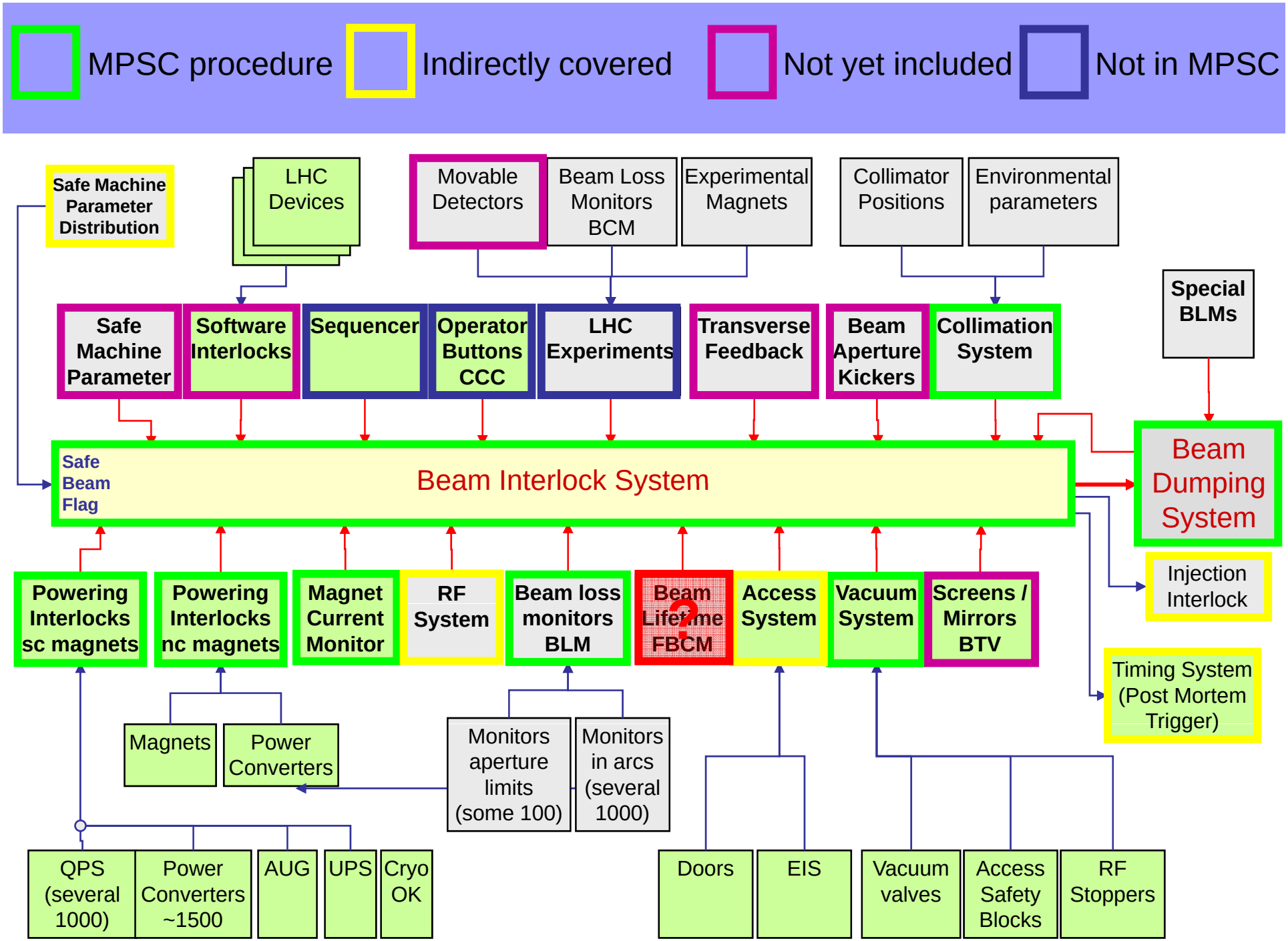
How to deal with front end failure of a channel in a user system

- If failure prevents assertion of USER_PERMIT=TRUE
  - If a maskable channel, it can be masked if stay with LHC_SAFE_BEAM=TRUE
  - If unmaskable problem must be fixed
- Fixing the problem =>Direct intervention
  - If this is not possible, channel's interlock input can be disabled
    - Disabling only done after consultation with MPS and system experts
    - Such actions require a review panel LTC or else establish LPP

LPP = LHC Protection Panel

Protecting the Machine: Beam Interlocks and Individual systems




MPSC procedure
Indirectly covered
Not yet included
Not in MPSC
Safe Machine Parameter Distribution
LHC Devices
Movable Detectors
Beam Loss Monitors BCM
Experimental Magnets
Collimator Positions
Environmental parameters
Special BLMs
Safe Machine Parameter
Software Interlocks
Sequencer
Operator Buttons CCC
LHC Experiments
Transverse Feedback
Beam Aperture Kickers
Collimation System
Safe Beam Flag
Beam Interlock System
Beam Dumping System
Injection Interlock
Timing System (Post Mortem Trigger)
Powering Interlocks sc magnets
Powering Interlocks nc magnets
Magnet Current Monitor
RF System
Beam loss monitors BLM
Beam Lifetime FBCM
Access System
Vacuum System
Screens / Mirrors BTV
Magnets
Power Converters
Monitors aperture limits (some 100)
Monitors in arcs (several 1000)
QPS (several 1000)
Power Converters ~1500
AUG
UPS
Cryo OK
Doors
EIS
Vacuum valves
Access Safety Blocks
RF Stoppers

Protecting the Machine: Individual systems – Key systems

For MPS there are a subset of user systems that crucial to starting the LHC

- Key systems:**BIS, BLMs, Collimators, LBDS, PIC**

- If any of these systems shows a problem => direct risk of damaging the machine
  => MPS must block attempts to operate the machine

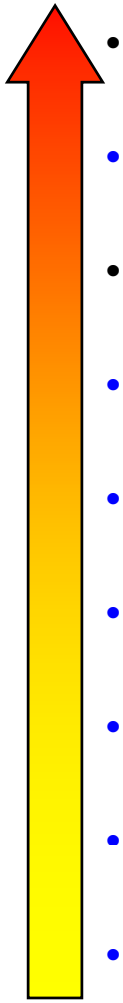
Observations

- Priority given to commissioning procedures for all key systems
- Detailed commissioning procedures and programme developed for BIS and LBDS

Concerns

- Commissioning is on a tight schedule
- Assess global MPS issues from inter-dependencies of ~modular individual systems
- Need to develop a commissioning fall-back strategy
  - What is to be done if (parts) of key systems are not ready for combined commissioning tests at a given point in time:
- Who will manage and coordinate the commissioning of the MPS across the LHC?
  - Applies to BIS + all individual systems
  - Is prioritised commissioning necessary (across systems, across the machine)?

Aside: Safety critical aspects of the LBDS



- Signal from beam interlock system (test in HWC/RR)
  - No trigger = no beam dump
- Energy tracking
  - Potentially catastrophic (whole beam at “any” amplitude)
- MKD retriggering (test in HWC/RR)
  - No retriggering could put whole 7 TeV beam at ~10σ
- TCDQ setting
  - Wrong w.r.t. orbit exposes LHC arc / triplets / collimators.
- System self-tests and post-mortem
  - Undetected ‘dead’ MKD severely reduces reliability
- Aperture, optics and orbit
  - Dump with bad orbit could damage extraction elements MSD, TCDS or MKB
- MKD – MKB connection and sweep form
  - Insufficient dilution could damage TDE, BTVDD and TDE entrance window
- Abort gap ‘protection’
  - Beam in the abort gaps risks quench, or TCT/LHC damage if TCDQ position error
- Fault tolerance with 14/15 MKD
  - The system is designed to operate safely with only 14 out of the 15 MKDs

Nearly all aspects need beam commissioning (validation or optimisation)
=> Clear commissioning programme is essential – including MPS aspects

Protecting the Machine: Individual systems MPS and operation

Individual systems: MPS commissioning requirements

- Each system must pass individual system commissioning
- Follow on with dedicated MPS commissioning procedures
  - Validate interaction of the individual system with the BIS
- All systems responsible for asserting there own USER_PERMIT (input to BIC)
- No user system initiates an action based info returned from BIS
  => BEAM_INFO==FALSE is not a sufficient condition for initiating actions

Recovery of the BEAM_PERMIT loop

- Done by re-establishing the USER_PERMIT of individual systems
- MPS requires post operational checks only from “singe-instance” systems before setting USER_PERIT==TRUE
  - At present only LBDS required to complete XPOC and IPOC
  - Individual system Post mortem analyses: try to identify reason for beam loss
    - Not always essential for re-establishing operation
    - Global PMA more important for re-establishing operation

Concerns:

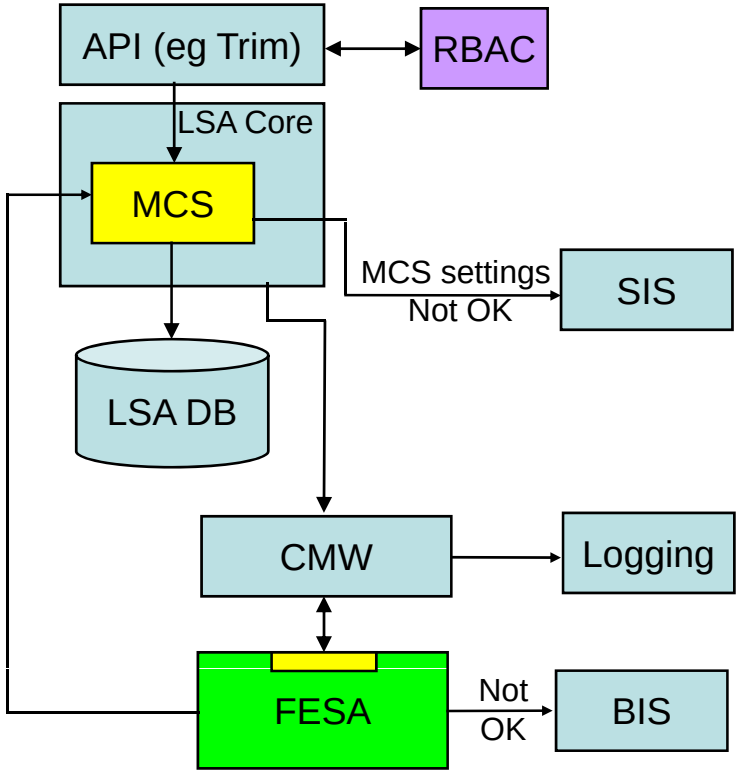
- Which MPS critical systems should perform an XPOC? (LBDS, BIS, Injection?)
- Global assessment strategy of individual post-mortem analyses not yet apparent
  - What MPS issues are checked. What are the operations implications

Protecting the Beam: MPS requirement of MCS

MPS demands parameters critical to safe operation be handled by Management of Critical Settings (MCS)

MCS must check (set and check) all interlock settings before every LHC fill

- Interlock setting = pre-defined safety tolerance on a parameter
- If |measured-reference| > interlock setting, set BIS and/or SIS Interlock



Role based access:
authentication + authorization

MCS manages parameter repository
and potentially generate SIS interlocks

If authorized: new setting stored in
DB with **MCS digital signature**.

If cycle resident: new setting sent
to front end with **MCS digital signature.**

FESA verifies **MCS digital signature**.
If OK, new setting written to HW.
If not OK, front end systems responsible
for alarm/interlock generation

Protecting the Beam: MPS and operational decisions

MCS to manage interlock settings, SIS reference sets, XPOC reference values, authorised operational settings

Observations:

- MCS specifications defined, and system mostly exits
- RBAC used for controlling modification of critical settings in active tables

Concerns:

- No explicit read back validation that critical setting is correctly set in hardware
  - Assumed if sent FESA without transaction error, it is correctly set
- Schedule and commissioning procedure needed for validation of MCS operation
  - How is MCS digital signature authorisation validated across different systems
  - RBAC implementation ready, needs validation with users
- Can MCS/+RBAC adapt to significant enlargement of set of critical settings?
- How does MCS handle changes of critical settings within a fill?

Procedure for changing a MPS critical setting (eg Master threshold table for BLM)

- At present, no clear mechanism defined. Concern: Decision not left to a single person
- Proposal:
  - Implications must be fully assessed and understood
  - Concern: Any change first authorised by joint OP/MPS panel (LPP/LTC?)
  - After authorisation, change implemented via RBAC and propagated correctly

Providing Evidence
Summary - Post Mortem Workshop: LEADE 15/10/2007

Development of Post Mortem Analysis (PMA)

- Statement: HWC should steer powering PMA, and OP should steer Beam PMA

HWC Post Mortem Analysis

- Post Mortem Analysis for superconducting elements – partially done
  - Semi-automatic analysis needed
  - Soft inhibit of re-powering needed when PMA shows non-conformity or fails
- Issues
  - MPWG to address use of buffers for periodic and transient requirements.
  - Cross system signal browsing, and correlation of signals needs to be clarified
  - SDDS analysis to be improved (X-Y info, etc). SDDS Task force being set-up

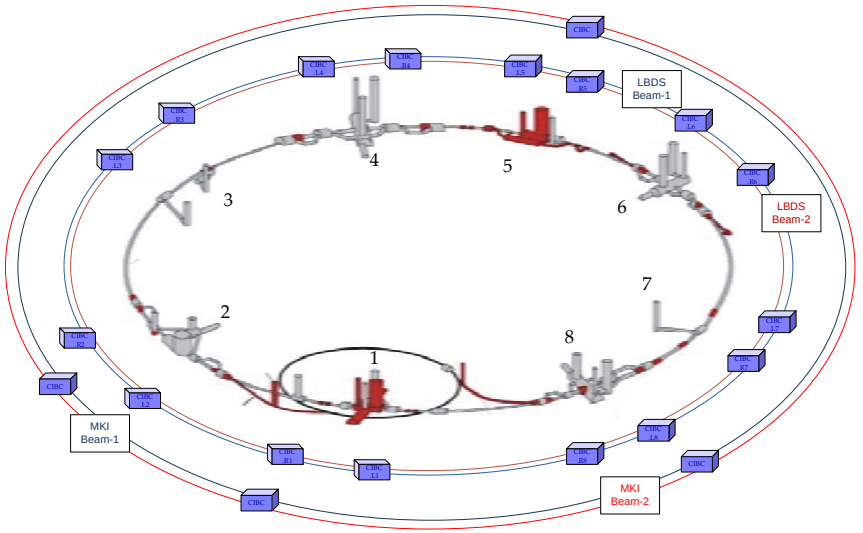
Beam Post Mortem Analysis

- Post Mortem Technology: Choice of Java or LabVIEW
  - Concern: Not clear on decision criteria, timescale or responsibility
    - AB/OP clearly has preference for Java
- Observations:
  - Injection: Shot-by-shot logging data required for injection quality “PM”.
    - Concern: Uses non-CERN standard data format and DB (ie SDA). Why?
  - LBDS: PM trigger must be a condition on Beam Dump Trigger.
    - Note: XPOC, based on LSA. LBDS proposal: not use PM data for XPOC.
  - OP: Rapid accurate PM analysis a top priority for operation.
    - Concern: PMA and LSA approaches must be coherent. Is this the case?

Protecting the Beam: Other MPS issues

Abort Gap Monitor

- Needed for ~Day 1. BI will provide AGM
- Not officially and MPS concern, but …
- Concerns:
  - Schedule for commissioning
  - Development of CCC interface.
    - Who?
  - What about abort gap cleaning?



Protecting the beam from the Expt's

- **Hardware injection inhibit from Expt into injection BICs**
  - Prevents injection (any intensity) into LHC
    - Hardware = BIS hardware => reliable
  - Concern:
    - Is generation of inputs reliable and standard across the Expt
    - Needs clear commissioning before these interlock inputs are un-disabled
- **Expt interlock**
  - Unmaskable interlock that can toggle USER_PERMIT
  - Concern:
    - Is generation of input reliable. Is it standard across the Expt
    - Needs clear commissioning before these interlock inputs are un-disabled

Summary and observations

- Our Machine Protection System comprises a large number of varied systems
  - Careful management and tracking of MPS commissioning must be in place
  - Commissioning plans must incorporate prioritising and fall-back planning.
  - MPS Commissioning procedures address almost all relevant systems
    - Detailed MPSC procedures for key systems are well advanced
- SPS Extraction logic should be finalised
  - Permits Safe Machine Parameter Controller to be implemented
- Need to clarify degree of redundancy in LHC_Safe_Beam flag:
  - More or less OK
- Full BIS System to be commissioned by May (Extraction BIC by end of March)
  - Are more resources required to finish full system in time?
- MPS requirements on XPOC for the BIS should be revisited
  - AB/CO(BIS) plan to implement XPOC + PMA.
- MCS implementation in place, but MPS related commissioning needs scheduled
  - Checking of MCS+ RBAC with SIS + FESA should not be underestimated
- Responsibility for critical settings/interlock input disabling not left to one person
  - MPS needs to consider a review panel to deal with MPS operational issues
- We need to require quality control the interlock inputs coming from the Expts

Last observation

Thanks to all involved for their patience, input and help.

This exercise has been very useful,

and now I have more questions

than before I started …

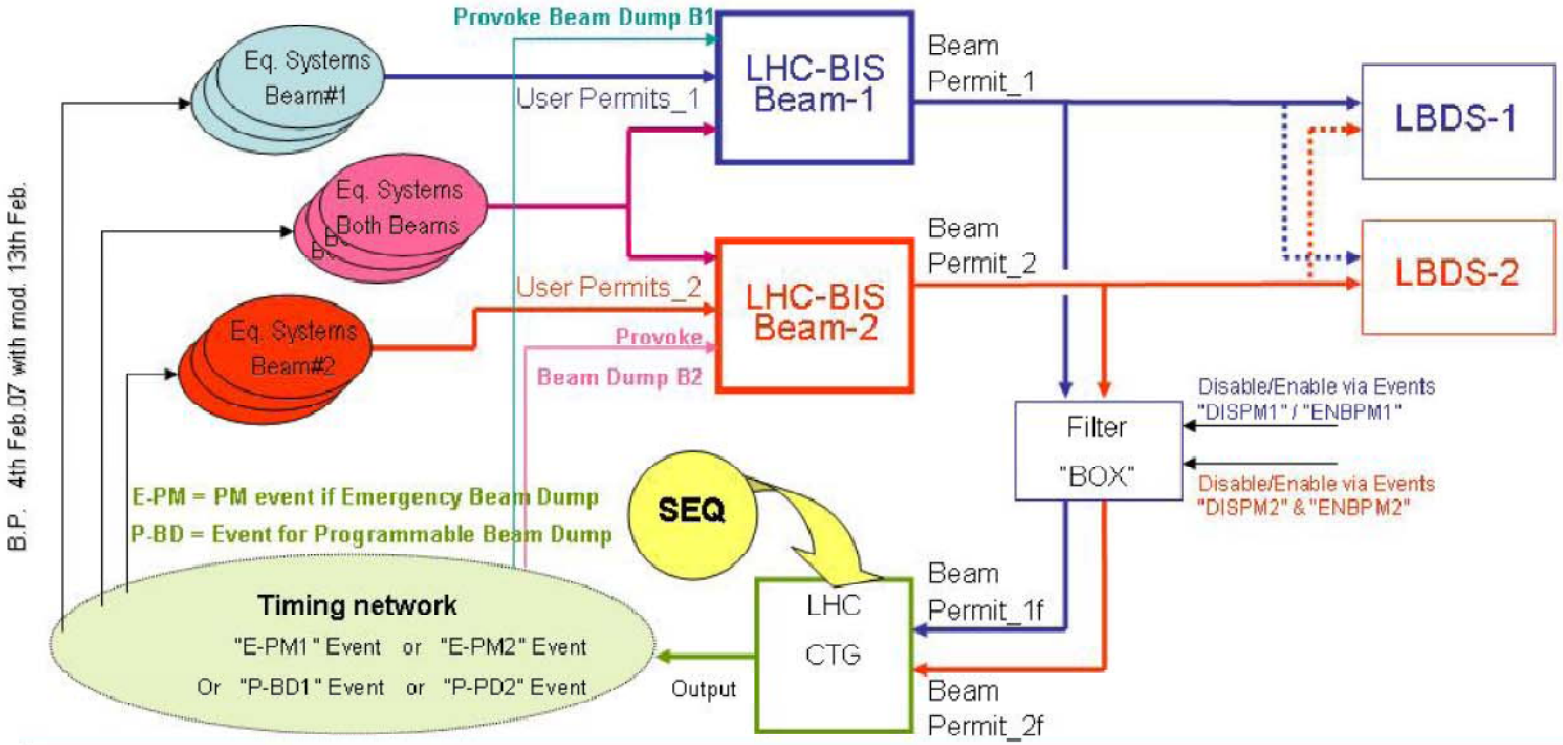
Spare stuff

BIS Interlock Inputs

Insertion Region	IR 1				IR 2				IR 3				IR 4				IR 5				IR 6				IR 7				IR 8			
Position (Left/Right)	L		R		L		R		L		R		L		R		L		R		L		R		L		R		L		R	
Beam	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Un-Maskable Independent User System Inputs:																																
Vacuum System	1	1			1	1	1	1	1	1			1	1	1	1	1	1			1	1	1	1	1	1			1	1	1	1
Experiment Movable Devices			1	1															1	1												
LHC Beam Dumping System																					1			1								
CERN Control Centre	1	1																														
Safe Machine Parameters			1	1																												
Un-Maskable Simultaneous User System Inputs:																																
Beam Loss Monitor System	1				1				1				1				1				1				1				1			
Powering Interlock Controllers	1		1		1		1		2				1		1		1		1		1		1		2				1		1	
Warm Magnet Interlock Controllers	1				1				1								1				1				1				1			
Vacuum System			1		1		1												1										1			
Experiment Detectors			2				1												2												1	
Experiment Movable Devices																															1	
Access System																															1	
Maskable Independent User System Inputs:																																
Collimation System	1	1	2	2	2	2	2	2	2	2							2	2	2	2	2	2			2	2			2	2	2	2
Transverse Feedback														1	1																	
RF System													1	1	1	1																
Beam Lifetime Monitor													1	1																		
Beam Position Monitor																							1	1								
Beam Aperture Kicker													1	1																		
Beam Television					1						1	1			1	1							1	1				1				1
Maskable Simultaneous User System Inputs:																																
Beam Loss Monitor System	1				1				1				1				1				1				1				1			
Powering Interlock Controllers	1		1		1		1		2				1		1		1		1		1		1		2				1		1	
Fast Magnet Current Monitors	1						2				3								1				2				3					
Experiment Magnets			1				1												1												1	
Beam-1	3		4		4		3		3		1		4		4		3		3		4		3		3				3		3	
Both-Beam	6		6		6		7		7		3		4		2		5		7		5		4		7		3		6		6	
Beam-2		3		4		3		3		3		1		4		4		3		3		3		4		3		1		3		4

Totals	Beam-1	48
	Both-Beam	84
	Beam-2	49

Beam dumps



In case of Emergency BD*, the 2 beams will be always dumped thanks to a coupling between BIS-1 & BIS-2

⇒ The "Filter Box" is not activated, and the two Beam_Permit changes are detected by the CTG
⇒ PM Events (lets call them E-PM1 and E-PM2) will be both broadcasted over the Timing Network
⇒ in order to freeze their PM buffers, the Equipment systems have subscribed to E-PM1 and to E-PM2.
** Whatever was the request' source: from "Both Beams Systems" **or** from "Individual Beam systems"*

In case of Programmable BD, only one beam is dumped (no coupling between BIS-1 & BIS-2)**

***always provoked by LHC-SEQ via the Timing*

⇒ one PM Event (lets call it P-BD1 or P-BD2) will be "generated" by the LHC-SEQ via the CTG.
⇒ This event is used to provoke a beam Dump. In addition, CTG generates the Disable Event ("DISMPn") for the Filter box.
⇒ As the Filter Box is activated: the corresponding Beam_Permit change is masked to the CTG (other one not masked).
⇒ (If needed for few systems) Freezing PM buffers is still achievable if they have also subscribed to "P-BD1" or "P-BD2"

Injection interlock inputs

- In SR2, Beam-1 Injection, Channel # is shown in second column:

CIB.SR2.INJ1	1	UNmaskable	Operator Switch
CIB.SR2.INJ1	2	UNmaskable	LHC Beam1-Permit
CIB.SR2.INJ1	4	UNmaskable	MKI2 Status
CIB.SR2.INJ1	5	UNmaskable	Vacuum
CIB.SR2.INJ1	7	UNmaskable	ALICE_ZDC
CIB.SR2.INJ1	8	Maskable	Collimation Motor-Control
CIB.SR2.INJ1	9	Maskable	Collimation Env_Param
CIB.SR2.INJ1	13	Maskable	FMCM on MSI
CIB.SR2.INJ1	14	Maskable	MSI Convertor Sum Fault

- In SR8, Beam-2 Injection, Channel # is shown in second column:

CIB.SR8.INJ2	1	UNmaskable	Operator Switch
CIB.SR8.INJ2	2	UNmaskable	LHC Beam2-Permit
CIB.SR8.INJ2	4	UNmaskable	MKI8 Status
CIB.SR8.INJ2	5	UNmaskable	Vacuum
CIB.SR8.INJ2	8	Maskable	Collimation Motor-Control
CIB.SR8.INJ2	9	Maskable	Collimation Env_Param
CIB.SR8.INJ2	13	Maskable	FMCM on MSI
CIB.SR8.INJ2	14	Maskable	MSI Convertor Sum Fault

- Add all EXPERIMENTS who choose to use injection inhibit system proposed in LEADE.

SPS extraction